Garlic Mustard in the Midwest: an Overview for Managers

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Midwest Invasive Plant Network

SUMMARY

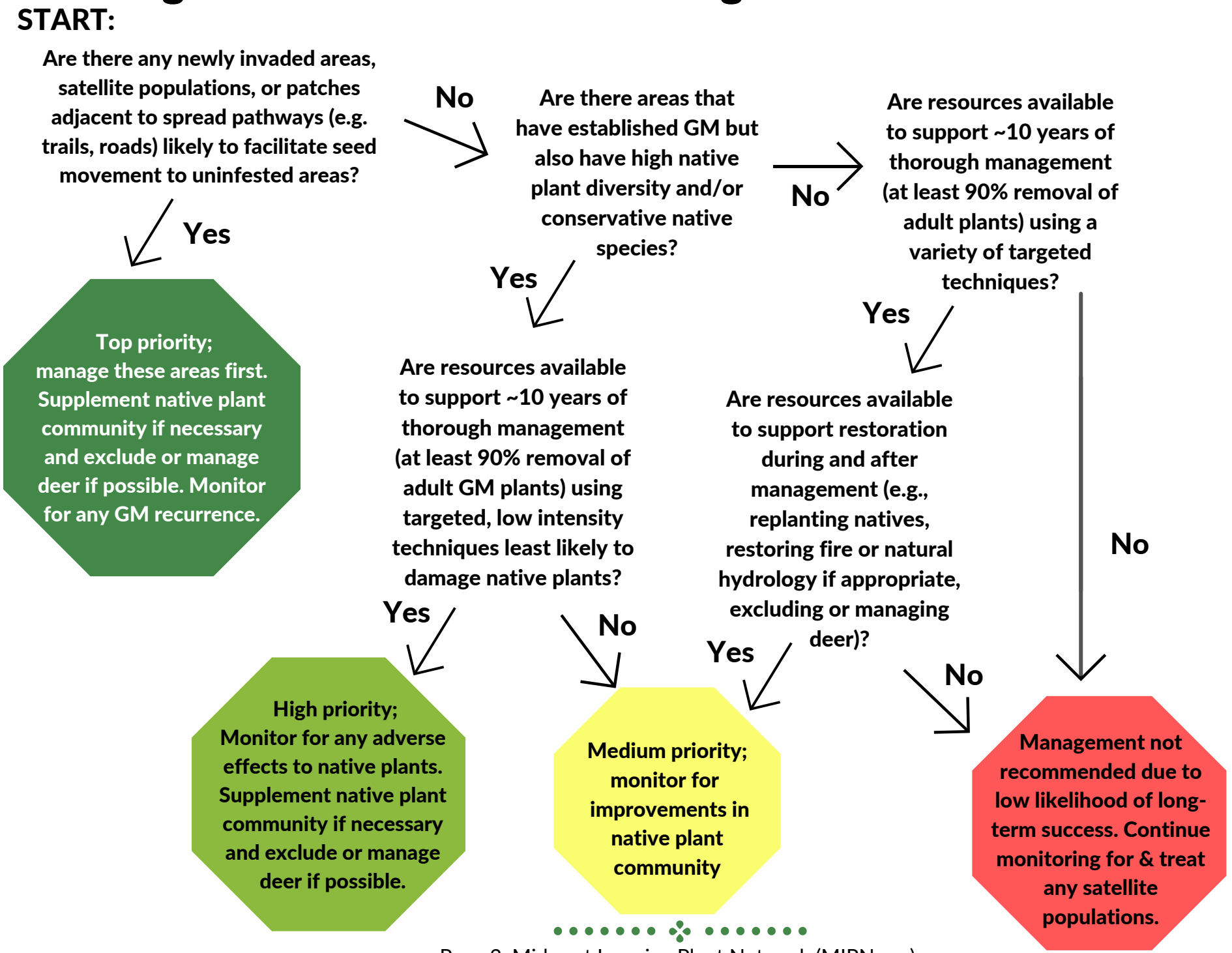
The Midwest Invasive Plant Network strongly advocates for the synthesis and transfer of new research findings to land managers. We are greatly encouraged by long-term monitoring of garlic mustard populations, a practice which is too rare in invasive plant research, and by studies that consider the role of garlic mustard among other important ecosystem stressors. Popular science and conservation media outlets have recently reported on monitoring results suggesting that garlic mustard populations eventually become self-limiting. While these indications are promising, following a comprehensive review of recent garlic mustard research, **it is MIPN's opinion that broad conclusions that garlic mustard populations will substantially decline or disappear in the absence of management with no lasting impact to the native plant community are premature and not well supported**. The impacts imposed by "doing nothing" could be substantial and irreversible. In this document, the Midwest Invasive Plant Network aims to summarize garlic mustard research findings and provide management recommendations based on the synthesis. This guidance is summarized in a management decision tree (see Figure 1, next page, and summary of decision tree outcomes on pages 8 & 10).* We recognize that managers face multiple stressors to the areas they manage and that this can make goal setting and management planning challenging. We support continued research to inform garlic mustard management and habitat restoration more broadly. Research that identifies the mechanisms responsible for natural garlic mustard declines, whether those processes operate across geographic regions, climates, and soil types, and how to differentiate these processes from background population fluctuations is needed before we can support a generalized conclusion that garlic mustard is declining.

