# Invasive Species Treatment Options: Alternatives to Herbicides

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Cover Photo: Multiflora rose courtesy of Paul Nelson and the Missouri Department of Conservation.

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# Introduction

Herbicide application is the most widely used method to treat invasive species because of its relatively low cost and high effectiveness, however there are tradeoffs associated with chemical applications in natural areas. Herbicides can impact non-target plant and animal populations even when used carefully. For this reason, landowners and natural resource professionals often seek alternatives to herbicides for treating invasive species populations. This is particularly desirable in high conservation value natural communities, rare and endangered species habitat, wetlands, near homes where children and pets may frequent, and near sensitive agricultural crops. In some cases, a non-herbicidal treatment is the most effective method of controlling or eradicating an invasive species. Effective treatments depend on invasive species' physiological traits and life history strategies. Plant physiognomy, vegetative and sexual reproduction strategies, seed dispersal vectors, light, water, and nutrient requirements, and the ecology of the treatment area are all important to understand before designing the treatment strategy. We review current literature on local priority invasive species, their traits, management options, and their relative effectiveness and cost. Species are listed in alphabetical order by scientific name following Michigan Flora nomenclature (http://michiganflora.net/home.aspx).

## Early Detection and Rapid Response

Prevention is the most important line of defense for invasive species. Land managers should be proactive in tracking movement of new invasive species through the state and country, training on identification of uncommon and emerging invasive species, reducing dispersal pathways such as unnecessary trails and roads, thoroughly cleaning equipment and boots, and re-vegetating disturbed or degraded areas with native plants.

The second line of defense is Early Detection and Rapid Response (EDRR). In a world of global commerce, species are moving around the world, country, and Michigan at a rapid pace, and there is an amount of vigilance required to prevent future invasive species. As new species or new populations establish, they become increasingly more costly, laborious, or impossible to eradicate, and many well-established invasive species in northern Michigan have become permanent fixtures within our landscape. For this reason, EDRR is the most cost-effective and viable strategy for managing invasive species. EDRR includes education on emerging invasive species, conducting monitoring programs, assessing emerging populations, and a timely implementation of an appropriate control treatment. Although small invasive species populations can seem intuitively to be low priority, careful consideration should be given to their likelihood to spread in the landscape; often prioritizing emerging populations will be the most effective means of long term control.

## Prioritizing Treatment Populations

Resources are always the limiting factor when addressing invasive species, making it important to establish priority species and populations. Depending on traits of the target species, the size and density of the population, the location of the population in the landscape, potential ecological or socio-economic losses, and available resources, populations can be assessed on a case by case basis to prioritize treatments. Generally speaking, populations in high quality natural areas and with high likelihood to for successful eradication or control should be prioritized. This parallels EDRR philosophy of prioritizing emerging species and populations before they become entrenched in the landscape. Seed-source populations are often targeted for species that are readily animal dispersed, because these populations will continually introduce new propagules to satellite areas. Satellite populations should be targeted for species with short dispersal distances in order to contain the population to a smaller, core land area. Species that are well established across the landscape are the most difficult and costly to treat and management programs have a lower success rate. Specific recommendations are given for each species.

## Integrated Management

Integrated management is the use of multiple prevention and treatment measures to manage an invasive species population. Integrated management plans are often more successful than choosing a single control measure, and essential for controlling some species and populations. Often specific combinations of treatments are more effective than the treatments applied separately. Recommendations for integrated treatments are included for each species.

Restoration of native plant communities is an essential but often overlooked component of invasive species management. Invasive species are usually opportunists that can quickly populate disturbed landscapes; disturbances from invasive species control measures can often lead to creating niches for returning or new invasive species. By restoring an area with a diversity of native species after treatment greatly increases the resilience of the vegetation community and inhibits the establishment of an invasive species through lowering number of seed germination sites and increased competition for light and water. All management strategies should include a restoration plan. More about restoration is included in the Cultural Controls.

## Considerations for Mechanical Control

Mechanical controls include hand-pulling, digging, girdling, tilling, cutting, mowing, or other physical forms of treatment. Physical removal (hand-pulling or digging) is often the most effective form of control for small populations but also is the most labor intensive. The effectiveness of mechanical controls depends on a plant’s proclivity towards resprouting from root or stem fragments and root crowns, as well as seed production and dispersal strategies, phenology, and ecological niche. If employing mechanical controls, review plant characteristics and follow all specifications closely (timing, method, frequency, etc). Invasive plants can be easily spread by mechanical methods if they are not prescribed correctly, exasperating an infestation.

Helpful tools include a stand-up weeder that can be used to sever a taproot (such as a dandelion tool, $25), a tree and shrub root-puller such as an “Up-rooter” or “Pullerbear” or similar product ($150), a brush-cutter ($100-$800), a spade shovel, hand pruners ($30), loppers ($60), chainsaws ($300+), and other landscaping tools.

## Considerations for Prescribed Fire

Prescribed fire is often used as a tool to control or eradicate unwanted plant species but it must be used with care and in the appropriate natural communities. Although widely known to have beneficial effects on vegetation communities, only certain communities are adapted to fire regimes. Information on the effects of fire on vegetation communities can be found on the USDA Fire Effect Information System (FEIS) website (https://www.feis-crs.org/feis/). The FIES website also publishes fire-tolerance information for many individual species.

Pre-European settlement vegetation maps indicate that Leelanau was primarily forested with mesic northern hardwood forest with pines and rich conifer (northern white-cedar) swamp (Albert and Comer 2008). The fire return interval in northern hardwood forests is between 450 and 3,000 years; the fire return interval for northern pine-hemlock hardwoods is between 151 and 178 years; and the fire return interval for northern white-cedar swamps is between 385 and 1,000 years (USDA 2012). This suggests that there are few natural communities in Leelanau County adapted to fire regimes for invasive species management (repeated annual burns) and many of our native plant species may not be adapted to this type of management. The use of prescribed fire should be carefully evaluated on a site by site basis.

Herpetofauna are very sensitive to fire and the effects are relatively understudied. The current decline in reptiles and amphibians in Michigan has caused concern about the cumulative effects of prescribed fire management. For specific guidelines on amphibian and reptile conservation in prescribed fire management areas visit the Midwest Partners in Amphibian and Reptile Conservation's fire management website at http://mwparc.org/products/fire/plain/.

Prescribed fire is typically applied by a professional consultant using low-heat ground fires. It may also include medium to high heat ground fires for some species' management or use of a propane torch directed flame. The latter method appears to becoming more common in the literature and may be more widely applicable than this paper suggests, especially for treating invasive shrubs that sprout from root crowns. A backpack propane torch costs about $250 plus fuel costs (Red Dragon brand is commonly used). This treatment is more expensive than ground fires. A permit is required for prescribed fire from the local fire marshal or the DNR.

## Considerations for Cultural Control and Restoration

Cultural control is the manipulation of vegetation structure and composition to increase competition with invasive species or reduce the ecological niche that the invasive species need to spread and reproduce. This is a form of ecological restoration, specific in technique and aim focusing on supplanting specific invasive species; technique will vary by treatment site conditions and target invasive plants. Cultural controls are considered critical for long term ecosystem resilience after all invasive plant treatments and can be used as treatment strategy.

Studies show invasive plant species do not significantly out-perform co-occurring native species in many traits such as growth rate, fecundity, and competitive ability (Daehler 2003).

Instead, they have a greater phenotypic plasticity that allows them to adapt to disturbances better than native species, and they typically are more efficient in utilizing high light and nutrients to construct tissues (Daehler 2003). Thus, it is often the abiotic environment that is facilitating the niche and the invasive species is the "passenger," rather than the invasive species "driving" their niche creation (MacDougall and Turkington 2005). It is also important to note, that while disturbances can often lead to the establishment of invasive species, once established some may work towards carving out their niche. This has been demonstrated in populations of allelopathic species who's chemical exudates inhibit interspecific species. Additional factors, such as interactions with herbivores or pests can further suppress native species in an invaded landscape.

Species-specific cultural control regimes are included below where information was available. Common techniques include seeding in native species that will fill similar functional roles to compete with invasives, or increasing tree and shrub cover to shade sun-loving invasive species. Steps to crafting a cultural control plan should include 1) surveying the site and collecting information about the abiotic and biotic conditions, resource concerns, and how it is interconnected with the larger landscape, 2) identify several restoration options/trajectories, considering desirable native species, how the site should be prepared (including pre-treatment of invasive species), and what maintenance will be necessary, and 3) consider ecological, social, economic, and legal implications of the different options such as permits working in wetlands or old field habitat that attracts uncommon birds sought by birders. The Plant Conservation Alliance, with the Bureau for Land Management and the Environmental Protection Agency, has published detailed steps for planning native plant restoration projects, "An introduction to using native plants in restoration projects" prepared by Jeanette Dorner, available https://www.nps.gov/plants/restore/pubs/intronatplant/toc.htm.

It is important to consider that "native species" sold by producers are often not local or Michigan genotypes of the species and in some cases native trees and shrubs are from clone stock or cultivars. Local genotypes perform better in local environmental conditions because the genotypes have been selected for thousands of years for that particular site (McKay et al 2005, Vander Minjnsbrugge et al 1997). It has also been suggested that local genotypes are preferred by pollinators and wildlife, though there is little research on this. There is no clear determination of "how local is local" (McKay et al 2005), however it is recommended to use seed from the restoration site unless there is reason to believe low population numbers have lead to low diversity and inbreeding (e.g. isolated small populations of endangered species). A common practice is to collect native seeds or cuttings from the restoration site and having them grown out at a nursery or farm. If that is not possible, native plant material may be obtained from several nurseries in Michigan; make sure to discuss with the producer where the seed comes from, and try to obtain genotypes from Northwestern Lower Michigan. See the Michigan Native Plant Producers Association website http://www.mnppa.org/members.html, the Wildflower Association of Michigan website http://www.wildflowersmich.org, or the local Conservation District for availability of native species.

## Disposal of Invasive Plant Parts

All invasive plant parts that are removed during control efforts need to be disposed of in a way that will not aid in further spreading the species. Flower heads, seeds, root fragments, and stems must be killed or left in a state in which they will not be able to re-grow; flowering heads may continue to mature and produce viable fruit even if the plant has been pulled or cut. The Michigan DNR recommends bagging plant parts in black plastic bags and disposing of the bags in the local land fill. Michigan law permits the disposal of invasive plant parts in this way (MDNR 2012). Plants may also be incinerated.

# Invasive Species Profiles

## Tree-of-heaven, *Ailanthus altissima* (Mill.) Swingle

### *Species Overview*

Tree-of-heaven is a tree introduced to North American from China in 1784. It is known for its fast growth and is common in urban landscapes often in abandoned yards, alleys and fencerows. This species is polygamo-dioecious, mostly having male and female flowers on separate trees but it can also produce bisexual flowers. Flowers produce samaras which are wind-dispersed September to October. One tree may produce as many as 325,000 seeds per year (Swearingen and Pannill 2009). Seeds are viable for one year and are not persistent in the seedbank. New seedlings have been noted to flower six months after germination (Feret 1973). Trees also produce root suckers that may sprout up to 50-90 ft away from parent tree and sprout vigorously from cut stumps, roots, and root fragments (Fryer 2010). Seedlings can produce horizontal roots capable of sprouting ramets (Call 2002). Tree-of-heaven is allelopathic and will inhibit interspecific growth.

### *Treatment Options*

**A. Mechanical Control**

Effectiveness: Low, not effective long-term control
Cost: Moderate (chainsaw $300+, loppers $50)
Labor: High
Permit: No

Stem cutting can be useful for small populations or temporary control of seed producing trees. Tree-or-heaven responds to cutting by vigorously resprouting suckers which would need to be re-cut in subsequent years. It may take many years of re-cutting to eventually exhaust root reserves (Swearingen and Pannill 2009). Seedlings may be pulled or dug in smaller, targeted areas with care to remove entire root. This should be done in the first three months after germination when the soil is wet (MNFI 2009). Emerging suckers can appear to be seedlings but have long linear roots. Literature suggests mechanical removal is not effective on its own as the tree will continuously resprout from roots (DiTomaso and Kyser 2007, DiTomaso et al 2013, Constan-Nava et al 2010, Swearingen and Pannill 2009).

