State of Michigan's

Status and Strategy for Glossy Buckthorn (*Frangula alnus* Mill.) Management

Scope

Invasive glossy buckthorn (now *Frangula alnus* Mill., once *Rhamnus frangula* L. hereafter GB) has invaded North America since the 1800's; however, it most likely did not become widespread and naturalized until the early 1900s (Converse 1984). This document was developed by Central Michigan University and reviewed by Michigan Departments of Environmental Quality and Natural Resources for the purposes of:

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

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

Biology and Ecology

I. Identification

Glossy buckthorn is a small tree or shrub that grows up to 23 ft (7m) tall (Figure 1). The bark is dark brown with a bright yellow inner bark and distinct lenticels (i.e. raised rectangular pores on bark). The heartwood is pink/orange in color. The branches and leaves have an alternate arrangement (Figure 2). The leaves are oval-shaped, 1.5 - 4.5 in (4 – 11 cm) long, 1 – 2.5 in (2.5 – 6 cm) wide, with smooth margins, green and glossy on top, pale green below, and distinctly veined. Flowers bloom from April to July and form at the leaf axils (Figure 3). The flowers are small, white-green and star-shaped. The fruits are red drupes, that may turn purple or black when ripe and contain 2 - 3 ungrooved seeds (Heidorn and Stork 2007; eFloras 2008).

Figure 1. Glossy buckthorn (*Frangula alnus*) shrub fruiting above the goldenrods (*Solidago* spp.) and herbaceous plants in Brandt Road Fen, Holly Recreation Area, Oakland County, Michigan. Photograph by Rachel Hackett

Species that are often mistaken for GB include: common buckthorn (*Rhamnus cathartica* L.), alder-leafed buckthorn (*Rhamnus alnifolia* L'Her.), and dogwoods (*Cornus* spp.). Common buckthorn and GB are both nonnative invasive species and are similar in growth pattern and habitat. Common buckthorn has opposite or sub-opposite leaf arrangement with serrated margins while GB has alternate leaf arrangement with smooth margins. Alder-leafed buckthorn and dogwoods are native species that grow in similar habitat. Alder-leafed buckthorn rarely grows greater than 3 ft. (1 m) tall, and the leaf margins have rounded teeth. Dogwoods have opposite leaf arrangement and the fruits and flowers are in clusters at the end of branches.

Figure 2. Glossy buckthorn (*Frangula alnus*) has shiny leaves with entire margins in an alternate arrangement. The fruits are dropes that turn black when ripe. Photograph by W.H. Wagner, courtesy of Michigan Flora Online (Reznecik et al. 2011)

II. Detection

Glossy buckthorn is best detected in early spring and late fall because it leafs out before natives and retains its leaves into late fall (MNFI 2012). Glossy buckthorn is also easy to distinguish when in fruit from July to September.

Some success has been shown using multi-temporal satellite imagery to detect GB and common buckthorn in oak openings with an overall accuracy of 88% (Kappa 0.73; Becker et al. 2013). Multi-temporal imagery had to be used because these species can often be hidden underneath canopy of other species and has shown difficulty in being distinguished multispectrally from other vegetation.

Figure 3: Glossy buckthorn (*Frangula alnus*) produces white star-shaped flowers from its leaf axiles. Photograph by R.W. Smith, courtesy of Michigan Flora Online (Reznecik et al. 2011)

III. Life History and Spread/Dispersal

Glossy buckthorn is a shrub or small tree. Seeds need a cold stratification to germinate and prefer light and moist conditions, like leaf liter. Seeds of GB can persist in the seed bank for an average of six years (Heidorn and Stork 2007). Dried seeds are unlikely to germinate (Godwin 1936).

The leaves emerge in early April to late May and turn yellow in October (Godwin 1943a). Flowers emerge in late May and June and may be produced throughout the growing season. Pollination of the flowers are dependent on insects including a variety of bees, wasps, flies, and beetles (Godwin 1943a). There is no self-fertilization due to self-incompatibility observed in the species (Medan 1994; MNFI 2012).

Fruits will form on shrubs less than 3 ft (1 m) tall (MNFI 2012). Red unripe fruits will first appear in July, but will ripen and blacken beginning in mid-August (Godwin 1943a). Immature fruits are mildly toxic to prevent frugivory and the ripened fruits act as a laxative to aid in seed dispersal (Heidorn and Stork 2007; MNFI 2012). Glossy buckthorn reproduces primarily by seed, but it will also resprout from stumps. Stumps that have resprouted can produce fruits within the same season. Seeds are dispersed by birds (e.g. robins, cedar-waxings rose-breasted grosbeaks, and starlings), small mammals (e.g. mice and other rodents), and gravity (MNFI 2012). The fruit and seeds can float for 1 – 2 weeks, but no studies have confirmed this as a common form of distribution or if the seeds are able to germinate after being saturated.