Garlic mustard seedlings are plentiful at a site in Wisconsin that has been infested for at least 10 years. Photo by Mark Renz, University of Wisconsin

Cover and header photo: David Cappaert via bugwood.org

*The decision support information in this document is secondary to any prevailing regulation requiring management of garlic mustard on public or private property.

Figure 1: Garlic Mustard Management Decision Tree



Background

Garlic mustard (*Alliaria petiolata*) is a biennial herbaceous plant that is invasive in deciduous forest understories. It has a broad native range encompassing most of Europe and the Caucasus. Its North American introduction occurred in the 1860's when it was brought to Long Island as a medicinal plant. Today, it is reported in natural areas of 38 states, with over 71,000 verified distribution records (EDDMapS 2021). It is most frequently reported in the Northeast and the Midwest. Garlic mustard can dominate forest understories, forming single-species stands and producing large amounts of seed, which remains viable for years. Garlic mustard invasion has negative impacts on native understory plant communities (summarized in Rodgers et al. 2008), with documented impacts on key native forbs like red trillium (Bialic-Murphy et al. 2020).

The Role of Garlic Mustard amid Multiple Drivers of Native Plant Decline

Discussions among invasive species experts about whether invasion by garlic mustard (and by other invasive plants) is the *cause* or *a symptom* of declines in native plant diversity are inconclusive and ongoing (see Bauer 2012 for a summary of this discourse). This is germane to management because if garlic mustard invasion is a driver of declines, then removing it should allow native species to recover (as long as seed is still present). However, if garlic mustard invasion is merely a symptom of some other disturbance driver such as habitat fragmentation, deer over-browse, earthworm activity, or climate change, then managing the garlic mustard is not likely to facilitate recovery. Research supports both of these conclusions, suggesting that response may be location specific. While understanding multiple stressor impacts at a management site is helpful, we argue that management of garlic mustard can be an important and practicable aspect of restoration, and its presence cannot simply be ignored. Below, we examine recent literature on garlic mustard interactions with other agents of disturbance.

<u>Garlic Mustard and Earthworms</u>

There is no doubt that earthworms have major impacts on ecosystem processes and native plants. Earthworms consume leaf litter at a rapid rate, increasing the rate of carbon cycling, decreasing carbon storage and the availability of primary plant nutrients, and preventing the replenishment of the organic soil horizon. Together, these impacts have caused declines in native plant understory communities, particularly among species that would normally root in the top organic layer of soils (Hale et al. 2008). Garlic mustard benefits from this reduction in native species and can dominate (Nuzzo et al. 2009).