**B. Biological Controls**

Effectiveness: Varies-High
Cost: Unknown (not commercially available)

Labor: Low-Moderate (stem inoculations)
Permit: Unknown

Tree-of-heaven has many known pests in the native and non-native ranges (Ding et al 2006). There are several insects (weevils, webworms), rust fungi, and native North American pathogens (*Verticillium spp*. wilt) that have all been suggested as future potential biological control agents (Ding et al 2006).

Native *Verticillium spp.* have been found on established tree-of-heaven sites in Ohio, Virginia, New York and Pennsylvania and are being studied for use as a biocontrol (e.g. Harris et al 2013, Kasson et al 2014, Schall and Davis 2009). Laboratory experiments with *Verticillium alba-atrum* have shown 100% mortality of tree-of-heaven but also 100% mortality of striped maple *(Acer pennsylvanica)* (Schall et al 2009). However, field surveys have reported only 1%-3% mortality of striped maple (Schall et al 2009, Kasson et al 2015). In studies of *Verticillium nonalfalfae,* a survey of 71 non-target trees revealed two native species that demonstrate infection: staghorn sumac (*Rhus typhina)* at 16% and devil's walkingstick *(Arailia spinosa)* at 17% incidence (Kasson et al 2015). Methods for formulation and inoculation with *Verticillium nonalfalfae* are underway in Pennsylvania (O'Neil et al 2015). For up-to-date information on this contact the Dr. Kasson or Dr. O'Neal at Department of Plant Pathology and Environmental Microbiology at Pennsylvania State University. It is unclear if this is safe and effective for northwestern Michigan forests.

### C. Cultural Controls

Effectiveness: Varies by site
Cost: Varies by site
Labor: Moderate
Permit: No

Forested areas that have been invaded with tree-of-heaven can be managed to reduce vigorous growth. Competition with fast-growing native trees such as poplars can slow growth of tree-of-heaven seedlings. These sites should not be heavily harvested unless tree-of-heaven is removed first; scarifying soil and opening the canopy can lead to heavy infestations of this very fast-growing tree (Fryer 2010). In early succession stands and non-forested areas broadcast poplar or other fast-growing tree seeds to compete with tree-of-heaven for resources (Fryer 2010).

## *Recommendations*

All literature recommends use of herbicide to control tree-of-heaven. Mechanical controls can be used as an early-response measure to temporarily destroy the above-ground vegetation and should target seed-producing (female) trees. Prescribed burning is not recommended as trees resprout vigorously (Fryer 2010). Long term control can be achieved by treating all cut stumps including suckers with glyphosate (Constan-Nava et al 2010), or stem or basal bark injections with imazapyr (DiTomaso and Kyser 2007) in late summer or fall. Stump injections are ineffective (DiTomaso and Kyser 2007). Herbicide application, even stump injections, has been demonstrated to kill 17% of non-target trees within 10 ft of the target tree (Lewis and McCarthy 2008). This is likely because tree-of-heaven exudes herbicide toxins from its roots (Lewis and McCarthy 2008). This is most appropriate for small populations typically seen in Leelanau County. If larger populations are identified, further research may be done into the safe use of the biocontrol *Verticillium spp* wilt.

## Garlic mustard, *Alliaria petiolata* (M. Beib.) Cavara & Grande

### *Species Overview*

Garlic mustard is a forb native to Europe and Asia, first introduced to Michigan in 1956. It is a biennial, forming a rosette in the first year, a flowering stalk in the second year, and then dies after flowering. It has allelopathic properties that inhibit growth of native species; it may also harm mycorrhizae populations that native species utilize for nutrient uptake (Roberts and Anderson 2001). Seeds are expelled from the siliques and can travel 3-4 ft from the parent plant. Seed production is inversely proportionate to density (Evans 2007). Seeds remain viable for 5-10 years in the soil (Evans 2007, Landis and Evans 2016). The population expands by an ‘advancing front’ from a single plant. Seeds are dispersed by expulsion from the plant and can be lodged in soil and spread by on the shoes and feet of humans or animals, and is also known to hitch a ride on heavy machinery such as logging trucks and skidders. Garlic mustard does not spread vegetatively. It can be found in a variety of disturbed sites; it is shade-tolerant and prefers mesic forests.

### *Treatment Options*

**A. Prescribed Fire**

Effectiveness: High
Cost: Moderate-High (contractors needed)
Labor: Moderate
Permit: Yes

Moderate intensity, early season prescribed fire can effectively reduce garlic mustard populations by killing plants and potentially killing some seed (Nuzzo 1991). Because garlic mustard will break dormancy before native plants, the ideal time to burn is mid April, as soon as garlic mustard emerges and before the spring ephemerals emerge. Follow-up visits in June should remove surviving plants by hand-pulling. Fires should take place annually for 3-4 years at minimum (Evans 2007). Fall fires have had mixed results and may increase garlic mustard spread (Landis and Evans 2016).

**B. Mechanical Control**

Effectiveness: Moderate-High
Cost: Low (weed-wacker $100)
Labor: High
Permit: No

Cutting or hand-pulling garlic mustard plants can effectively control garlic mustard if done before seed production each year for a period of ten years. If cutting stems by hand or mowing, stems must be cut at the ground level to effectively reduce seed production from regenerating stems; stems cut 10 cm above the soil will regenerate and produce seeds (Nuzzo 1991). Any cutting or mowing strategy needs to include growing season-long monitoring to remove plants regenerating from the root crown. Plants will bolt and produce flowers between April and June and a single cutting event will not control all plants for the entire growing season (Landis and Evans 2016). Cutting stems is generally most practical in a large monoculture with no native vegetation, with successive mowings per year.

Hand-pulling is more effective in preventing regrowth than cutting if it removes the upper portion of the root (Evans 2007). All plants in a population should be pulled in their second year before flowers have formed while soils are moist, to dislodge the root more easily. Rosettes may be pulled in smaller populations. Follow-up monitoring should look for bolting rosettes through June (Landis and Evans 2016). Pulling causes soil disturbances and may encourage seed germination; tamp soil down after pulling. Faster germination of existing garlic mustard seeds in the seedbank may help speed the eventual exhaustion of the seedbank.

Stem and flower biomass must be taken from the site and disposed of in a sanitary way. Even flowers that have not set seeds can continue to grow and seed after the plant has been pulled. Plants that have been piled up can have enough residual moisture and sugars to continue to grow and re-root. Additionally, decomposing garlic mustard biomass will inhibit native plant establishment and growth. Clean all equipment and shoes carefully. Do not park a vehicle near a garlic mustard infestation.

## C. Biological Controls

Effectiveness: Unknown (in development)
Cost: Not yet available
Labor: Low
Permit: Yes

Several potential biological control agents for garlic mustard have been identified and are being tested for release. These include four species of European weevils *(Ceutorhynchus spp)* currently being reared at a high containment facility (Katovich and Becker 2014). For more information contact Richard Reardon (USFS) at rreardon@fs.fed.us.

## D. Cultural Controls

Garlic mustard is shade tolerant and in some cases it can invade high-quality natural areas with dense native vegetation (USFS 2016). There is also some evidence that native herbs in Wisconsin are tolerant of it allelopathic effects, and that having a healthy native community can slow the spread of garlic mustard (Phillips-Mao 2012). There is conflicting information whether restoration activities such as increasing native plant cover will control this species (USFS 2016, Phillips-Mao 2012). There is evidence that white-tailed deer browse inhibits some native species' competitive ability in garlic mustard invaded sites. Deer fencing may help increase percent cover of native forest species and increase competition with garlic mustard (Waller and Maas 2013, Knight et al. 2009). Highly invaded sites may also be restored with browse tolerant or unpalatable native species such as wild ryes (*Elymus hystrix, E. canadensis, E. lanceolatus,* etc) or other grasses.

### *Recommendations*

Successful garlic mustard control requires long term and thorough removal of all plants to eradicate seed sources for a period of at least 5 (to 10) years. A population that has been established for a longer period of time will have a larger seedbank and will keep germinating for more years than a younger population (Drayton and Primack 1999). The site should be monitored for an *additional 3 years after the last garlic mustard plants have been observed* (Nuzzo 1991).

Hand-pulling all garlic mustard plants annually is the most effective means of control. Pull in the spring before flowering and follow-up in about a month to look for bolting rosettes. Mow large monocultures if they are too large to hand-pull, however, monitor regrowth. Rapid response to small infestations before the seed bank develops is critical. These can be hand-pulled easily and monitored for five years. Large infestations should be replanted with native species that are tolerant to deer browse to complete with emerging seedlings. Continue to watch for development of the garlic mustard biological control weevil.

## Japanese barberry, *Berberis thunbergii* DC.

### *Species Overview*

Japanese barberry is a perennial shrub native to Asia, first collected in Michigan in 1909. Barberry flowers in April and May, and fruits ripen midsummer and are dispersed by deer and birds. Seeds are only viable for 1-2 years suggesting barberry does not persist in the seedbank (MDNR 2012). In addition to seeds, Japanese barberry regenerates through rhizome and root crown sprouts and from root fragments. Japanese barberry is also widely used in ornamental landscapes and has been spread widely by humans. It can tolerate full sun and full shade and is widely adaptable to wet or dry soil. Barberry will leaf out before native shrubs making easy to identify in the early spring. Japanese barberry has been correlated to high deer tick presence (MDNR 2012).

### *Treatment Options*

**A. Mechanical Control**

Effectiveness: Moderate
Cost: Low (gloves $10, stand-up weeder such as "Up-rooter" $150)
Labor: High

Permit: No

Cutting stems is the least effective method of barberry control. The shrub will vigorously resprout from the root crown and must be re-cut throughout the growing season and in follow-up years to exhaust root reserves. Mowing can be practical for large monocultures if done several times throughout the growing season; these areas should be monitored for native species regeneration and re-seeded if necessary. Individuals regrowing with native species may then be hand-pulled.

Hand pulling is the best way to control small and scattered populations of barberry because it has a shallow root system, but care must be taken to remove all of the rhizomes, or treat re-sprouts (Ward et al 2013a). Pull plants in the early spring when they first leaf out and the soil is moist. Gloves are needed for protection against spines and a stand-up weeding tool that grasps the stem can decrease the labor of bending over and pulling. Check from re-growth from root fragments later in the growing season and in the next year and pull any remaining plants. Dispose of all plant materials with seeds or roots.

**B. Prescribed Fire**

Effectiveness: Moderate
Cost: High (contractor needed, back-pack mounted propane torches, $250 plus propane)
Labor: High
Permit: Yes

Prescribed burns using ground-fires have low effectiveness and often do not kill adult shrubs (MDNR 2012), however directed flame is an effective method of treatment. This uses a propane torch at 40,000 BTUs to burn the base of the shrub and the root crown, killing all basal buds. Heat should be applied for 10-20 seconds to each side of the plant, until stems begin to glow (Ward et al 2013a). It should only be used during damp periods when a ground fire will not be ignited. This is most best applied in forested areas with scattered clumps of barberry; it seems to be less effective in open areas (Ward et al 2013a). Monitor for re-emerging sprouts and re-treat.

This has been demonstrated to be as effective as herbicide for initial treatments: 20-60% kill rate depending on clump size (Ward et al 2010). In follow-up treatments, directed fire decreased in effectiveness with increasing clump size moreso than herbicide; two follow-up treatments should be planned where the average clump size is larger than 150 cm (Ward et al 2010). A study by Ward et al in 2013 (b) cited that labor costs of directed flame method to be four times higher than that of herbicide.

A permit must me acquired from the local fire department or the Michigan DNR.

### *Recommendations*

Target mature shrubs with the most seeds (high light areas) in the highest quality natural areas by hand-pulling or applying a directed flame from a propane torch. For most small or scattered populations hand pulling is more cost-effective than burning. Large infestations and monocultures may be mowed if practical. All treatments will require follow-up visits to hand-pull or burn root ramets, preferably mid-season. Hand pulling and burning is comparable to herbicide in effectiveness, though hand pulling is more labor intensive and burning with directed propane flame is more costly.