Glossy buckthorn establishment can be suppressed with increased canopy coverage, but will respond quickly to light gaps by sprouting vigorously. Seedlings are more likely to establish when soil is disturbed or there is a breach in the canopy allowing sufficient light for germination, but can establish in undisturbed soils as well (Heidorn and Stork 2007).

IV. Habitat

Glossy buckthorn is native to Eurasia and northern Africa. The westernmost part of its range is Portugal and Spain and extends east throughout Europe to Turkey and the Caspian Sea in the southeast to Russian Siberia in the northeast. It is found in the British Isles (except Scotland), and up to the 64° – 66° parallel in the Scandinavian Peninsula. Glossy buckthorn is also found in Algeria and Morocco in Africa. Uses of GB over the years include medicinal (bark is a drug in Germany; bark and berries are used at purgatives), charcoal, sap-green dye, burning oil, wooden teeth, and wooden pegs (Godwin 1943a).

Glossy buckthorn is found in fens, raised bogs, scrub, margins and undergrowth of wet woodlands. The soil conditions can be alkaline, neutral, or acidic peat. Glossy buckthorn can tolerate dryness but likes moist soils. It cannot survive permanent inundation. It is shade intolerant, so grows in open wetlands, on moist woodland margins and in moist forest gaps (Godwin 1943a). Glossy buckthorn is often found in disturbed areas, such as recently plowed areas, overly logged areas, and along power lines (Burnham and Lee 2009; Reznicek et al. 2011).

V. Effects from GB

Extensive scientific research has been completed on the ecological effects of GB. Many studies have indicated that GB has the ability to do the following in invaded areas (Medan 1994; Krock and Williams 2002; Fagan and Peart 2004; Heidorn and Stork 2007; NRCS 2007; Fiedler et al. 2011; Fiedler and Landis 2012; Mills et al. 2012):

- Decrease soil pH
- Lower the water table
- Increase decomposition rates, decreasing the number of vegetative hummocks

- Decrease light availability to the understory and shade out native species
- Decrease graminoid (e.g. grasses, sedges) relative abundance
- Cause potential allelopathic effects similar to common buckthorn
- Decrease total plant cover and reduce recruitment and survival of native saplings including economically valuable hardwoods
- Alter pollinator communities in abundance and diversity
- Harm songbird habitats
- Create an acceptable environment for exotic earthworms

A study conducted by Fiedler and Landis (2012) quantified the abiotic and biotic effects of GB in Michigan prairie fens. Fiedler and Landis (2012) found that areas invaded with GB had a decreased soil pH, lowered water table, decrease in number of peat hummocks presents, decreased light availability, and decreased relative abundance of grass and grass-like species when compared to non-invaded areas.

It was suggested that GB has similar allelopathic effects to that of common buckthorn, but a study conducted by Krock and Williams (2002) found that neither fresh leaves nor roots of GB had allelopathic characteristics. Further research would be needed to determine if ripened fruits or decaying leaves have allelopathic potential.

Glossy buckthorn reduces the recruitment and survival of saplings within a forest understory and only 10% of tree saplings are able to penetrate the GB canopy (Fagan and Peart 2004). Glossy buckthorn is likely to favor the regeneration of less valuable hardwoods (e. g. sugar maple, hemlock, beech, and Norway maple). This hinders the regeneration of historically prominent white pine and reduces the economic return in the logging industry (Fagan and Peart 2004).

Glossy buckthorn has a higher recruitment and fecundity than native wetland shrubs (Mills et al. 2012). Mills et al. (2012) found that the frequency of GB seedlings in Cedarburg Bog, Wisconsin, was seven times greater than the amount of seedlings produced by all four studied native species combined. In the same study, it was found that 94% of sampled units containing adults also contained seedlings, suggesting that greater seed fall under the parent due to higher fecundity (Mills et al. 2012). Medan (1994) found that medium to full-size GB individuals have the potential to produce 430-1,560 offspring per year.

The presence of GB can alter pollinator communities in both abundance and diversity. Fiedler et al. (2011) observed rapid shifts in pollinator communities when GB was removed from invaded areas of prairie fens. Removal of GB from invaded areas created a more diverse and abundant pollinator community, which is important for restoration efforts.

Glossy buckthorn can create monocultures that harm the songbird habitat. Since GB leafs out early, it tends to be a chosen nesting site for birds. However, in a study at Morton Arboretum it was found that nests constructed in GB were more susceptible to predators than those built in native shrubs (Heidorn and Stork 2007; NRCS 2007).