The common earthworm, *Lumbricus terrestris*. Photo by Joseph Berger via bugwood.org

While earthworms harm native plants and facilitate garlic mustard invasion, there are no practical management options available other than outreach campaigns or regulation to discourage human behaviors that facilitate further spread. Once earthworms are established, there is no direct management that can be applied at scale to remove them. However, a recent study demonstrated decreases in earthworm biomass in areas invaded with garlic mustard following garlic mustard removal (Stinson et al. 2018). This suggests that earthworms and garlic mustard may have a symbiotic relationship and benefit from each other's presence. The key is, of these two invaders, only garlic mustard can be managed.

Garlic Mustard and Deer

Over-abundance of white-tailed deer is also often identified as a driver of forest understory community change. Land development along with the elimination of apex predators has resulted in areas of high deer density. These native herbivores consume native plants, which co-evolved as part of their diet, while showing a strong aversion to eating garlic mustard. When deer densities are high in a forest, extensive damage to the herbaceous and woody understory can be expected, opening niches for species that deer avoid, including garlic mustard. High deer density also alters soil mycorrhizal fungal communities and causes soil compaction, further disadvantaging native plants (Shelton et al. 2014).

Two recent paired-plot studies examined the influence of abundant deer and garlic mustard on native plant species, both together and separately. Both studies found that deer exclusion had the strongest positive effect on native plant health metrics (Bialic-Murphy et al. 2020, Waller and Maas 2013). Both studies also demonstrated impacts of garlic mustard on native plant species in the absence of deer. Bialic-Murphy et al. (2020) found that when deer were excluded, garlic mustard had negative impacts on fruit production and survival of red trillium (*Trillium erectum)*. Waller and Maas (2013) found that garlic mustard also had discrete negative effects on the height and vegetative production of common wood sedge (*Carex blanda*) and wild geranium (*Geranium maculatum*). It should be noted that some recent field studies assessing garlic mustard impacts on native plants have not found any significant impacts (e.g., Davis et al. 2012) while others have (e.g., Brouwer et al. 2016). Impacts may be very species or location specific, may depend on garlic mustard residence time, and may depend on weather patterns, particularly during studies of relatively short duration. It has also been suggested that impacts emerge in native species demographic analysis rather than in counts of abundance and species richness or biomass (Bialic-Murphy et al. 2020).

White-tailed deer, *Odocoileus virginianus*.

Photo by Ken Lund, CC-BY-SA 2.0 via flickr.com

The impacts of garlic mustard on native understory species red trillium (*T. erectum*) can be isolated from deer browse impacts. Photo by Charles T. Bryson, USDA Agricultural Research Service via bugwood.org.

What is a manager to make of all of this information? High deer populations significantly impact native plants. Land managers with the ability to exclude or manage deer populations should do so to whatever extent possible. However, this can be a major challenge, as deer fencing may be cost-prohibitive and may conflict with other site management goals, such as public access and recreational activity. Harvesting or hunting deer to reduce populations is an alternative technique, but goal setting for deer population control is usually made at the state level by natural resource agencies with extensive input from stakeholders. Deer management decisions integrate a number of stakeholder positions, including hunter desire for high deer density, land-owner concerns over damage, deer-vehicle collision rates, herd health, and human health concerns. While we recommend maintaining low deer densities to reduce impact to native plants (see Shelton et al. 2014), in instances where low-to-moderate deer density cannot be maintained, garlic mustard management may still be beneficial, particularly where infestations are recent or resources are available to support other comprehensive, long-term restoration activities (see Decision Tree, page 2).

Garlic Mustard Population Dynamics

As a biennial plant, garlic mustard has two distinct life stages. In its first year, it germinates and seedlings form a rosette of basal leaves that overwinter. In its second year, it produces a flowering stem, bearing seeds in long pods called siliques. Towards the end of the second growing season, the siliques split open, dispersing their seeds, and the adult plants die. Some seeds may germinate the following spring while others may remain dormant but viable in the soil for several years. Studies have revealed a trend in some garlic mustard populations where rosettes or adult plants dominate in alternating years (Pardini et al. 2009, Davis et al. 2012, Van Riper et al. 2010). This is likely a result of competition between adult plants and seedlings, and is particularly evident in areas with high garlic mustard density. A large infestation may include patches that are dominated by adult plants, patches that are dominated by seedlings, and patches that are mixed during the same growing season. Like other annual and biennial species, garlic mustard is prone to population booms during years with favorable weather and crashes during years with adverse conditions (Van Riper and Becker 2014).