## Slender false brome, *Brachypodium sylvaticum* (Huds.) P. Beauv.

### *Species Overview*

Slender false brome is an Eurasian perennial grass first found in Michigan in 1986 in Benzie Co. (Esch Rd.), and has since spread north into Leelanau Co. between Empire and Glen Arbor. These are the only populations known to Michigan and of few populations in the eastern U.S. This grass spreads by rhizome and by seed, creating dense monocultures in forested areas, out-competing native plants. Flowering begins in July during the second year of growth and around 100 seeds per plant are dispersed in August. Seeds are mammal-dispersed and can travel significant distances on fur and socks, making it commonly dispersed in recreational areas (Heinken and Raudnitschka 2002). It has also been shown to dispersed by logging equipment (Boersma et al 2006). When near water, seeds are dispersed by currents. It is unclear how long the seeds persist in the seedbank. Individual plants are long-lived (>20 years) (Haeggstrom and Skyten 1996). False brome is shade and sun tolerant, and tends to invade forests and woodlands.

### *Treatment Options*

**A. Prescribed Fire**

Effectiveness: Low-Moderate
Cost: Moderate (contractors needed)
Labor: Moderate
Permit: Yes

A 2014 study that investigated the effectiveness of prescribed burns in Oregon and found that hot summer burns did not significantly reduce false brome, and that late-season low temperature burns may increase false brome cover (Fjeran 2014). A different study found that low-intensity fires increase spread of false brome, while high-intensity fires decreased cover and spread (Poulos and Roy 2015). False brome can resprout vigorously after fire if it is not killed.

A permit is needed from the DNR or the local fire marshal for prescribed fires.

**B. Mechanical Control**

Effectiveness: Moderate-High
Cost: Low-High (hot foam Waipuna equipment rental $700/mo + $900/200 L foam)
Labor: High
Permit: No

Hand-pulling is effective if the entire root is removed and plants are pulled before they go to seed. May is generally a good time to start hand-pulling because soils are loose. Areas typically should be monitored and re-treated for 2-3 years. This may only be practical for small populations.

Mowing can help reduce seed-set if it is timed when plants begin to flower, but it will not kill the perennial grasses. If plants are mowed in seed, it will lead to the dispersal and spread of false brome. Mowing in April-June followed by mulching with 3-6 cm of native straw and seeding can effectively reduce grass populations after one to two years but will not likely eliminate a population.

A new method of treatment applies hot foam to the grasses. The hot foam treatment system, trademarked "Waipuna," is a 200°F non-toxic water and sugar mixture that is spayed from a truck-bed tank that super-heats plants and kills them over about four hours. This was used in 2002 by the Eugene BLM to treat roadside populations and resulted in an 88% reduction in grass percent cover after one year. Studies suggest two years of application are needed for effective control. This was found to be practical for roadside applications but expensive as compared to other mechanical and chemical controls. See http://www.invasive.org/gist/tools/hotfoam.html for more information on the Waipuna™ machine.

### *Recommendations*

Prevention of spread is critical in control efforts of false brome. Machinery, clothing, and equipment should be thoroughly cleaned after use in a false brome infested area. Where established, a combination of treatments is recommended. Herbicide application has been the most widely used and effective method of control, as mowing and burning have not been successful, and hand-pulling is too laborious for large populations. An integrated treatment such as (1) early season physical removal (i.e. high heat fires, mowing, or hot foam) followed by (2) mulching with 3" of native straw for the course of the growing season, then (3) fall planting of native grasses can be successful at significantly reducing populations after one to two years of treatment (see Institute of Applied Ecology False-brome Working Group control methods table: http://appliedeco.org/wp-content/uploads/efficacy-of-false-brome-may2007-draft.pdf).

## Oriental bittersweet, *Celastrus orbiculatus* Thunb.

### *Species Overview*

Oriental bittersweet is a perennial woody vine native to Asia and was first collected in Michigan in 1976. This vine may grow to 100 ft long and climb to the height of tree canopies, smothering and girdling trees, and also forms an extensive root system which contributes to clonal/vegetative reproduction. It is highly responsive to sunlight, and it will rapidly grow towards light gaps and thrives in full sun. Oriental bittersweet is typically dioecious, with male and female flowers on separate plants but can have perfect flowers within an inflorescence, thus male plants can produce fruit. Fruit production begins at two years of age, and is highest in full sun on female plants. Fruit is dispersed by birds and small mammals in late winter, and has been shown to remain in the gut of birds for as much as 42 days (MDNR 2012) thus can be dispersed significant distances and even along migratory routes. Seeds can germinate and persist in very low light levels in wait for canopy gaps. Most seeds germinate within the first year in late spring, and the seedbank is short-lived. Plants are cultivated for ornamental landscapes and are widely dispersed by humans. Habitat is grasslands, woodlands, closed-canopy forests, roadsides and fence rows. It cannot successfully establish in wetland soils.

### *Treatment Options*

#### A. Prescribed Fire

Effectiveness: Low
Cost: Moderate (contractor needed)
Labor: Moderate
Permit: Yes

Prescribed fire is effective in killing above ground portions of plants but will not destroy the large root system, which will resprout after fire (MNFI 2009). Killing the above-ground portion of the vine is an important step in management, and aids in control of seed production and dispersal. Burning can stimulate the seed bank and may result in new bittersweet seed germination (MNFI 2009). Burning also clears away shrubs and understory plants that may be shading bittersweet. In a study published in 2016, bittersweet resprouted more vigorously on burned sites than mechanically-cut sites (Pavlovic et al 2016). This study concluded that bittersweet has a positive response to burns that increases the number of stems and opportunities for growth to the forest canopy (Pavlovic et al 2016). Caution must be taken to avoid Oriental bittersweet vines acting as a ladder, carrying fire up to the tree canopy (MDNR 2012).

A burn permit issued by the local fire department or the DNR is required.

#### B. Mechanical Control

Effectiveness: Moderate (short term control)
Cost: Low (pruning shears $30, shovel)
Labor: High
Permit: No

Cutting stems is an effective and important method for killing above-ground portions of the vines that may be damaging native shrubs and trees (MDNR 2012). It is also important for the destruction of seed source populations. A "window cut" method should be used: vines cut at the base of the plant and several feet above the base so that stems cannot grow back together. The above-ground portion may be left in place to decompose.

Cutting will stimulate resprouting and, even if cut multiple times per year, will not kill the vine or lead to effective long term control (MDNR 2012), however it will temporarily result in a 50% reduction of non-structural carbohydrates (sugars used for growth)

(Pavlovic et al 2016). Weekly repeated mowing or cutting may eventually exhaust root reserves however there is no evidence of its effectiveness. In one study, mechanical control alone was shown to reduce bittersweet cover more than herbicide use alone, however, the combination of the two methods reduced cover significantly more than either used alone (Farmer et al 2016).

Treatment of the root system is vital to controlling the vine. Hand-pulling or digging the root can be difficult because of the large size and the often multiple stems arising along the length of the roots. Pull stems slowly to avoid breaking the root and tamp down soil afterwards (MDNR 2012). If portions of the roots are left in the soil, the plant will regrow. Young plants may not be seedlings but rather root-sprouts from a large plant.

### C. Cultural Controls

Effectiveness: Low
Cost: Varies
Labor: Varies
Permit: No

Oriental bittersweet prefers full sun, but it appears to be extremely plastic in light requirements and can grow in very low light more efficiently than its native counterpart *Celastrus scandens* (Leicht and Silander 2006). For this reason, it can invade even high-quality, intact natural communities and restoration and shading is not an effective long term control. Limiting exposed soils to seed sources can help to decrease germination rates (MDNR 2012).

Oriental bittersweet is allelopathic and can affect germination and growth of interspecific species. In a greenhouse experiment *Celastrus orbiculatus* was shown to inhibit growth of *Elymus hystrix,* a native grass, more than garlic mustard, a plant typically cited for allelopathic strength (Cipollini and Bohrer 2016). This may have implications for restoration activities on bittersweet-affected soil.

## *Recommendations*

Since seeds can be dispersed long distances, a landscape approach is necessary. Control measures should focus on eradicating seed-source populations. Begin by understanding distribution of this species in the area, then target seed source populations. It is also important to target smaller populations in high-quality natural areas.

Cutting is an effective and important short-term control, especially for large plants that produce a large seed crop. However, because of the extensive root system, and its propensity to sprout from the root collar and root fragments, mechanical controls are not effective long-term methods. Controlled burning is not recommended as it clears soil for new seed sites and stimulates root sprouts.

Mechanical control in combination with herbicide (triclopyr or glyphosate) is the most effective methods of control (MNFI 2009, MDNR 2012, Swearingen 2009, Wooten 2013). The

MDNR recommends treating cut stems with a concentrated herbicide solution, while a study on Presque Isle found cutting stems then spraying with a foliar herbicide on re-growth 5 weeks after cutting was more effective then immediately treating cut stems (Wooten 2013).

## Canada thistle, *Cirsium arvense* (L.) Scop.

### *Species Overview*

*Circium arvense (Asteraceae),* Canada thistle, is a perennial forb introduced from Europe as early as the 1600s (MNFI 2009). The height ranges from 0.6-1.5 m tall and can form large monocultures spreading through seed and deeply-rooting, laterally-spreading rhizomes. The root system can spread laterally 2-3 meters per season per plant, and is a key component of its invasive habit via competition and allelopathy (Gover et al 2007). Plants are dioecious with separate male and female patches; a patch is often a single, multi-stemmed clone. It blooms June through September, and produced small seeds with hairy tufts that facilitate wind dispersal. Each plant can produce 1500-5000 seeds which can germinate 8-10 days after flowering begins and persist in the seed bank for up to 20 years (MNFI 2009). The ecological niche is disturbed open areas, roadsides, agricultural fields, and may invade prairies and open wetlands. It is shade-intolerant (MNFI 2009).

### *Treatment Options*

**A. Prescribed Fire**

Effectiveness: Low
Cost: Moderate (contractor needed)
Labor: Moderate
Permit: Yes

Prescribed fire has had mixed results in controlling Canada thistle. The Missouri Department of Conservation (2017) found that late spring burns are effective treatment for a single year because they remove above-ground biomass, but early spring burns can increase sprouting and reproduction, and that burns must be conducted annually for at least three years to have long-term decreases (not eradication). In North Dakota, studies have suggested that burning can lead to short term increases in Canada thistle, then a decrease over several years (Travnicek at al 2005), and, that burning in prairies has no significant long term effect on Canada thistle (Lym and Travnicek 2015). The Michigan Natural Features Inventory (MNFI) concluded that burns can lead to the stimulation of this species causing post-burn spread by rhizomes and are not recommended (MNFI 2009).

A burn permit issued by the local fire department or the DNR is required.

**B. Mechanical Controls**

Effectiveness: Moderate
Cost: Low (pruning shears $30)

Labor: High
Permit: No

Mechanical control can be successful at eliminating Canada. This approach removes above-ground biomass in order to exhaust the root system of starch reserves. The root system will decrease in size and eventually die. This process requires sustained removal of above-ground biomass by multiple treatments per year over multiple years (Gover et al 2007). If the above-ground leaves and stems are allowed to grow and photosynthesize, they will replenish root starch reserves. This can take 10 years of repeated mechanical above-ground removal (MNFI 2009). Cutting or pulling must take place three times per season (in June, August, and September) in order to starve underground parts (MDC 2017). Just before fall is the most important time to maximize injury to the root system because it will be moving sugars to the roots to prepare for the next growing season (Gover et al 2007). Late spring (bud to early bloom stage) is the second most important time for biomass removal because the energy that was stored in the roots has been sent above-ground for reproduction, causing a seasonal-low in stored root energy (Gover et al 2007).

Mechanical treatment is feasible for light to moderate infestations. MNFI (2009) recommends beginning control in the highest quality areas, pulling seedlings by hand within 2.5 weeks of germination. For highly-infested areas, mowing can be used in alternative to hand-pulling, however it may remove desirable native species. It is important to note that all root fragments can sprout new plants; for that reason removal of the root is not recommended as it disturbs upper soil layers, creating new establishment sites and it can be too difficult to remove all root parts.

### C. Cultural Controls

Effectiveness: Moderate-High (long-term resilience)
Cost: Moderate (varies)
Labor: High
Permit: No

Because this plant is shade-intolerant, ecological controls include facilitating rapid canopy closure by trees, shrubs, or tall, fast-growing herbaceous plants in order to outcompete Canada thistle for light (Ross). This species cannot establish well in heavily vegetated natural communities or shaded areas (MDC 2017).