Glossy buckthorn is often found in soils with higher nitrogen content, which makes the surrounding soil environment more favorable for exotic earthworms. Exotic earthworms can alter soil nutrients by increasing the nitrogen, carbon, pH, and moisture (Heidorn and Stork 2007).

Socio-economic effects of GB are that the fruits of GB can stain human structures and cars (Minnesota DNR), and GB could be a potential host for the soybean aphid *Aphis glycines* Matsumura, which is a major crop pest for North American soybean production (Hill et al. 2010) Although it has not been confirmed as a true host, nymphs have been observed on the leaves of GB (Kim et al. 2008). A soybean aphid infestation could result in a $3.6 to $4.9 billion crop loss in soybean production in ten years if not effectively controlled (Kim et al. 2008). Soybean aphids are a vector for alfalfa mosaic, soybean mosaic, bean yellow mosaic virus, and crown fungus (Godwin 1943a; Kim et al. 2008; MNFI 2012).

Current Status and Distribution in Michigan

The range of GB in North America extends from Nova Scotia to Saskatchewan in Canada, and in the United States as far south as Tennessee to Idaho in the west, and occurs in all New England states as shown in Figure 4 (USDA 2014). It is likely GB was introduced in North America before 1800, but it did not become widespread until the early 1900s (Converse 1984). The spread of GB was likely due to the use of GB for ornamental and rehabilitation plantings (Frappier et al. 2003; Gucker 2008). The first known collection in North America occurred in London, Ontario, Canada, in 1898 (Frappier et al. 2003). The first documented occurrence in the Great Lakes region was in 1913 in the lower Great Lakes, in Ontario, Canada, and was a deliberate release (United States Environmental Protection Agency 2008). Glossy buckthorn is thought to have spread from three urban cities in southern Ontario based on collections made in London (1898), Ottawa (1899), and Guelph (1906) (CABI 2014). In Michigan, the first collected specimen was in Delta County in 1934 (Reznicek et al. 2011).

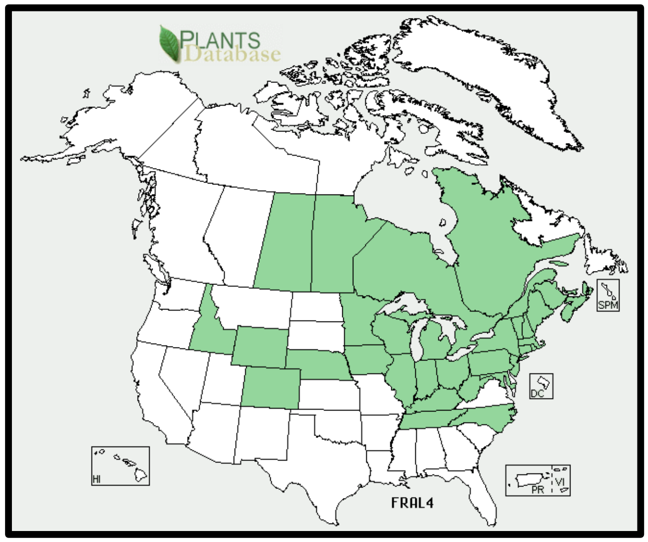

Figure 4: Distribution of glossy buckthorn (*Frangula alnus*) in North America. Map courtesy of USDA PLANTS Database (2014)

Michigan Flora has documented GB in 34 counties including Alpena, Baraga, Barry, Benzie, Barrien, Calhoun, Delta, Emmet, Genesee, Hillsdale, Houghton, Ingham, Iron, Jackson, Kalamazoo, Kent, Leelanau, Lenawee, Livingston, Mackinac, Macomb, Manistee, Marquette, Mason, Mecosta, Menominee, Oakland, Ontonagon, Osceola, Schoolcraft, Van Buren, Washtenaw, and Wayne Counties (Figure 5). The Midwest Invasive Species Information Network (MISIN) has reported occurrences of GB in 12 additional counties including Alcona, Antrim, Clinton, Dickinson, Gogebic, Grand Traverse, Montcalm, Newaygo, Ottawa,