Garlic mustard populations also tend to move on the landscape over generations rather than persisting in place year after year.

While seeds are primarily gravity dispersed, they can be moved by wind scatter, flooding or runoff, and human or wildlife activity. A study of site-level garlic mustard distribution over time, found an average spread of 5.4 meters per year with substantial variation between plots (Nuzzo 1999). The same study found satellite populations forming up to 40 meters from the primary invasion front. The high degree of temporal and spatial variation demonstrated by populations of biennial plants like garlic mustard makes demographic monitoring and modeling particularly difficult, and careful sampling design is critical (Elzinga et al. 1998).

Long term monitoring has provided some limited evidence that garlic mustard populations may be self-limiting, eventually declining in the absence of management. A greenhouse study found that garlic mustard seedlings grow poorly in soil with a long history of garlic mustard presence compared to seedlings grown in soil with no garlic mustard history (Poon and Maherali 2015). This indicates that over time, garlic mustard may change soil in a way that reduces its own success. The underlying mechanism is unknown but both nutrient depletion and negative plant-soil feedback through excretion of chemicals by garlic mustard roots have been suggested by Cipollini (2016) and Blossey (2021) respectively. Further, long-term field transect monitoring in the Northeastern and Midwestern U.S. indicated that the population growth rate of garlic mustard at sites with a history of invasion decreased over time, and that at 57% of sites, particularly those in the Northeast, the growth rate fell below 1, indicating shrinking garlic mustard populations (Blossey et al. 2020). The same study also found decreases in adult plant stem height and silique production over time, again, particularly in the Northeast.

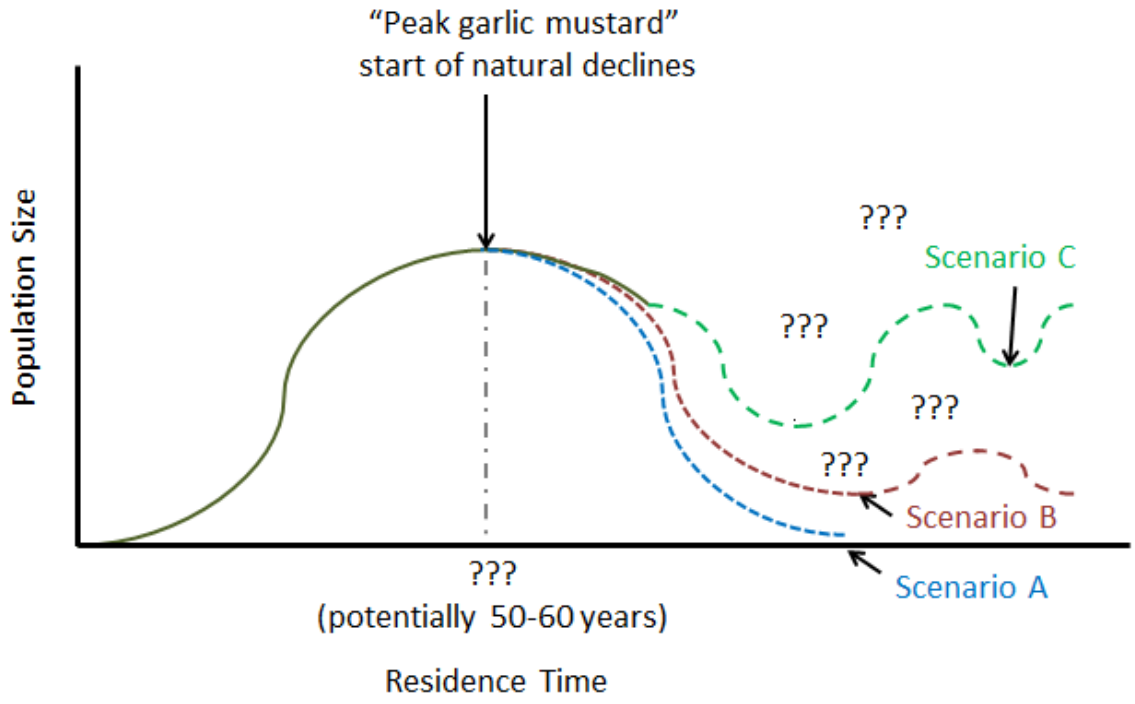
While it is encouraging that garlic mustard may eventually decline without intervention in some locations, there are several unknowns that temper how this information might be applied to management decisions. The first unknown is the duration of garlic mustard invasion required to trigger population decline. The sites used in the Blossey et al. (2020) study were known to be invaded for **at least 8-15 years**, but the actual residence time of garlic mustard at any of the sites is not known. Based on what we know of the species dispersal pattern in North America (as detailed in Lankau et al. 2009), some of the eastern-most sites in the study showing the greatest declines may have been invaded for as long as 50-60 years (indicated as “peak garlic mustard” on Figure 2). Indeed, Lankau et al. (2009) found year-over-year increases in garlic mustard cover at sites believed to have been invaded for up to 50 years, though the *rate* of cover increase declined with estimated residence time.