Additionally, encouraging establishment and growth of functionally similar native species has been shown to decrease establishment of Canada thistle by interspecific below-ground competition for resources. In a prairie restoration study by Norland et al (2013), common yarrow *(Achillea millefolium)*, black-eyed Susan *(Rudbeckia hirta)*, and prairie coneflower *(Ratibida columnifera)* were found to have appropriate functional similarities to provide adequate competition so to significantly reduce Canada thistle's canopy cover after two years of growth.

Control efforts may take advantage of the diecious and clonal habit. If resources are limited, eradication could focus on female clones (identified in flower), as male clones do not produce seed.

## D. Biological Controls

Effectiveness: Unknown
Cost: Low ($0-$200 per target population)
Labor: Low to Moderate
Permit: No

There are several biological controls that have been approved for Canada thistle, however none have been shown to be effective at reducing populations on a large scale. The most widespread agent is the *Hadroplontus litura* weevil which feeds on the root system. These alone have not been shown to reduce populations in North Dakota (Lym and Travnicek 2015). Similarly, the gall-fly *Urophora cardui* causes meristematic galls with no long term damage (Lym and Travnicek 2015). A release of these insects to one area costs between $100-$200 (Biological Control of Weeds, Inc 2017).

The native painted lady butterfly, *Vanessa cardui,* caterpillar feeds extensively on Canada thistle and can reduce populations dramatically (Lym and Travnicek 2015). However, this is generally only found in southern states such as Arizona and New Mexico, with intermittent migrations as far north as Canada once every 8-11 years. It is also known to feed on soybeans and sunflower crops and therefore is typically not considered appropriate for introduction (Lym and Travnicek 2015).

The native pathogen *Pseudomonas syringae* pv. *tagetis* can kill Canada thistle by releasing a toxin within the phloem, however commercial cultivation and production has been unsuccessful precluding it from becoming a treatment option (Lym and Travnicek 2015).

The rust fungus *Puccinia punctiformis* was first recognized as a potential biocontrol agent as early as 1893, however disease establishment has been largely unsuccessful due to an incomplete knowledge of the disease cycle (Berner et al 2013). It occurs naturally across the range of Canada thistle and is host-specific (CDOA 2017). Recent studies suggest imitating natural disease cycles can successfully establish the rust fungus and have successfully inoculated fall rosettes in four counties' field sites (Berner et al 2013). A 2015 study found that 50-60% of rosettes adjacent to inoculation points become infected, and shoot densities decreased by 43% after 18 months, 60% after 30 months, and 80% after 42 months (Berner et al 2015). There is an available online guide prepared by Dr. Berner with detailed instructions for the treatment process: identify infected thistles, collect *P. punctiformis* infected leaves, dry leaves, and re-inoculate target populations in the fall with the dried leaf powder (see www.canadathistlecontrol.com). The rust fungus primarily attacks the roots, and can often be asymptomatic throughout its lifecycle on the above-ground portion of the plant, making it difficult to detect successfully inoculated populations. Field trials in Colorado have demonstrated significant die-back 3-4 years after inoculation (CDOA 2017).

### *Recommendations*

The most effective traditional form of control removes the above-ground biomass of the plant repeatedly through the season without disturbing soil, and is repeated for multiple seasons (via mechanical control). The use of herbicide to remove the above-ground biomass is functionally similar to mechanical removal of the biomass; both techniques kill plants through starving root reserves. The major difference between the two techniques is that fall season transport of herbicides to the rhizomes of the Canada thistle helps further reduce root mass. If mechanical and herbicide methods were to be combined, mechanical removal would take place in June and August, followed by an herbicide treatment in September while the plant is transporting sugars to its root. Because seeds have a 20-year life in the seedbank, repeated follow-up visits are needed to monitor for seedlings. Seedlings should be pulled within 2.5 weeks of germination (MNFI 2009).

Both herbicide and mechanical removal involves a site visit 3 times per year and attention to each individual stem, they are estimated to take comparable amount of time. Mechanical removal will involve removal of cut stems, collection, and disposal of in an appropriate manner. Supplies and equipments costs are low (pruners, black plastic bags), but labor costs are high, depending on degree of infestation and navigability of the site. It will avoid herbicide-related costs including back-pack sprayers, maintenance of sprayers, and herbicide safety training. This is recommended for spot-treatment of populations, and widespread occasional individuals.

Ecological control is a preferred method in both long-term control and prevention. Canada thistle is an early succession species that establishes on disturbed soils, so it is important to avoid creating disturbances. Rapidly establishing native plants that have similar functional traits, as well as shading plants such as tall herbs, shrubs, and trees, will serve both long-term control and prevention. Restoration costs can vary widely based on project and tend to be high in the short term and low in the long term. Costs include the prices of plants or seeds used in the restoration project, labor to prepare the soil and install the plants, and labor for follow-up visits to monitor and remove Canada thistle and other undesirable plants.

Biological control using *Puccinia punctiformis* represents an emerging area of research, but initial accounts appear promising as a component of an integrated pest management strategy. The spread and inoculation process could be incorporated into field visits while performing mechanical control, as thistle biomass will be collected anyways. Success of this treatment may not be visually measurable for several years as it can be asymptomatic above ground, therefore it should be combined with mechanical control to control seed production and spread. It is unclear if this is as effective in combination with mechanical control.

## European swamp thistle, *Cirsium palustre* (L.) Scop.

### *Species Overview*

European swamp thistle is a herbaceous biennial or monocarpic perennial native to the British Isle and was first reported in North America in the early 1900s. Its current distribution in North America is the Great lakes region. Monocarpic perennials generally flower within two years (biennial) but may take longer. First year plants grow a rosette of leaves; the rosette stage can last as much as 3 (to 6) years. Second year plants (up to fourth year plants) grow an erect, 3-6 ft tall stem that forms several small flower heads. Each plant can produce as much as 2,000 seeds. Seeds are small with a pappus to allow for wind dispersal up to 250 m, though most seeds are dispersed to within 10 m of the parent plant (Gucker 2009). Seeds can also be dispersed by water run-off, humans and animals, and hundreds of miles on equipment. Seeds do not last more than 3 years in the seed bank; most seeds germinate during the first year (Gucker 2009). All plants will die after flowering, however if the flowering stem is damaged, it may regrow in the same or next growing season (Gucker 2009). It prefers moist soils and is shade-tolerant. Habitat preference include roadsides, wet old fields, fens, marshes, swamps, and interdunal wetlands (MNFI 2009). It appears to be an early and mid-succession species in North America (Gucker 2009).

### *Treatment Options*

#### A. Mechanical Controls

Effectiveness: High
Cost: Low (stand-up dandelion-style weed puller, $15)
Labor: High
Permit: No

First-year rosettes can be hand dug or pulled, making sure to remove root or cut it a few inches below the rosette to fully kill the plant (GLIFWC 2006). Plants that have sent up a flowering stem can be controlled in the same way as the rosettes, preferably before the formation of the flowers so that biomass can be left on site. If a flowering head has formed, the flowers must be bagged and disposed of off-site in a sanitary manner.

Mowing, or removal of the flowering stem without removal of the root can be successful, though this must be repeated for 3-4 years for each plant. If the root is not severed to kill the plant, it will send up a new flowering shoot after the original one is cut; thus it biennial duration can be extended for as much as six years with continued mowing or stem-cutting (WDNR 2004). The new shoot may be sent up in the same year after cutting or the following year, and tends to produce more seed than undisturbed plants (Nordin 2002).

#### B. Biological Controls

Effectiveness: Low
Cost: Low ($15-$150 when available)
Labor: Low
Permit: No

Several insects are known to feed on marsh thistle, however none have emerged as an effective biological control. For instance, the *Cheilosia corydon* fly was released in 1991 in Oregon for thistle control but it has attacked native and exotic thistles alike (ODA 2011). This is not an acceptable trait of a biocontrol, especially in coastal Michigan where endangered endemic Pitcher’s thistle occur. The weevil *Rhinocyllus conicus* has been undergoing field trials in British Columbia (Cao et al 2012), however previous work has demonstrated a lack of host-specificity and may feed on other thistles (Arnett and Louda 2002).

**C. Herbivory**

Effectiveness: Moderate (non-target species impacted)
Cost: Unknown
Labor: Low
Permit: No

Goats have been suggested as a control for swamp thistle because they are attracted to the flowering head and less than 1% of seeds are viable after digestion, making it unlikely they would disperse seeds (Cao et al 2012). However, goats do not selectively feed on marsh thistle, and they can cause other damage to native plants including trampling and exposing new seed sites (Fraser 2000). This approach would only be appropriate for dense monocultures.

**D. Cultural Controls**

Effectiveness: Moderate (preventative)
Cost: Varies
Labor: Varies
Permit: No

The best practice for controlling marsh thistle at a state-wide level is the prevention and spread of new populations by avoiding disturbing wetland soils. In particular, avoid building roads and trails in wild wetland areas because the combination of the disturbance and the vector leads to the establishment of new populations.

### *Recommendations*

There is relatively little information available on marsh thistle control beyond mechanical control and herbicide use. However, mechanical controls appear to be highly effective, particularly when the root is severed. Most control programs recommend cutting off just the flowering heads, however this would be more time consuming in controlling the population than severing the taproot, because *each plant* would need to be re-cut for 3-4 years to kill it. If severing the taproot, each plant would only be treated once. Severing the taproot is as effective and time consuming as herbicide application, but costs less. Sites need to be monitored for 3-4 years, treating new seedlings as they emerge from the seedbank. Seeds are viable for three years in the seedbank, so if all individuals are treated in a population for three years the infestation should be properly controlled.

## Autumn-olive, *Elaeagnus umbellata* Thunb.

### *Species Overview*

Autumn-olive is an Asian shrub that was first collected in Michigan in 1939. Humans were initially the primary vectors, planting this shrub widely for wildlife habitat. It produces a large number of small, sweet berries in September and October that are dispersed widely by birds and mammals. It can also resprout vigorously from root crown after cutting or fire (MNFI 2012). Plants may bear fruit by three years of age, and are able to produce up to about 50,000 seeds per year with germination rates around 70%. Seeds typically germinate within the first year and are not thought to remain in the seed bank for very long. Seed-source populations outside management areas will cause repeated invasions. Autumn-olive prefers full sun and moist soils, but will persist and produce a small amount of seed in full shade and upland areas.

### *Treatment Options*

#### A. Mechanical Controls

Effectiveness: Low-Moderate
Cost: Low (stand-up weeder such as "Up-rooter" $150)
Labor: High
Permit: No

Mechanical control can be useful for small infestations and young plants. Hand-pulling or digging can effectively control seedlings and young plants that have not yet grown a large root system (MNFI 2012). Target early stage invasions with thorough hand-pulling and digging. Roots are easiest to remove when soils are moist. Tamp soils after any disturbance. A stand-up weeding tool can be a helpful tool to remove clumps.

Cutting and mowing stimulates fast resprouting from the root crown (MNFI 2012, Solecki 1997). In areas where repeated cutting and mowing is practical, such as old fields, it may be done repeatedly throughout the growing season to slow spread and reproduction capacity, but has not been demonstrated to kill plants (Solecki 1997). Cutting and mowing is most frequently done in combination with herbicide application, which together is effective in killing the plant.

#### B. Herbivory

Effectiveness: Moderate
Cost: Unknown
Labor: Moderate
Permit: No

Goats and sheep will eat autumn-olive readily, killing the shrubs by debarking the stems and defoliating the branches (MNFI 2012). Multiple seasons of browsing are needed to eventually kill the shrubs (MNFI 2012). Goat and sheep are not selective and will also browse native species, therefore this is most practical by fencing them into areas with a low native species diversity and a high abundance of autumn olive.

Contact the Grand Traverse Regional Land Conservancy on their experience using goats to address invasive species concerns.

## C. Prescribed Fire

Effectiveness: Low-Moderate
Cost: Low
Labor: High
Permit: Yes

Prescribed burns can be used to kill the aboveground potions of autumn-olive if there is enough fuel to generate adequate heat. This is most effective for seedlings and large shrubs: Subsequent burns (1-3) that ignite and fully burn dead stems may generate enough heat to kill the root crown of large shrubs (MNFI 2012). This can be less effective for small plants that do not have enough aboveground biomass to generate sufficient heat (MNFI 2012). If the heat of the fire is not sufficient to kill the root crown, burns will be ineffective and shrubs will regrow and can potentially increase in size and vigor (Stark 2000). There is some evidence that hot fires (>300-500°C) do not kill autumn olive seeds (Emery et al 2011), and exposing soil may create good seed sites for germination. It should be noted there are no published studies on the effectiveness of fire and temperatures necessary for killing autumn-olive.