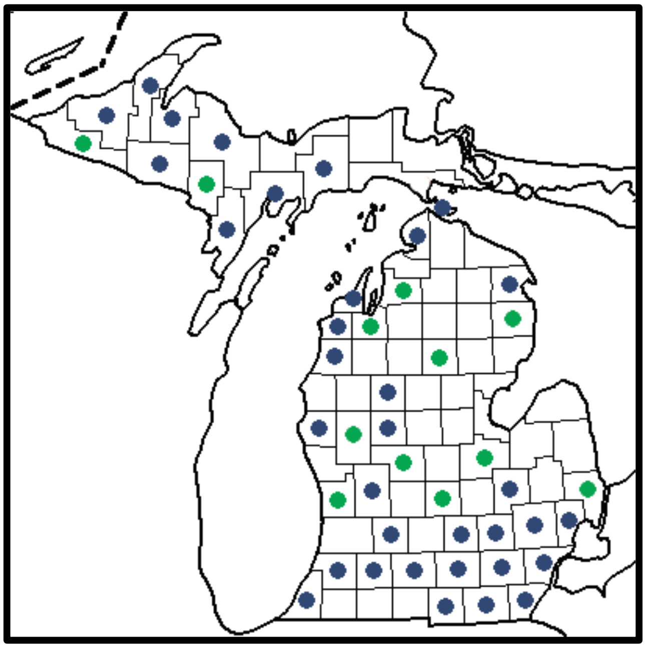

Figure 5: Blue dots indicate counties in Michigan where a specimen of GB has been collected and included in Michigan Flora. Green dots indicate counties where GB was documented by Midwest Invasive Species Information Network, but not by Michigan Flora. County map developed by Michigan Flora online (Reznicek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

Roscommon, Saginaw, and St. Clair counties (MISIN 2014). According to Michigan Flora, the occurrence in Mackinac County is only on Bois Blanc, Mackinac, and Round Islands.

In the central and western Upper Peninsula, scattered populations ranging in size were reported (MISIN 2014). Numerous populations of GB were recorded along Victoria Road in the Ottawa National Forest and Porcupine Mountains State Park. Populations have also been recorded in Seney National Wildlife Refuge, with some ranging greater than one acre in size. In northern Houghton County, several sparse to patchy populations have been recorded in neighborhoods near Calumet. No recordings of GB have been sited in Sault Ste. Marie State Forest area, the Tahquamenon Falls State Park, and Newberry State Forest Area in the Upper Peninsula.

In the northern Lower Peninsula, sparse populations have been found in Traverse City State Park and in surrounding neighborhoods in areas approximately ½ acre in size. Two monocultures of GB have been recorded in the northern and southern borders of the Manistee National Forest. In the eastern portion of Huron National Forest, a few sparse populations of GB were found and a single dense population approximately ½ acre in size GB was recorded. Also, one dense population of GB was recorded in the Thunder Bay River State Forest. No recorded populations of GB have been sited in the Pigeon River Country State Forest area, the Gaylord State Forest Area, Atlanta State Forest Area, or Sleeping Bear Dunes.

In the southern Lower Peninsula, GB has been reported in most all countries and is suspected in others.

Management of GB

I. Prevention

Glossy buckthorn has the ability to infest natural areas; however, disturbed, open areas are more susceptible to GB invasion. Glossy buckthorn is not a federally listed noxious weed, nor is it listed under any Michigan Act as a restricted or prohibited species (Michigan Invasive Plant Council 2014; MDARD 2014). It is, however, identified as a state regulated species in Minnesota, Wisconsin, Illinois, Tennessee, Vermont, New Hampshire, Massachusetts, and Connecticut (Center for Invasive Species and Ecosystem Health).

Prohibiting the sale, importation, transportation, and trade of GB and GB cultivars ('Columnaris' and 'Aspenifolia') can assist in preventing the spread and dispersal of GB. Refraining from over harvesting in particularly susceptible areas and using caution when choosing possible logging sites could prevent the sprouting of new GB (Fagan and Peart 2004). Education targeting horticulture industry and gardening groups could also reduce new introductions of GB. The following actions may prevent and limit the dispersal of GB:

- Build a coalition of local, statewide, and Great Lakes regional partners to monitor for GB and other aquatic invasive species
- Add GB to Michigan's restricted or prohibited species list
- Educate horticulture industry, landscaping industry, and home owners about GB
- Identify and protect high-value, uninfested sites

II. Management/Control

Once GB has become established it is very difficult to control. Small, new infestations are able to be eliminated but require quick reaction before the plants mature and are able to seed (MNFI 2012). If control of the infestation is desired, a multi-method strategy of mechanical and chemical controls called an integrated pest management plan has shown to be the most effective strategy. Control treatment is repeated for many years to achieve management goals.

a. Chemical

Triclopyr ester and triclopyr amine are the most common herbicides used to treat GB in the field, with the triclopyr amine formula of triclopyr approved for use in wetlands with proper permits and licensing. Chemical treatment applications include basal bark, cut-stump, foliar spray, and injection. A summary of chemical controls that have shown some effectiveness are in Table 1.

1. Basal bark

Basal bark applications apply the herbicide to the stem and any exposed roots of the tree or shrub. Triclopyr ester (e.g. Garlon 4 Ultra ®) with a penetrating oil (e.g. AX-IT®) can be used for GB control any time of the year with the exceptions of during heavy sap flow, when direct application to the stems is hindered, or when stems are wet. This treatment is best used on stems with greater than ¼ in to less than 6 in diameters (MNFI 2012).