If a natural decline of garlic mustard is occurring, the long-term trajectory, consistency, and uniformity of this decline are not known. The lowest average population change rate reported in literature was 0.977, which is just under the equilibrium rate of 1.0 (Blossey et al. 2020). It is assumed a population decline will continue.

Will the population completely crash and become locally extinct, as has been suggested in presentations and media pieces (e.g., Blossey 2021, Hetzler 2021)? Will it stabilize around some low, non-dominant level? Alternately, will it stabilize around a below-peak level that is still sizeable enough to impact other species? These possible scenarios are indicated by lines A, B and C respectively on Figure 2. Another unknown is whether natural declines will occur at the same rate across garlic mustard's invasive range. The declines in population and plant vigor in Blossey et al. 2020 were not as pronounced for Midwestern sites, despite some of those sites, particularly the ones in Northeastern Illinois, having a similar possible garlic mustard residence time to Northeastern sites based on the invasion pattern presented in Lankau et al. 2009.

Additional unknowns relate to the long-term impacts to sites experiencing garlic mustard invasion cycles. Some monitoring sites have had garlic mustard present for decades, but it is unknown if they lacked native species to begin with and garlic mustard had little effect, or if the boom of garlic mustard populations negatively impacted the pre-invasion native plant community. Finally, it is not clear whether soils, following decades of garlic mustard invasion, will be in suitable condition to support native plant regeneration following garlic mustard decline or whether these sites will be vulnerable to secondary invasion.

Figure 2: Theoretical population curve for garlic mustard over time



Garlic Mustard Management Decisions

While garlic mustard has been heavily researched for decades, numerous questions remain. Site managers must decide how to prioritize management efforts for this species amidst other priorities. The Midwest Invasive Plant Network has developed a decision tree to assist managers in weighing options (see Figure 1, page 2). The decision tree utilizes many of the same decision-making factors as other tools designed for this purpose, such as the Invasive Plant Management Decision Analysis Tool (Zimmerman et al. 2011). Managers should keep in mind that use of decision support tools is secondary to any prevailing regulations requiring management of garlic mustard. Figure 1 bases recommendations on the site's invasion history, the likelihood of spread to new areas, native plant community health, and the availability of resources for continued management and comprehensive restoration. The decision tree has four possible outcomes: top priority, high priority, medium priority and not recommended for management.

Top Priority Sites

These are sites that are newly invaded or those that pose high risk of spreading seed to uninvaded areas. New invasions include small, new populations resulting from long-distance seed dispersal, satellite populations associated with larger infestations, and the leading edges of large infestations. Garlic mustard will not yet have established a seed bank in these locations, providing managers with a vital opportunity to prevent that from happening. Managers should also prioritize management of adult plants adjacent to known vectors of seed spread, including trails, rights-of-way, streams and drainages to prevent colonization of new areas.