### *Recommendations*

Successful long-term treatment is approached at a landscape level because of the propensity for spread by bird and mammal dispersal, and the large regional populations already present. Large, sun-grown plants that produce the most seed should be targeted first, particularly populations near in or near high-quality natural areas. If seed source populations are not removed, satellite populations will continuously establish.

Repeated high-heat controlled burns for several years may be practical for dense patches in fire-adapted communities and areas of low conservation value such as old fields. It is important that there is enough fuel to burn the root crowns sufficiently. Directed flame by propane torch on the root crown (as used for Japanese barberry) could be a new technique for autumn-olive, and theoretically may be quite effective. These treatments are only effective if pursued aggressively and combined with monitoring and follow-up treatments, as autumn-olive resprouts vigorously and this may initiate new seedlings. These techniques are likely to be more costly and laborious than cut-stem herbicide applications because of their moderate effectiveness and need for repeated applications.

Populations in high-quality natural areas should be treated by hand-pulling or digging as possible. If clumps are too large or widespread to remove all the roots within high-quality areas, cutting stems can be a temporary stop-gap measure. Successful control may need to combine cut stem treatment and herbicide application to kill the roots. If this method is chosen, treatments in late summer are most effective.

## Japanese Knotweed, *Fallopia japonica* (Houtt.) Ronse Decr. (and hybrids)

### *Species Overview*

A perennial forb originating from Japan, Japanese knotweed was first recorded in Michigan in 1919. It grows robust stems in dense thickets, primarily spreading vegetatively by rhizome but also forms a deep taproot. Stem and root fragments form new plants readily are thought to be the primary method of reproduction. Populations of Japanese knotweed across Europe and at least some of those in the U.S. are of an identical female clone, and often a fertile male plant is not present to set viable seed (Hollingsworth and Bailey 2000, Gaskin et al 2014). One study has demonstrated that all Japanese knotweed in the western U.S. is genetically identical and spread only vegetatively, and that all fertile seed-bearing knotweeds are hybrids between Japanese knotweed and giant knapweed *(Fallopia sachalinensis),* named Bohemian knotweed *(Fallopia x bohemica)* (Gaskin et al 2014). Other studies have suggested that there are male clones of Japanese knotweed fertilizing the widespread female clone (Groeneveld et al 2014). Studies in Massachusetts and Quebec identified Japanese knotweed producing viable seed which was observed germinating at several field sites (Forman and Kesseli 2002, Groeneveld et al 2014). Seeds and vegetative fragments are dispersed by wind, water, and humans. It can tolerate a variety of soil and light conditions, but it prefers moist conditions and is often found along riverbanks, wet depressions, forest edges, and roadsides.

### *Treatment Options*

**A. Mechanical Controls**

Effectiveness: Low
Cost: Moderate-High (loppers $50, brush-cutter $150, or brush mower)
Labor: High
Permit: No

Hand-pulling and digging is inefficient because of the extensive and deep root system. Damaged roots will re-sprout vigorously and can be “disastrous” (MNFI 2012). Digging may be appropriate for very small populations. Roots may persist underground without sprouting for three years, so four years of monitoring is recommended.

Cutting removes aboveground biomass but may stimulate the underground rhizome causing further spread and growth. MNFI does not recommend cutting as a form of control because any stem or root fragments can be transported, root at the node, and spread the infestation. One study observed repeated cutting reduces rhizome growth significantly, and found four cuts per season causes a net depletion in belowground biomass (e.g. Seiger and Merchant 1997). Other literature recommends that if you must cut stems, cut every 2-3 weeks during the growing season (Soll 2004).

Cutting is most efficient where brush-cutters or lawn mowers can be used. Cut in early summer, mid-summer, late summer, and fall to reduce rhizome size. If resources are limited to one cut per season, cut in June. If herbicides are to be used in combination with cutting, cut in late August. The risks of spreading Japanese knotweed by fragmentation may outweigh the benefits of mechanical treatments (MNFI 2012). Most literature recommends cutting only in combination with herbicide application.

**B. Biological Controls**

Effectiveness: Moderate-High
Cost: Unknown (not yet available for use in U.S.)
Labor: Low
Permit: Unknown

A species of psyllid, *Aphalara itadori,* has been tested in extensively in Britain as a biological control agent, and was released in 2010 for field testing. Studies in the U.S. have demonstrated a 50% reduction in total plant biomass in 50 days (Grevstad et al 2013). This has not yet been released in the U.S. (MNFI 2012) though some publications state the release is "imminent" (Clements et al 2016).

A secondary biological control agent, a leaf-spot pathogen *(Mycosphaerella polygoni-cuspidati)* from Japan, is being tested for field release in the U.K.

### *Recommendations*

Local populations of Japanese knotweed should be assessed for fertile seed production and hybridization with giant knotweed or backcrosses with Bohemian knotweed. Current research suggests that hybrid Bohemian knotweed is much more common than Japanese knotweed, and that many populations are misidentified. Accurate assessment of species and seed viability is necessary in crafting the best management practices.

Most management strategies point to the necessity of herbicide for controlling Japanese knotweed. While mechanical controls may be useful for controlling very small populations, it can be ineffective and even lead to spreading large infestations. There is little information available on prescribed fire, and DNR suggests that it is not effective. The best practice for controlling large populations combines cutting stems and herbicide application. Mow or cut stems in early June, then apply herbicide to re-growth six weeks later (Gover et al 2005). Imazapyr is most effective because it is active in the soil for an extended period (MNFI 2012). Glyphosate is most commonly recommended but there is some evidence of glyphosate resistance (Gaskin et al 2014).

## Glossy buckthorn, *Frangula alnus* Mill.

### *Species Overview*

Glossy buckthorn is a Eurasia shrub first collected in Michigan in 1934. As most non-native invasives, it is associated with disturbed habitats such as roadside ditches, powerline cuts, and disturbed wet forests, but it also spreads aggressively into high conservation-value natural communities such as fens, bogs, wet prairies, and northern white-cedar and tamarack forests. It prefers wet, calcareous soils. Shrubs (single or multi-stemmed) reproduce from seed production and root crown sprouts following top kill. Adult shrubs flower in early summer and produce 500-1,500 viable seeds per year (Medan 1994), with the most seed produced on shrubs in full sun. Birds are the primary dispersal agents, though mammal, gravity, and water dispersal is also likely. Seeds are thought to be viable for 2-7 years (Gucker 2008).

### *Treatment Options*

#### A. Prescribed Fire

Effectiveness: Moderate
Cost: Moderate (contractors needed)
Labor: Moderate
Permit: Yes

Evidence suggests fire can damage and suppress glossy buckthorn for several years, decreasing number of stems and canopy cover (Catling et al 2002, Neuman and Dickmann 2001). Fire will not effectively control adult shrubs unless burns are repeated for 5-6 years, killing all root crowns and seedlings (Heidorn 1991, Solecki 1997). Damaged root crowns have been noted to resprout vigorously and new growth may go to seed in the same year as it was burned. Fire is most effective when done in the early spring as soon as leaves emerge and needs to have medium to hot temperatures. A five-second treatment by a propane torch on stems less than 4.5 cm diameter will kill young plants (MNFI 2012).

A burn permit from the local fire marshal or DNR is required.

#### B. Mechanical Controls

Effectiveness: Low
Cost: Low (shovel, loppers $50, stand-up weeder $150)
Labor: High
Permit: Yes

Hand-pulling and digging can be useful for controlling small populations of glossy buckthorn shrubs that are smaller than 4” in diameter. Remove as much of the root system as possible, and always tamp soil and replace leaf litter.

In several studies, stems were either cut or mowed during the growing season leading to an increase in native species cover in the first year, but buckthorn resprouted densely in following years leading to no significant long-term changes (Clark and Mattrick 1998, Sinclair and Catling 1999). Mid-season cutting (July) has been shown to produce the weakest re-sprouts (MBWSR 2015). Girdling can also be substituted for cutting stems but root crowns will re-sprout immediately. Glossy buckthorn has been noted to grow as much as six feet and fruit in the first year after cutting, limiting the usefulness of cutting without combining with other treatments. The NRCS recommends covering small root crowns with a coffee can for two years after cutting to contain sprouts and kill the root.

### *Recommendations*

Satellite populations and those in high-quality natural areas should be targeted first. Seed production and dispersal from core populations is also critical in reducing re-introduction to satellite areas. Remove as many sun-growing adult shrubs as possible initially, followed by annual seedling and small shrub treatments. Treat small populations by hand-pulling and digging shrubs, targeting seed-producing shrubs first. A combination of cutting stems and prescribed burning may be effective at killing glossy buckthorn if the fire is able to burn hot enough (Laatsch and Anderson 2000). In Minnesota, some success has been had by cutting stems in July followed by burning new sprouts in April (MBSWR 2015).

Control methods that disturb the soil and open the canopy tend to invigorate seedling germination and can lead to monocultures of buckthorn seedlings. After cutting and fire, seeding with native species has been shown to significantly reduce glossy buckthorn seedling numbers (Scrivner and Leach 1998) and can also help build a fuel load for future prescribed burns (MBSWR 2015). If high-heat fires are not an option, herbicide may need to be used to treat glossy buckthorn.

## Blue lyme grass, *Leymus arenarius* (L.) Hochst

### *Species overview*

Blue lyme grass was is a perennial, rhizomous grass planted for stabilizing sand dunes in Michigan and first collected outside of cultivation in 1941. It occupies sandy soils including shifting sand dunes and beaches along Lake Michigan, and if often used to stabilize slopes. It spreads by seed and rhizome growth and fragmentation. Seeds and rhizome fragments are dispersed up the coastline by wind and wave action.

### *Treatment Options*

**A. Mechanical Controls**

Mechanical controls are not recommended because root break easily and rhizomes will regrow (MNFI 2012).

### *Recommendations*

Little information is available on treatment options for blue lyme grass at this point. The MNFI recommends early spring herbicide treatments.

## Common Privet, *Ligustrum vulgare* L.

### *Species Overview*

Common privet is widely cultivated European shrub that was first collected in Michigan in 1896. There are six species of non-native privet species in the U.S. In addition to common privet there is Chinese privet (*L. sinense*), Japanese privets (*L. japonicum*), and Amur privet (*L. amurense*), not known to Michigan, and California privet *(L. ovalifolium)* and border privet *(L. obtusifolium)* that are found in Michigan but not reported to be invasive here. Common privet is a perennial shrub that may grow to 16 ft tall. It has perfect flowers that bloom in mid-June and hundreds of fruits per bush ripen in September and persist on the bush throughout the winter. Seeds are distributed by birds and other animals. Seeds do not persist in the seed bank; nearly all germination occurs during the first growing season (Panetta 2000) though germination rates have been reported to be low, 5-27% (SEPPC 2003). The shrubs also spread vegetatively by sprouting root fragments (MNFI 2012). Privet tolerates sun and full shade and can occupy a variety of habitat types including old fields, woodlands, forests, and riparian areas; they prefer moist soils.

### *Treatment Options*

**A. Mechanical Controls**

Effectiveness: Low-Moderate
Cost: Low (shovel, loppers $60, stand-up weeder $150)
Labor: High
Permit: No

Young plants and seedlings can be easy to pull or dig, making sure to remove all roots. Root fragments may resprout and follow-up treatment are needed (MNFI 2012). For larger shrubs, remove with an uprooting tool. Cutting or mowing can be effective in limiting seed production if done at least once per growing season, but shrubs will resprout (Remaley and Bargeron 2003). One report indicated that a population of privet was eradicated after two cutting treatments (Batcher 2000).

**B. Prescribed Fire**

Effectiveness: Low-Moderate
Cost: Moderate (contractors needed)
Labor: Moderate
Permit: Yes

Fire is likely to top kill privet but there is little information on it's use for control. There has been some evidence that privet resprouts following fire, and, that ground fires may be difficult to administer since privet prefers moist areas (Faulkner et al 1989). There is other evidence that some species of privet may be killed through repeated burns (Batcher 2000). It is likely that a directed flame on the root crown would kill privet.

A burn permit is from the local fire marshal or the DNR is required.