2. Cut-Stump

Cut-stump application is an integrated mechanical and chemical approach to GB treatment: the trunk of the GB is cut and an herbicide is applied to the stump to prevent sprouting. Tricoplyr amine is approved for use in wetlands, but it must be applied immediately after cutting (MNFI 2012). Triclopyr ester in addition to 3% Imazapyr with a penetrating oil and triclopyr ester with a penetrating oil are effective to control GB, but they are not approved for use in wetland areas. Imazapyr is effective against GB resprouting over an extended period of time, however, because of its persistence in the soil, it may kill native vegetation.

3. Foliar Spray

   Foliar spray applications apply the herbicide to the leaves of the plant. Triclopyr amine in addition to a wetland-approved non-ionic surfactant and triclopyr ester with a vegetable oil based multi-purpose adjuvant are best used after spring sap flow and in the fall after many native plants have gone dormant. These treatments kill GB effectively; however these herbicides are broad-leaf specific and may kill native vegetation if not applied carefully (MNFI 2012).

4. Injection

   Herbicides are injected with into the stem, roots, or rhizomes of the plant. Triclopyr amine is suitable for large specimens; however injection is labor intensive (MNFI 2012).

Table 1. Summary of effective herbicide treatments on glossy buckthorn (*Frangula alnus*). For each herbicide, example brand names, percent active ingredient (% A.I), any recommended adjuvants, treatment timing, advantages, disadvantages, and the cited literature was listed. The first column indicated the type of herbicide application or part of the plant that was treated. Directions on the pesticide label should always be followed and the state Department of Environmental Quality and Department of Natural Resources should be consulted for up to date regulations, restrictions, permitting, and application information. Table from the Glossy Buckthorn Factsheet (MNFI 2012)

	Herbicide	% A.I.	Adjuvant	Timing	Pros	Cons	Reference
Basal Bark	**Triclopyr ester** (e.g. Garlon 4 Ultra ®)	22-30%	Use a penetrating oil (e.g. AX-IT®), unless it is already included in product (e.g. Michigan blend)	Use any time of year, including winter months *except* during heavy spring sap flow *or* when snow or water prevent application at ground level *or* when stems are wet	• Relatively selective herbicide and technique • Less labor-intensive than many other techniques if conditions are appropriate	• Use only on stems that are >1/4 inch and < 6 inches in diameter. • Not approved for use in wetlands	(MNFI 2012)
Cut-stump	**Triclopyr ester** ® (e.g. Garlon 4 Ultra) + Imazapyr ® (e.g. Arsenal)	15-18% + 3%	Use a penetrating oil (e.g. AX-IT®).	Use any time *except* during spring sap flow	• Most effective herbicide combination for this technique (in killing buckthorn—as well as many other plants) • Can be used on stems > 6 inches in diameter	• Imazapyr is highly Active in the soil and may kill adjacent plants. • Not approved for use in wetlands	(MNFI 2012)
Cut-stump	**Triclopyr ester** ® (e.g. Garlon 4 Ultra)	31-44%	Use a penetrating oil (e.g. AX-IT®), unless it is already included in product, e.g. Michigan blend	Use any time *except* during spring sap flow	• Relatively selective herbicide and technique • Can be used on stems > 6 inches in diameter	• Not approved for use in wetlands	(MNFI 2012)
Cut-stump	**Triclopyr amine** (e.g. Garlon 3A®)	31-44%		Use any time *except* during spring sap flow	• Safe for use in wetlands • Relatively selective herbicide and technique • Can be used on stems > 6 inches in diameter	• Cuts must be treated *immediately* - will not mix with penetrating oil	(MNFI 2012)

	Herbicide	% A.I.	Adjuvant	Timing	Pros	Cons	Reference
Foliar Spray	**Triclopyr amine** (e.g. Garlon 3A®)	2-3%	Use a wetland-approved non-ionic surfactant (e.g. Cygnet Plus®)	After spring sap flow, while plant is actively growing but before leaves change color Fall ideal as many natives go dormant earlier	• Safe for use in wetlands • Kills buckthorn very effectively • Broad-leaf specific—will not harm sedges and grasses.	• Since it must be used during the growing season, it is not a suitable technique for high-quality sites with many broad-leaf natives	(MNFI 2012)
Foliar Spray	**Triclopyr ester** ® (e.g. Garlon 4 Ultra)	2-3%	Use a vegetable oil based multi-purpose adjuvant (e.g. SprayTech® Oil)	After spring sap flow, while plant is actively growing but before leaves change color Fall ideal as many natives go dormant earlier	• Kills buckthorn very effectively • Broad-leaf specific—will not harm sedges and grasses	• Since it is used during the growing season, it is not a suitable technique for high-quality sites with many broad-leaf natives • Not approved for use in wetlands	(MNFI 2012)
Injection	**Triclopyr amine** (e.g. Garlon 3A®, Renovate®)	27%		Use any time *except* during spring sap flow	• Suitable for very large specimens. Extremely selective herbicide and technique • Safe for use in wetlands	• Labor intensive. (Inject 1 ml into cambium at 3-4 inch intervals around entire trunk)	(MNFI 2012)