High Priority Sites

At these sites, garlic mustard has established a seed bank, but indicators of a healthy native plant community are present. Indicators may include relatively high native plant cover or richness, and presence of keystone or rare species. It is important for managers to realize that garlic mustard management will need to continue for at least 10 years to exhaust the seed bank, and that management must be thorough, preventing reproduction in at least 90% of adult plants each year, to be successful (Corbin et al. 2016, Pardini et al. 2009). Garlic mustard removal strategies at these sites should be targeted and planned to minimize off-target injury, soil disturbance and trampling.

Medium Priority Sites

These sites have an established garlic mustard seed bank and lack strong indicators of native plant community health. However, resources are available both for long-term garlic mustard management **and** other restoration activities to address disturbances and rebuild the native plant community. Suitable restoration actions will vary by location, but may include initiating a prescribed fire regime

(continues on page 10)

Garlic Mustard Volunteer Events: Best Practices

Garlic mustard management is often conducted by volunteers as part of a coordinated pull event or competition. Easily identifiable without much training and easy to uproot from moist soil without tools, garlic mustard lends itself well to these events. While getting members of the community involved in natural area stewardship is a great thing, MIPN discourages volunteer pull events in situations where the decision tree recommends against garlic mustard management due to poor likelihood of successful control. While managers may be tempted to view this as a "nothing to lose" situation, volunteers may become discouraged if their work doesn't lead to long-term improvement. We also caution against large volunteer events at high priority sites with native plants that are sensitive to trampling or soil disturbance. If volunteers are sent to these sites, their placement should be planned carefully and more plant identification training may be needed. While we appreciate the friendly competition generated by pull-a-thons, where a prize typically goes to the person or team removing the most garlic mustard by weight, some ecologists have raised valid concerns about the export of ecosystem nutrients caused by removing large quantities of garlic mustard (Blossey 2021). Alternatives include the following:

Option 1:

- Schedule volunteer events early in the spring, when garlic mustard is in bud or early flowering (<5% of plants with silique formation)
- Volunteers uproot the plants
- Plant material is composted on site (Chapman et al. 2012 found no viable seed production in plants uprooted at this stage)
- Pull-a-thon winner is selected randomly or based on completeness of removal in an assigned area

Option 2:

- Schedule volunteer events later in the spring, when garlic mustard is in early silique formation (at least 50% of plants with immature siliques)
- Volunteers cut and bag the flowering stems, leaving roots and lower leaves in place (Pardini et al. 2008 found that plants cut mid-stem at this stage were unable to re-flower)
- Pull-a-thon winner is selected randomly or based on number/weight of cut stems

2-3 weeks later...

Photos: Chris Evans, U of Illinois Extension via bugwood.org

(continued from page 8)

restoring natural hydrology, deer exclusion, deer population management, and canopy thinning. If garlic mustard or other invasive plants have dominated for several years, it is likely that managers will need to actively restore the native plant community by introducing seed or live plants, keeping in mind that native species that are not highly mutualistic with arbuscular mycorrhizal fungi may be more successful in soils impacted by garlic mustard allelopathy (Bialic-Murphy et al. 2020). It is important for managers to realize that garlic mustard management will need to continue for at least 10 years to exhaust the seed bank, and that management must be thorough, preventing reproduction in at least 90% of adult plants each year, to be successful (Corbin et al. 2016, Pardini et al. 2009).

Management Not Recommended

The final decision tree outcome is a recommendation not to manage sites with a garlic mustard seed bank and without indicators of strong native plant community health where resources for long-term management and restoration are either not available or highly uncertain. Management is not recommended because long-term success is highly unlikely. Sporadic management may make infestations worse by disturbing soils and encouraging flushes from the seed bank.

In Summary

All land managers in the Midwest should be monitoring vulnerable habitat continually for new or expanding garlic mustard populations and prioritizing management of new infestations, removal of reproducing plants along known seed transport pathways, and managing the leading edge of growing populations. Garlic mustard is very responsive to disturbance, and managers should be especially vigilant for seed bank flushes following disturbance events. At Midwestern sites where garlic mustard populations had previously been low for years, managers have observed strong garlic mustard seed bank response following projects impacting perennial cover (e.g., invasive shrub removal, canopy thinning for oak savannah restoration, etc.).

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