### *Recommendations*

Management should focus on treating seed source populations by removing mature, fruiting shrubs and controlling root collar sprouts. A combination of mechanical controls and prescribed fires may be used to effectively control this species: Remove aboveground (and belowground) biomass as possible by mechanical methods, followed up by burning root crowns with high heat prescribed fire. Directed flame from a propane torch on the root crown may be effective (as discussed in barberry control methods) but there are no known trials of this methods. Most literature focuses on the use of herbicides (foliar and cut stump methods) as the preferred treatment.

## Bush honeysuckles, *Lonicera* spp.

### *Species Overview*

Invasive honeysuckles are comprised of a group of Eurasian shrubs and a Japanese vine, including Morrow's honeysuckle *(Lonicera morrowii),* tartarian honeysuckle *(L. tartarica),* hybrid honeysuckle *(L. xbella)*, European fly honeysuckle *(L. xylosteum),* amur honeysuckle *(L. maackii),* and Japanese honeysuckle *(L. japonica).* Only the first four species listed have been recorded for Leelanau County, though the other two can be found in southern Michigan and may make their way north. Functionally, our four invasive honeysuckles are quite similar and are known to hybridize and back-cross, therefore they can be grouped together for treatment methods.

All of our invasive honeysuckles are robust shrubs growing to 15 ft tall. They flower in full sun and shade at 3-5 years old, producing orange to red fruit dispersed by birds and mammals in late summer and fall. The seed crop per shrub is around 20,000 per year (Barnes 1972) though other estimates are much higher (Munger 2005). There is some disagreement over the length of viability of seeds, but it is thought they generally do not build up in the seed bank, but, under some conditions may be viable for up to 12 years (Munger 2005). Bush honeysuckles are able sprout vigorously after stem damage from the root crown, as well as spread vegetatively through root suckering and layering (Barnes 1972). There is some evidence that roots remain shallow (<6" deep) (Barnes 1972). They are found establishing in a wide range of habitats including old fields and roadsides, woodlands, forests, swamps, bogs, fens, sand plains, and most dry to facultative wet sites.

### *Treatment Options*

**A. Mechanical Controls**

Effectiveness: Low-Moderate
Cost: Low (shovel, loppers $50, stand-up weeder $150)
Labor: High
Permit: No

For light infestations, hand-pull or dig small shrubs making sure to remove the root crown. Tamp any disturbed soil to reduce germination sites. Since bush honeysuckles are shallow-rooting small and medium sized plants can be dug or pulled relatively easily. A shrub uprooting tool may be useful. Root fragments typically do not sprout.

Cutting stems can temporarily reduce seed production. There is some evidence that repeating cutting in well-shaded forests may kill honeysuckles, but in high light areas they have demonstrated vigorous re-growth even with repeated cutting. Cutting must be done once per year, preferably just before seed set, in July. In one study, three years of cutting the stems of forest-grown plants each July resulted in a 70% mortality rate. The same treatment of open-grown plants did not reduce the population (Luken 1990). Cutting stems does not appear to be effective for plants receiving high light.

B. **Prescribed Fire**

Effectiveness: Low
Cost: Moderate (contractor needed)
Labor: Moderate
Permit: Yes

Prescribed fire has shown some effectiveness at reducing honeysuckle vigor and some mortality though research is lacking. Fire effectively kills aboveground biomass, and is likely to kill seedlings and unhealthy plants; root crowns are often protected from fire damage by topsoil because they are 1-6" deep (Hoffman and Kearns 1997, Nyboer 1992, Smith 2004). Studies suggest that prescribed burns have a generally adverse effect, and with repeated burns honeysuckle shrubs begin to decline (Munger 2005). Burns must be repeated each year for 3-5 years to have a negative effect; single burns do not significantly control populations, though some individuals may die (Kline and McClintock 1994).

A burn permit from the local fire marshal or the DNR is required.

### *Recommendations*

Control bush honeysuckles by targeting the largest seed-source populations. After treatment, it is important to restore bare soil to native flora. Overplanting of tall shrubs and trees will help shade honeysuckles, making regenerating plants more susceptible to future mechanical controls. Follow up monitoring and removal of seedlings is needed after adult plants are removed for several years.

Shaded population should be treated by hand-pulling, digging, or cutting plants. Hand pulling and digging is most effective, but cutting may work in well-shaded areas. Several years of cutting should effectively control shaded populations. Populations in high light areas should be hand-pulled or dug, but not cut unless combined with herbicide; cutting may result in even more vigorous regrowth. Controlled burns may be an option to kill the root crown if hand pulling or digging is not practical. Burns should be done annually for 3-5 years, but results are often mixed, and literature does not suggest the best time of year to burn. In low-quality areas such as old fields, honeysuckles may be pulled by tractor and chain as long as native vegetation is immediately restored to reduce invasion success of honeysuckle seedlings or other non-natives.

## Purple loosestrife, *Lythrum salicaria* (L.)

### *Species Overview*

Purple loosestrife is a perennial herb introduced to the U.S. from Eurasia in the early 1800s. Plants are long lived (up to 22 years) and can grow up to eight feet tall (Munger 2002). Reproduction is vegetative and sexual. Vegetative reproduction is though rhizomes which grow at a rate of one foot per year, sending up multiple new plants with each year's new growth (Swearingen 2009b). Plants are able to produce two to three million seeds per year during its extended (June to September) flowering season (Swearingen 2009b). Seeds are very small and are dispersed by gravity and water, and perhaps somewhat by mammals and birds. Seeds are thought to remain viable for 2-3 years, but because of the number of seeds a plant can produce, they can dominate the seed bank and difficult to "exhaust" (Munger 2002). Seedlings grow quickly and produce spreading rhizomes and seed by 2 years old (Rawinski 1982). There is some evidence that plants can lay dormant in some years and grow normally in others (Munger 2002). It is an obligate wetland species and can be found in most wetland habitats, but particularly open areas such as lakeshores, river edges, marshes, roadside ditches, and other emergent wetlands.

### *Treatment Options*

**A. Mechanical Controls**

Effectiveness: Low
Cost: Low
Labor: High
Permit: No

Small populations of purple loosestrife can be managed by hand-pulling. Plants are very easy to spot at the beginning of the flowering period, usually July in NW Michigan, before plants form seeds. Pull when soil is wet and remove as much of the rhizome as possible. New stems will grow from rhizome fragments and soil disturbances may also spur seedling germination, so it is important to monitor for new plants in following years, using the same removal techniques (Munger 2002). Seeds are thought to be able to remain viable for two to three years, so treatments must remove all adult plants for at least that long to exhaust seed bank. Plants may also lay dormant, so monitoring for several years after eradication is necessary.

Mowing and cutting will not kill the root and is generally inappropriate for wetlands. If necessary, adult plants can be cut just before flowering to limit seed production that season. These will quickly resprout and flower in the following season.

**B. Biological Controls**

Effectiveness: Moderate-High (long-term)
Cost: Moderate ($150 for one population of *Galerucella* beetles)
Labor: Low
Permit: No

Biological control is the preferred method of purple loosestrife control. Four species of insects have been approved for release by the USDA: a root mining weevil, *Hylobius transversovittatus*, a flower-mining weevil, *Nanophyes marmoratus,* and two leaf-feeding beetles, *Galerucella calmariensis* and *G. pusilla.* These species, for the most part, are obligate feeders on purple loosestrife. Literature suggest *Galerucella* beetles are most effective (Munger 2002) and these are recommended by MNFI (2012). Significant reduction in purple loosestrife populations and increase in native species diversity has been observed within several years following introduction at most, but not all, research sites (e.g. Boag and Eckert 2013, Britton et al 2014, McAvoy et al 2016, Waterfield 2013). Some areas have seen a rapid re-growth of other invasive species as loosestrife declines (McAvoy et al 2016).

Once released, beetles have been observed to disperse at about 200 m/year from the original release site (McAvoy et al 2016). In Ontario, these beetles have been observed to have spread widely beyond their introduction sites, so there is significant natural spread and reproduction where there are sufficient populations of loosestrife (Boag and Eckert 2013). If loosestrife populations decline to low levels (after several years of biocontrol), the beetles may eventually die off. At this point, purple loosestrife will begin to re-establish and beetles may have to re-introduced. This cycle can be continuous, however it keeps the loosestrife from forming monocultures, restores native vegetation, and is the most cost-effective treatment (Katie Grzesiak, NW MI Invasive Species Network, pers. comm.).

*Galerucella* beetles were introduced to purple loosestrife populations along the southern stretches of the Narrows Natural Area (date unknown). Surveys during the growing season of 2012 noted that about 15% of individuals appeared to have died, while the remaining individuals suffered significant leaf damage; these appeared to have delayed flowering and smaller flowering stalks. There was no beetle-related herbivory noted on any other species (from the Floristic Quality Assessment of Narrows Natural Area, 2012).

### C. Cultural Controls

Effectiveness: Low-Moderate
Cost: Varies
Labor: High
Permit: No

Purple loosestrife growth will become depressed in shaded areas. If appropriate, plant cuttings of willow, dogwood, or other wetland woody species to compete with purple loosestrife for sunlight.

Loosestrife tends to become dominant when soils are disturbed in wetland areas (were seeds are present). Avoid activities that would disturb soils; if hand-pulling, tamp soils, cover with sufficient native litter and duff and monitor.

### *Recommendations*

Treat early colonizing and satellite populations first, working towards the core populations. Treat small and satellite populations by hand-pulling annually for successive years, or, at minimum, removing seed heads to reduce spread. Follow up for at least 3 years in July to monitor and treat as necessary. Survey connected streams and waterways to look for more seed-source or satellite populations.

Treat core populations by using a combination of ecological, biological, and mechanical controls. Biological controls are most cost-effective for large infestations because there will be enough of the host plant to provide the needed habitat for the insects to establish and reproduce. Combine with ecological and mechanical controls if practical given the site conditions. For example, clip flowering stems of plants that are not killed by the biocontrols, but leave the foliage to provide forage for the beetles to encourage their reproduction. Plant woody species if the site can support them. Monitor health and spread of biological control beetles and reintroduce if needed. This integrated approach will provide good long-term control and is more cost-effective than herbicide use. It is extremely difficult to completely eradicate purple loosestrife by any method but this can curb their invasive nature.

## Wild parsnip, *Pastinaca sativa* L.

### *Species Overview*

Wild parsnip is the "wild" form of the cultivated parsnip. It was listed during the first survey of Michigan in 1838, presumably introduced from Eurasia for cultivation. This wild form has reverted from the cultivated form to have a smaller (but edible) root and perhaps more irritating foliage. Wild parsnip is a monocarpic perennial; it may live for several years in a vegetative form, but will die after flowering. Plants typically flower in their second, third, or fourth year of vegetative growth (Baskin and Baskin 1979). Each plant is capable of producing around 1,000 seeds each, and seeds can last four years in the seedbank (Averill and DiTommaso 2007). It does best in full sun and is shade-intolerant. Typical habitats include roadsides, fields, and disturbed areas, as well as fens, prairie, and savannahs. The sap causes a burn-like rash, phytophotodermatitis.

### *Treatment Options*

**A. Mechanical Controls**

Effectiveness: High (small populations)
Cost: Low (protective clothing, gloves, and eyewear; stand-up weeder or spade $25)
Labor: High
Permit: No

Cutting and hand-pulling are very effective at controlling and eradicating wild parsnip, but can be labor intensive for large populations. The best practice is to cut each plant's taproot two inches below ground level with a small shovel or spade before the plant sets fruit, preferably in early June, and then pull the plant and dispose of it. The plants will not send up a new shoot if the top of the taproot is cut.

Mowing can be used as an alternative to cutting-pulling in monocultures, but plants will typically resprout later in the season or the next year. If mowing, do so just as flowers emerge ("bolt") but before seed is set to reduce late-season flowering and increase mortality. One study found that mowing a prairie with some wild parsnip increased parsnip abundance, likely because it decreased competitive with native species (Kline 1986). Do not mow when wild parsnip is in seed; seeds are easily dispersed this way.

### *Recommendations*

Mechanical controls are the only applied method of non-herbicidal treatments. Prescribed fire has not been successful in experimental treatments, and will not kill the plants (though it will kill aboveground biomass). The wild parsnip webworm has been researched as a biocontrol however it is not aggressive enough to effectively reduce populations (Averill and DiTommaso 2007). Treatment should prioritize removing seed sources from an area by cutting stems below the soil surface when adult plants are bolting. Return in a week or two to check for late-bolting plants and remove these as well. Continue this process for 3-4 years, and, if no plants have been allowed to go to seed, the populations should be eradicated.