b. Physical or Mechanical Control

One effective way to control GB invasion in an area is to remove the seedlings before they are able to seed (Czarapata 2005). Early and late life removal can be done in a number of ways including pulling, wrenching, cutting, and burning.

To effectively control GB, the roots must be pulled before it reaches 0.5 in (1.25 cm) in diameter (Figure 6). Once a GB seedling matures a tree puller or wrench can be used for removal. Damp soil improves the ability to remove the roots with the rest of the plant (Czarapata 2005). While this method is effective, it is also time consuming and tree pulling equipment can be expensive. Pulling needs to be repeated for multiple seasons to exhaust the seed bank or hold off the spread from a nearby source.

Figure 6. A glossy buckthorn (*Frangula alnus*) seedling. Photograph by Keith Goulet

Cutting down mature GB is a quick way to remove the canopy of the plant, but it triggers intense sprouting from the stump. Unless secondary measure of herbicide application to stump or girdling are taken, cutting is not an effective method of long-term control of GB.

Select herbicides applied to the stump after cutting, usually with a spot spray or sponge, effectively kills the tree (Table 1; MNFI 2012). This combination cut and herbicide application method is used by most management agencies, because it is effective for older infestations and less labor intensive than other methods (MNFI 2012). Scorching or burning the cut stumps has no significant effect on new sprouting (Nagel et al. 2008).

Girdling of the stump can also reduce the number of new sprouts that are produced after cutting. Girdling is when a deep ring of bark is removed from around the tree, removing the cambium and exposing the underwood (Figure 7). When a stump is cut and girdled no new sprout will occur above the girdle (Karlovitz 2008). Glossy buckthorn with a girdle anywhere on the stump has 40%-50% fewer sprouts then those cut without girdles (Karlovitz 2008).

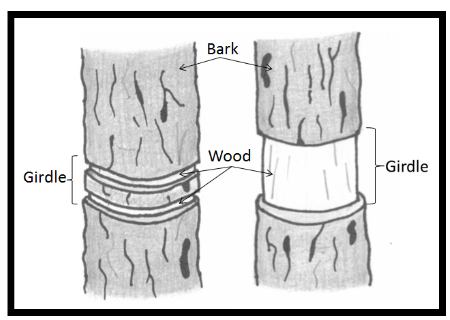

Figure 7. Two methods of girdling a tree. Illustration by Caitlin Richards

Girdling a tree will eventually kill the plant, however it could take years for it to die. Girdling must be done to each stem to be effective (Czarapata 2005). Herbicides can also them be applied to the girdled band to hasten the plants death (Czarapata 2005).

The controlled burning an area is not effective with mature stands of GB, but it may kill young seedlings (Czarapata 2005). If an area is cleared of standing GB prior to burning, seedling sprouting may occur post-burning. A burned area can reinfest quickly with GB, possibly even worse than the initial infestation (Miller et al. 2010). Seedlings can resprout many years after control treatments are performed.

Due to the dense canopy formed by GB there is little understory vegetation that could fuel a fire, so artificial fuel is needed or the use of a propane torch (Miller et al. 2010). These burnings are most effective in fall, early spring, or both and when repeated for multiple years.

c. Biological

In 2004-2005, possible insect biological controls of common buckthorn and GB were examined in conjunction (Gassmann et al. 2006). Several insect species were marked for further research in controlling common buckthorn, but only one was marked as a species specific predator for GB (Gassmann et al. 2008): a leaf hopper *Zygina suavis* Rey. Gassmann et al. (2008) suggested that further surveys may reveal additional host-specific insect species, but it is unlikely.

Three fungal combinations were believed to have detrimental affects on GB: *Puccinia coronata* Corda*,* a species of *Cytosporina*, and a combination of the *Nectrica cinnabarina* (Tode) Fr.with a species of *Fusarium* were believed to be of biological concern to GB (Godwin 1936).

No further research on biological controls was found at the time of this report.

III. Indirect Management

Glossy buckthorn can withstand moderately dry soils but cannot survive permanent waterlogging (Godwin 1943a). In areas that are traditionally wetlands, but have their water tables artificially lowered, returning the water table back to its original depth could drown the roots of GB (Czarapata 2005).

Glossy buckthorn is restricted to grow in open woods and early-successional forests, because it has high light requirements. Due to this sensitivity to light levels, if a forest invaded by GB is progressing through the pattern of succession, GB may eventually be choked out by taller canopy plants (Cunard and Lee 2008). Assisting this progression could hasten the natural crowding of GB. Any disturbance to the forest after shading out GB would likely result in a new colonization in the canopy gap, given the seeds in the seed bank are still viable.

Research Needs

In order to better understand GB ecology and management in Michigan, the following research areas should be addressed: ecological and socioeconomic impacts of GB, monitoring needs, invasion patterns, control techniques, and long-term integrated management studies.

I. Biology and Ecology

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

A better understanding of long-term ecological effects of GB on flora and fauna, particularly birds, GB's value as a food source, and the transformation of plant associations following GB invasion and control would better inform management practices and work to educate interested parties about GB. In addition, long-term effects of GB on nutrient cycling and microbial communities are poorly understood at this time.

There has been recent conflicting research on the allopathic effects of GB. Laboratory research has been conducted on fresh leaves and roots showing no allopathic effects, but additional lab and field research is needed to determine if ripened fruits or decaying leaves have allelopathic potential (Krock and Williams 2002). Understanding whether or not GB creates long-term effects in the soil or has allelopathic effects improve comprehension of the short-term and lasting ecological effects of GB, which are important for restoration efforts.

Glossy buckthorn has been targeted as a potential host for the soybean aphid, *Aphis glycines.* These reports have yet to be verified and investigated for the soybean aphids use and effects on GB. Determining host suitable of GB for the soybean aphid is an important agricultural and economical issue considering the damage the aphid causes to crops. If it is a host, then the agricultural industry could be approached to join the battle against the invasive species.

II. Monitoring

Monitoring high-value sites for presence or absence of GB is important for ecological conservation. Further documentation and investigation of GB invasions for spatial patterns could help develop more effective integrated management plans.

III. Management

In terms of control research, effective biological controls have yet to be determined and more extensive research is needed to find identify potential agents of biological control. Some research has been conducted and have found one promising host specific species, however, based on prior studies, it is unlikely that a host-species viable for biological control will be found (Gassmann et al. 2008). Godwin (1943b) mentioned several saprophytes associated with GB and indicated that the fungus *Nectaria cinnabarina* caused a die-back of

GB in the 1930's. More research on the effects of saprophytes and other potential biological agents on native vegetation could develop into another option for biological control.

Since determining species as biological controls for GB has been difficult, exploring genetically engineered agents could be worthwhile. Research has indicated that some fungi, insects, and mites could potentially be used as agents of control (Godwin 1943a; Gassmann et al. 2008; CABI 2014). If these agents could be modified to be suitable in various habitats, biological control of GB could be an effective alternative.

Little research has been conducted in regards to monitoring long-term restoration efforts and the re-colonization of native species after GB removal. Investigation on the potential biological legacy of GB both abiotically and biotically could allow for more realistic predictions of recolonization after treatment of GB. Hydrology, soil properties, microbial communities, decomposition rate, and species composition both flora and fauna post-treatment could be affected.

Future Directions for Michigan and GB Management

Glossy buckthorn invaded North America in the early 1800s, but it did not become widespread and naturalized until the 20th century (Converse 1984). Complete eradication of GB is challenging due to its high seed production, vigorous growth, and regeneration (CABI 2014). Therefore, it is important to continue to monitor and manage invaded areas, and research more effects of GB and of control of GB.

Prevention – Dispersal of GB is primarily attributed to birds and rodents, not human pathways (MNFI 2012; CABI 2014). This limits the feasible methods humans can apply to preventing the spread of the species. One way to prevent new releases of GB is for Michigan to place GB on its restricted or prohibited species list, and only allowing infertile cultivars to be planted. Educating the horticulture industry on the identification, restrictions, and ecological impacts of GB can aid in the prevention of new releases. Other methods to limit dispersal are cleaning boots and equipment when traveling between sites.

Maintaining natural vegetation and ecological conditions and eradicating seedlings can effectively prevent an invasion of GB. Some disturbances that greatly increase the likelihood of a GB infestation include very destructive fires, clear cutting, and lowering of the water table.

Monitoring - Since GB is highly widespread, it is important to identify high-value sites to focus monitoring efforts. Monitoring areas that have not yet been infested and adding GB to existing monitoring programs will assist in early detection and increase the potential for eradication and protection of GB in valued areas. In addition, evaluating potential pathways and dispersal trends on a landscape-level could provide information to more effectively protect areas from GB invasion.