## Reed canary-grass, *Phalaris arundinacea* L.

### *Species Overview*

Reed canary-grass is a circumboreal species that is historically native to the U.S yet it is thought that invasive-acting populations are from multiple Eurasian introductions (Dore and McNeill 1980, Jakubowski et al 2014, Lavergne and Molofsky 2007). Reed canary-grass was recorded in Michigan during the first surveys (1838) but it is unknown when the invasive form was introduced; it is thought that it began spreading in the early 1900's in livestock forage and bank stabilization seed (Waggy 2010). American and Eurasian strains are indistinguishable based on physical characteristics, but, in general, populations that form dense monocultures are through to be a Eurasian strain, while populations that are not aggressive are thought to be native (Waggy 2010).

Reed canary-grass is a perennial grass that spreads by seed and rhizome. The non-native variety forms dense monocultures in a variety of wetland soils, preferring full sun and intermittent flooding. Preferred habitat includes floodplains, fens, riparian areas, ditches, wet prairies and old fields, and other open wetlands. Reed canary-grass is somewhat shade intolerant; where already established it can persist in shaded areas. Grasses flower June though July and set seed in late-July through August and each plant sets between 100 and 600 seeds (Waggy 2010). Seeds are dispersed by gravity, water, machinery, humans, and other animals. Seeds may persist in the seed banks for 20 or more years, though most seeds germinate within 1-6 years (Goss 1924, Toole and Brown 1946). Rhizomes are found in the upper 1-6" of soil (Mueller 1941). Rhizome fragments can produce new plants.

### *Treatment Options*

## A. Prescribed Fire

Effectiveness: Low
Cost: Moderate (contractor needed)
Labor: Moderate
Permit: Yes

Fire top-kills reed canary-grass, but rhizomes generally survive because of the moist soil conditions they occur on (Howe 2000). Fire does not kill seed and may stimulate the seed-bank (Foster and Wetzel 2005). Post-fire, reed canary-grass reestablishes or increases in abundance (Waggy 2010). There is some suggestion that repeated fires may effectively control reed canary-grass (i.e. late fall annual burns for 6 years) but results were not published (Waggy 2010). In a series of studies by Howe (1995), reed canary-grass was found to increase in summer-burned plots but decreased in spring-burned plots (but not “controlled"). Prescribed fire is useful for aboveground biomass management but does not successfully control the grass alone.

In integrated control treatments in Illinois, reed canary-grass was reduced from 88% cover to 14% cover by March burns to remove thatch, followed by herbicide (sethoxydim) application as the grass regrew in May. This process was then repeated in late summer, followed by native seed additions. Reductions were measured after three years of repeating this process (Simpson 2009). A similar integrated treatment was applied in Wisconsin but reed canary-grass was only reduced temporarily; however native species cover and diversity did increase significantly among reed canary-grass (Wilcox et al 2007). Other studies found fall herbicide application most effective in integrated treatments because it is translocated to the rhizomes (Adams et al 2006).

Prescribed fire may be difficult to apply in wetlands. Burn permits from the local fire marshal or the DNR are required.

## B. Mechanical Controls

Effectiveness: Low
Cost: Low-Moderate (brush-cutter $100+)
Labor: High
Permit: No

Hand-pulling and digging reed canary grass are not effective controls (Waggy 2010). There may be some exceptions to this for very small populations, especially in upland areas where it is not likely to grow aggressively (Henderson 1990).

Cutting and mowing provides temporary control of aboveground biomass but will not kill rhizomes. Reed canary grass may increase in density after cutting by rhizome and root crown sprouts and seedling recruitment (Waggy 2010).

## C. Cultural Controls

Effectiveness: Moderate (long-term)
Cost: High (bare root or potted woody species)
Labor: High
Permit: No

In a study in Washington, reed canary-grass stems were decreased by 56% where willows were planted a meter apart, and by 68% were willows were planted a half-meter apart (Kim et al 2006). Observational data from the Mebert Creek Preserve Floristic Quality Assessment suggests dense shade from northern white-cedar is effective at limiting reed canary-grass establishment (May 2016).

### *Recommendations*

Intensive integrated management is necessary to control established reed-canary grass populations. No one treatment alone has been successful at controlling reed canary-grass (including herbicides), and no combined, intensive treatments have been demonstrated to eradicate this species. The literature suggests that the best approach combines prescribed burns, herbicides, and restoration planting. An appropriate approach may be some variation of these, such as: 1) early spring prescribed fire to remove thatch, 2) herbicide treatment as new shoots and seedlings emerge, probably in late summer or fall in order to translocate herbicides to the rhizomes, 3) a repeat of step 1 and 2 the next year, followed by 4) a dense planting of fast-growing woody wetland species such as willow trees or (for a denser canopy) northern-white cedar. The planting should occur after herbicides are inactive in the soil and before the reed canary-grass reestablishes, so that the trees can quickly overtop and shade new shoots. This is not practical for very wet areas such as wet prairies and fens, where trees would not naturally occur; native grasses, sedges, and forbs should be used in these situations.

## Reed, *Phragmites australis subsp. australis* (Cav.) Steud.

### *Species Overview*

Invasive *Phragmites* is a non-native haplotype "M" of the circumpolar grass species. The grass is tall, up to 15 ft, and has hard canes and vigorous rhizomes. Rhizomes contain 80% of the plant's biomass and can grow to 60 ft long. Around 2,000 seeds are produced per plant annually and are dispersed by the wind in late July through August. Vegetative reproduction occurs through rhizomes. Vegetative dispersal is also possible if rhizomes fragments are transported by water or equipment to new areas. Habitat is coastal and interior marshes, bogs, fens, swamps, lake margins, roadside ditches, and wet areas. This species is shade intolerant, but can persist in forested areas.

### *Treatment Options*

## A. Prescribed Fire

Effectiveness: Low

Cost: Moderate-High (contractor needed)
Labor: Moderate
Permit: Yes

Prescribed fire is recommended to remove excess above-ground biomass, kill *Phragmites* seeds, and promote native plant growth by stimulating the native seed bank and increasing light (MNFI 2009). Burning will not significantly kill rhizomes. Burning is considered a secondary control method and is not recommended to be used alone as it can lead to increased vigor and growth (Hazelton et al 2014, MNFI 2009). Burning is a means of mechanical removal and it is not effective unless combined with hydrological restoration (flooding) or herbicide application (Marks et al 1994).

Burns done after herbicide treatment are more effective than burning alone (MNFI 2009) or herbicide treatment alone (Ailstock et al 2001, Carlson et al 2009). Herbicide and burning combined are effective in restoring native plant diversity more quickly than only herbicide treatment in the short term. Burning may also be combined with post-burn flooding to reduce oxygen availability to the rhizomes and "drown" plants (Hazelton et al 2014).

Burns may be conducted in the winter to remove biomass that shades native plants without harming fire sensitive species (reptiles and amphibians, birds, insects, some native plants). This is a form of native species management and temporary physical control. Without integrating other treatments this could promote vigor of the stand.

*Phragmites* burns very hot and fast, and should be performed by a trained professional. A burn permit is required by the local fire department or the Michigan DNR.

## B. Mechanical Controls

Effectiveness: Low
Cost: Moderate-High (brush cutter or mower $300+)
Labor: High
Permit: Varies (on Lake Michigan shoreline)

Cutting or mowing stems can be used to reduce above-ground biomass that shades native plants, reduce photosynthetic capacity, and starve roots, however it can also stimulate shoot production and increase stem density (Hazelton et al 2014). Appropriately-timed cutting of *Phragmites* stems will not, on its own, eliminate it, though it may help reduce short-term dominance (Hazelton et al 2014). As with burning, cutting or mowing is a secondary control method to remove biomass but will not kill roots. Mowing during seed dispersal will spread the population.

There is some disagreement in the literature on when to cut *Phragmites*. The Michigan DEQ recommends cutting to remove excess biomass and spur native plant growth between August and the first hard frost, or in the winter when the ground is frozen. However, Asaeda et al (2006) found cutting in June more effectively decreased biomass then cutting in July. Several sources cite that cutting without first treating with herbicides or cutting at the wrong time of year will stimulate plant growth and increase density and spread (MDEQ, MNFI 2009). It is generally agreed upon that cutting without first applying an herbicide treatment is an ineffective long-term method (Hazelton et al 2014). Cutting has been shown to be more effective when combined with post-cutting flooding over the tops of the stem fragments (Marks et al 1994, Kiviat 2006, Smith 2005), or, if the plants are well covered with thick plastic sheeting and mulched (Rudd et al 2014, Burdick et al 2010). Covering after cutting also kills native plant populations thus is generally not a preferable treatment.

Hand cut small populations or use a brush cutter for large, dense stands. Mow to a height greater than 4" and watch out for small animals and native plants. After mowing, collect and bag all plant material and dispose of in a sanitary way. Attempts to hand pull or to remove root system will not be successful because of the extensive rhizomes. Mechanical soil disturbance (tilling, disking) can lead to increased stand density and spread the rhizomes (Rudd et al 2014).

Mowing and cutting below the normal high water mark of the Great Lakes requires a Great Lakes Shoreline Management permit from the MDEQ, Land and Water Management Division. These permits are active for up to five years.

## C. Water-level Management

Effectiveness: Varies
Cost: Varies
Labor: Varies
Permit: Varies (in some wetlands)

*Phragmites* prefers wetland soils, thus if water level management is an available option it may be employed as a strategy in a larger *Phragmites* control plan (e.g. St. John's Marsh, St. Claire lakeshore). Water levels greater than 12" have been shown to reduce the lateral spread of rhizomes and stolons and kill some seedlings (Rupp et al 2014). Also, dry soil inhibits seedling germination, however adult plants have been recorded in upland habitat.

Flooding can be employed after the removal of biomass by burning or cutting to starve roots of oxygen. It is unclear the length of time an area needs to be flooded and the relative effectiveness.

## D. Biological Controls

Effectiveness: Unknown
Cost: Not available
Labor: Low
Permit: Currently restricted

For biological controls to have a fidelity towards the non-native subspecies of

*Phragmites*, and not the native species, would require an "unprecedented degree of specificity" never before seen in biological controls (Cronin et al 2016). However, several biological control agents have been tested throughout the past several decades.

Currently two species of European noctuid moths *(Archanara)* are being tested for preference towards non-native *Phragmites* and preparations are being made for a field trial in New York (Blossey et al 2013). They are currently considered a quarantined species.

## E. Herbivory

Effectiveness: Variable
Cost: Unknown
Labor: Low
Permits: No

Goat and cattle have been used to manage *Phragmites* around the United Stated and Europe. A study conducted in Maryland showed that goats can significantly reduce stand biomass and increase native species diversity (Brundage 2010). This appears to be most successful in *Phragmites* monocultures; goats have been shown to preferentially browse native forbs over grasses in mixed stands (Teal and Peterson 2005). Cattle are being used to reduce *Phragmites* by several agencies around the Great Salt Lake with some success but no published findings (Hazelton et al 2014).

## F. Cultural Controls

**Effectiveness**: Variable (long-term control)
**Cost**: Moderate-High
**Labor**: High
**Permit:** Varies (some wetland permitting requirements)

Facilitating succession towards a shrub or treed wetland will lead to long term control (Rupp et al 2014). This is appropriate for areas in which the abiotic components support shrub-carrs and swamps as their natural communities such as upland-wetland transition areas or disturbed shrub-carrs and swamps. This is most effectively done by planting fast-growing species that can adapt to wet and dry conditions such as red-osier dogwood *(Cornus sericea)* and willows *(Salix spp.)*, among others.

All control programs should focus on native species restoration. Areas that are treated and not restored are typically reinvaded (Hazelton et al 2014). Denuded or disturbed wetlands soils are the primary vector for seed establishment historically (Taylor 1938) and today. It is important to consider how many *Phragmites* seeds may be in the seed bank. It is unclear how long they remain viable in the seed bank. Native seeds or plants should be established immediately after control measures to compete with emerging seedlings and rhizome remnants (Peter and Burdick 2010). The native seedbank remains highly diverse and viable in *Phragmites* stands and re-seedling may not be necessary

(Ailstock et al 2001, Baldwin et al 2010), however the type of control used alters seedbank composition (Hazelton et al 2014). Herbicides changed native species composition but not percent cover in treatments of St. John's Marsh on Lake St. Claire (Getsinger et al 2013). Established native plants (potted plants, plugs, or remnants) can preemptively exploit *Phragmites'* niche and are more effective competitors than native seedlings (Byun et al 2013).