Networking data – Statewide monitoring methods would benefit from creating or participating in systems that centralize and provide open access to diversity data (e.g. MISIN, Weed Map – Cooperative Weed Management Area, MiCorps Data Exchange Network – Great Lakes Commission, VertNet, Nonindigenous Aquatic Species Database - USGS, Biodiversity

Information Serving Our Nation (BISON), and Global Biodiversity Information Facility (GBIF)). These databases house biological specimen or observation data including species location, verification, photographs, density, and even links to genetic data. Preliminary efforts within the state of Michigan have agencies contributing to regional databases (e.g. MISIN, Cooperative Weed Management Area, Nonindigenous Aquatic Species Database), but participation is not consistent or standard throughout programs. In addition, state databases are not always networked within an agency, across the state, throughout the region or relative to national efforts.

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

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

Management – A statewide strategy of eradication of GB is not feasible. The species is distributed in most wetlands across the state, and its primary distribution method is attributed to seed dispersal by animals. Identification, management, and regular monitoring is important to preserve high-value wetlands and uninfested wetlands.

Long-term management of infested sites should include an integrated pest management plan including cutting and herbicide treatment of stumps and seedlings and possibly initiating regular controlled burns after infestation is more contained. Investigation at a landscape-level could improve current management techniques. Because of GB’s ability to colonize open areas, it is important to select uninfested areas when choosing potential logging sites. If uninfested areas are not available, then long-term management of logged areas is necessary to allow regrowth of native species.

Measuring effective control - When controlling GB infestations, long-term management of areas is important. Since GB seeds can remain viable for several years, it is important to actively manage areas until the seed bank has been exhausted. For GB, assessing stump re-sprouting, canopy cover, and number of seed producing individuals are quantitative measures for evaluating effective control.

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

Document citation

Hackett RA, Karbowski HM, Richards CM, and Monfils AK (2014) Status and Strategy for Glossy Buckthorn (*Frangula alnus* Mill.) Management. Michigan Department of Environmental Quality, Lansing, Michigan.

This document was a product of Environmental Protection Agency - Great Lakes Research Initiative 205(j) grant between the Michigan Department of Environmental Quality and Central Michigan University in 2014.

Table 2: Objectives, Strategic Actions, Leads, and Expected Outcomes of GB Management

Guidance and Outreach for Glossy Buckthorn Management			
Objective	**Strategic Action**	**Who is leading effort in Michigan?**	**Expected Outcome**
Increase public awareness of prevention methods	• Coordinate and collaborate with local and regional partners of wetlands with high value and/or uninfested sites • Add GB to prohibited or restricted species list • Educate public of identification, early-detection, and prevention	• AIS Core Team • The Nature Conservancy (TNC)	• Increase public awareness of GB • Reduce intentional plantings of GB • Protect high-value sites
Provide technical guidance to those interested in GB management	• Creation of a GB technical guide and GB prioritization tool.	• MNFI	• Increase management efforts
GB Monitoring and Data Management			
Develop a mechanism for monitoring and reporting AIS species	• Develop a system of identifying wetlands with high likelihood of infestation • Survey high-value and/or uninfested wetlands	• AIS Core Team • MISIN • BISON	• Develop a more thorough and up-to-date statewide distribution GB
Contribute regularly to regional, national, and global diversity information networks	• Consolidate Michigan biological and abiotic data • Standardize resources • Standardize data collection • Network existing data • Regularly synchronize data	• MISIN • Weed Map - CWMA • MiCorps • VertNet • NAS - USGS • BISON • GBIF	• Develop adaptive monitoring strategy that responds to up-to-date distribution • Promote AIS research of regional, national, and global extents • Prevent data redundancies
Educate public on identification and reporting of AIS in Michigan	• Target users of wetlands that are high-value or uninfested sites	• MISIN	• Increase public awareness of GB
Research Needs for GB Management			
Chemical: Develop integrated treatments that will increase management success and minimize the ecological and economical effects	• Investigate less labor intensive methods of integrated management • Analyze spatial patterns of invasions on a landscape-level	• TNC • DNR	• Reduce labor costs and increase effectiveness • Prevent loss of listed species
Biological: Establish biological control methods that will increase control and minimize effects of GB	• Feasibility of host-specific genetic engineered disease or pathogen		• Develop a more comprehensive approach to battle already established populations
Mechanical: Develop integrated treatments that will increase management success and minimize the ecological and economical effects	• Investigate less labor intensive methods of integrated management • Analyze spatial patterns of invasions on a landscape-level	• TNC • DNR	• Reduce labor costs and increase effectiveness • Prevent loss of listed species
Indirect Management: Increase scientific understanding and likelihood of natural succession and shading on GB	• Further investigation into shading and succession effects on GB		• Reduce labor costs

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