Landscape-context management, with close attention to adjacent land uses is critical to controlling *Phragmites* and has been vastly neglected in management plans (Hazelton et al 2014). Landscape management should consider connection among wetlands, source populations, potential areas to new establishment, and surrounding land uses. Nutrient load inputs from surrounding wetlands or run-off can spur aggressive growth (e.g. Lake Michigan shoreline stands fertilized by decomposing *Cladophora* algae). Natural communities in northern Michigan are typically low in nitrogen and phosphorous, and native plants are adapted to live in these conditions. Native plants cannot take advantage of increased nutrient loads but *Phragmites* will (as with other non-natives). Novel methods to remove nitrogen loads from soil include high carbon (and low nitrogen), additives such as saw dust, to increase microbial nitrogen immobilization (Ianone et al 2008).

### *Recommendations*

High-quality natural areas and low-density or small *Phragmites* populations should be prioritized for management, as these areas are more likely to be successfully restored than large monocultures (Hazelton et al 2014). The literature stresses using a combination of treatment methods, multiple treatments, maintaining the treatment schedule, and being adaptive in management technique over time as new information arises. Though there are a significant number of *Phragmites* management projects across the U.S., very few have long-term monitoring in place or publish data on effectiveness (Hazelton et al 2014). Actual eradication in any project area is rare, and many years of follow-up treatments are critical, thus monitoring and natural community restoration is essential (Hazelton et al 2014). Landscape-level control of nitrogen has been suggested as the most important long-term control strategy for the future (Kettenring et al 2011).

The use of herbicide (glyphosate and imazapyr) is recommended as the primary treatment method in all literature reviewed, with non-herbicidal controls used as secondary treatments; non-herbicidal treatments alone have not been demonstrated to successfully control *Phragmites* populations. Exact treatment will vary by site and should include a variety of treatment types. Successful methods initially treat stands with herbicides, followed by a secondary treatment of a controlled burn or mechanical biomass removal. As soon as possible after control methods, native plant populations should be surveyed and restored as needed, with a focus on cultivating native plants that compete with or shade remerging *Phragmites.* Spot herbicide applications are typically recommended for follow-up control.

## Common buckthorn, *Rhamnus cathartica* L.

### *Species Overview*

Common buckthorn is a large Eurasia shrub that was first collected in Michigan in 1914 after being planted widely across the U.S. It spreads by fruit and is dispersed widely by birds, but does not reproduce vegetatively. Adult plants begin to flower and fruit around age 5-6. Flowers are dioecious, with male and female on separate plants, but it may also have some hermaphrodite flowers. A single female plant is thought to produce between 200 to 1,500 fruits per season (Zouhar 2011). Fruits ripen in September and are then dispersed by gravity, birds, and possibly mammals. Seeds tend to accumulate densely under parent plants (Zouhar 2011). Seeds remain viable in the seedbank around 2-6 years and but only have high germination rates in the first year, after which it steeply declines (Zouhar 2011). Common buckthorn can be found along field edges, roadsides, woodlands, forest canopy openings, floodplain forests, riverbanks, and area under bird perches. It is long-lived and tolerant to full sun and shade.

### *Treatment Options*

**A. Prescribed Fire**

Effectiveness: Low-Moderate
Cost: Moderate (contractor needed)
Labor: Moderate
Permit: Yes

Where there is sufficient fuel, prescribed fires can kill seedlings and aboveground biomass of adult shrubs (Boudreau and Willson 1992). Adult shrubs will resprout from the root crown post-fire and seed germination may be encouraged by fire though increasing light, scarifying the soil, and increasing soil temperature (Bisikwa 2005). Fire does not appear to kill buckthorn seeds. No studies have reported successful mortality of adults from fire alone. Several studies found that buckthorn is very difficult to burn, especially in moist sites (e.g. Apfelbaum and Haney 1990, Packard 1988).

Fire may be useful in killing the vast seedling carpets the buckthorn forms, especially in combination with other treatments to remove adult shrubs. Suggested methods include early spring burns (before native species emerge), or directed propane-torch wilting, for two seasons (Boudreau and Willson 1992, Tu et al 2001). Torching is often preferred because of the damp conditions that buckthorn tends to grow in. Torching can also be used to kill saplings by burning the base of the main stem.

**B. Mechanical Controls**

Effectiveness: Low
Cost: Low (stand-up weeder such as “Up-rooter” $150)
Labor: High
Permit: No

Hand-pulling and digging can effectively remove buckthorn, particularly because it will not resprout from root fragments. Seedlings are easiest to hand pull where they occur in small numbers and infrequently; where dense carpets of seedlings occur, it can be too time consuming to hand-pull and they may quickly resprout in the same density from the seed bank (Tu et al 2001). Adult shrubs may be pulled using a stand-up weeder. Areas where the soil is disturbed from pulling or digging often regrows a dense seedling layer; these should be tamped down after disturbance and planted with native species. Annual monitoring should watch for re-growing seedlings.

Cutting stems is not an effective control treatment for buckthorn because it will resprout from the root crown. In some studies, they grew back denser in the year after cutting (e.g. Moriarty 2005). In another study, stems that were double-cut (cut a second time four hours after cutting the first time) lead to 50% mortality (Gourley 1984), however this was only demonstrated once. Some literature recommends covering the cut stem with a cut baggie or tin can, securing it firmly, and leaving in place for 1-2 years to prevent resprouting (Minnesota DNR). It may be practical for small populations in high-quality natural areas. Cutting is effective for temporary reduction of fruit production if stems just before setting fruit. There is no information on mowing seedlings.

### C. Cultural Controls

Effectiveness: Low
Cost: Moderate
Labor: Moderate
Permit: No

Several studies have documented a lack of regenerating native species in buckthorn-dominated areas (e.g. Delanoy and Archibold 2007, Packard 1988). For this reason it is important to plant native species following buckthorn removal to immediately cover exposed soils and provide shade and competition with buckthorn seedlings. Planting native grasses may help build a fuel load for future prescribed burns. Native shrubs such as *Cornus sericea* and *Salix spp.* may compete well with invasive shrubs.

## *Recommendations*

Target satellite populations of fruiting shrubs in the highest conservation areas first, and then work towards more heavily infested areas. If there is a large infestation of fruiting shrubs nearby, this will be a seed source for new satellite populations, so it is important to address as soon as possible after targeting satellite populations. The prolific rates of new seedling establishment needs to be addressed in return treatments.

Treat common buckthorn using multiple approaches. Target fruiting (female) buckthorn by digging or pulling as possible. If not possible, cut fruiting stems, preferably twice in one season. If there is appropriate amounts of fuel, use prescribed fire to further treat cut stems and particularly seedlings. A directed propane torch approach could be substituted for prescribed fire to make sure root crowns are sufficiently burned in wet areas. After clearing and treating an area, plant native overstory species and monitor for buckthorn seedlings. A carpet of seedlings often forms after disturbances; retreat these with prescribed fire for several years until the seed bank is exhausted, and reseed with native species.

## Multiflora rose, *Rosa multiflora* (Murray)

### *Species Overview*

Multiflora rose is an large rose native to eastern Asia that was once widely planted for "living fences," introduced in Michigan by the 1930s. It produces large arching canes up to 15 feet long that root at the tip to form new plants. Fruits are small hips bore on compound inflorescences. A mature plant is capable of producing 1 million seeds per year that remain viable for 20 years (Czarapata 2005, Kaufman and Kaufman 2007). Seeds are bird and mammal dispersed. Multiflora rose is widely adaptable to soil and light conditions, though it prefers moist soils and high light. Habitats occupied are broad and include open woodlands, forest edges, old fields, marsh edges, and swamps.

### *Treatment Options*

**A. Mechanical Controls**

Effectiveness: Low (short term)
Cost: Low (gloves, protective clothing and eyewear, loppers $60)
Labor: High
Permit: No

Small plants and seedlings can be pulled by hand, taking care to remove the root to prevent resprouting. This is not an cost-effective control as plants can quickly grow too large to be practical to hand-pull, and the tall canes with robust thorns provide effective defense against humans. Some resources suggest pulling large shrubs with a chain and a tractor if possible. If this method is used, it is important to re-tamp soil and plant native species.

Mechanical control is most often applied by cutting stems of individual plants or mowing large monocultures with a brush-mower. Cutting aboveground biomass will inhibit seed production and spread but it is not effective at killing the plant unless done intensively. Areas must be mowed three to six times per growing season for two to four years to have effective mortality (NRCS Job Sheet NH-314).

Always wear protective gear when handling multiflora rose.

**B. Prescribed Fire**

Effectiveness: Low
Cost: Moderate (contractor needed)
Labor: High
Permit: Yes

Prescribed burns can be used to remove the aboveground biomass if there is enough fuel on the forest floor to create sufficient heat. This will not kill all the roots and they will resprout within a few weeks, but is helpful to remove aboveground biomass, making large patches more manageable. Burns are most effective in early spring when the plants are sending energy to the leaves.

There have been some experiments with directed flame treatments; these will kill large shrubs back to the base but they tend to regrow. More research is needed.

**C. Biological Controls**

Effectiveness: Moderate
Cost: Not available (wild populations exist)
Labor: Low
Permit: No

Biological controls are not currently available for multiflora rose, however there are two pests that are being researched, the rose-rosette disease native to the western U.S. and the European rose chalcid (wasp). The rose-rosette disease has been slowly spreading eastward and is thought to have potential for effectively controlling multiflora rose. (NRCS Job Sheet NH-314). It infects all old world rose species and commercial hybrids, but is reported to not infect several native roses: *R. setigera, R. acicularis, R. arkansas, R. blanda. R. palustris,* and *R. carolina* (Windham et al, no date). These biocontrols are not specific to multiflora rose so it is unlikely they will become available commercially.

### *Recommendations*

Physical removal of above-ground biomass (cutting, mowing) will help reduce seed production and spread, but will not kill the plant, and is also extremely laborious for large plants in natural areas that cannot be mowed. Hand-digging smaller plants, or large plants that have had their canes removed can effectively control plants but is very labor intensive. Prescribed fire can be used in fire-adapted communities if there is sufficient fuel to produce enough heat as a substitute for mechanical removal, but roots will most likely need to be addressed. It is unclear how well fire kills seeds in the seedbank. Most literature recommends using herbicide to kill the roots in combination with mechanical control or prescribed burns to manage aboveground biomass.

## Japanese hedge-parsley, *Torilis japonica* (Houtt.) DC.

### *Species Overview*

Hedge-parsley is an annual or biennial forb from Europe that was first observed in Michigan in 1952. First year plants form a rosette and may flower, or flower in their second year. After flowering the plant dies. Seeds are small with hooked hairs that allow it to catch fabric and fur, dispersing by animals. Seed viability information is not available. It can tolerate full shade to full sun, though it prefers partial shade and establishes along forest edges, woodlands, fields, fencerows, and roadsides.

### *Treatment Options*

**A. Mechanical Controls**

Effectiveness: Moderate-High
Cost: Low
Labor: High
Permit: No

According to information from the Aldo Leopold Foundation (2014), hand-pulling is effective and practical for small populations. If the root is not removed, it can re-sprout. Focus on larger second-year plants that can be easier to identify and remove. Plant may develop flowers over several weeks so return visits may be needed to make sure all flowering plants have been removed. Hand-pulling is as or more effective than herbicide application (Panke and Renz 2012).

Mowing can be used to slow reproduction of large populations if it is timed correctly. Plants must be mowed as flowers form/bolt but before seeds set. If mowed to early, plants will re-flower, and if mowed too late, mowing will broadcast seeds and further invasion. One study showed that after mowing bolting plants, <5% of plants re-grew (Renz and Heflin 2014). Mowing is only recommended for areas such as roadsides.

### *Recommendations*

Because adults are short-lived, primary controls should focus on stopping seed production. Work from satellite populations inward to primary infestations. Hand-pull new populations of hedge-parsley before it goes to seed (mid-summer) for several years. Once populations go to seed, do not enter the area so that seeds are not caught on clothing and spread further. There is little information available on hedge-parsley control.

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