Garlic mustard

Alliaria petiolata

Garlic mustard is native to Europe and parts of western Asia. It was likely introduced to North America for medicinal and herbal uses as well as erosion control. It was first recorded in 1868 at Long Island, NY, and there were likely multiple introductions. It has spread to at least 37 states and six Canadian provinces. Eight states list it as a noxious weed. It is one of few non-native invaders in North America that can tolerate shade, and it thrives in the forest understory. It grows in a variety of soil types but does best in moist, well drained soils. It begins its spring growth before natives emerge and forms dense populations by outcompeting native species for sunlight, moisture, nutrients and space. It is allelopathic, and chemicals released from its roots alter mycorrhizal communities that are critical for many native species including economically valuable trees. Unlike many invaders, garlic mustard reproduces only from seed. It has been implicated in local extirpations of toothworts, which are the primary food source for caterpillars of the West Virginia white butterfly. Chemicals in the plant appear to be toxic, as eggs laid on garlic mustard failed to hatch.

Identification

Habit:

Garlic mustard is a cool season herbaceous biennial. During its first year it produces low clusters of leaves (basal rosettes) which remain green through winter. The second year, it sends up a flowering stalk and can grow up to 1 m (3 ft) tall.

Leaves:

First year garlic mustard leaves are basal; they grow from a central point at ground level. They are kidney-shaped and toothed. After the plant sends up a flowering stem in its second year, the leaves alternate on the stem and are triangular, toothed and stalked. The leaves smell of garlic when crushed.

Stems:

Usually, garlic mustard sends up one flowering stem per rosette, but occasionally there are more.

Flowers:

Garlic mustard has numerous small, white flowers held in clusters at the tops of stalks or in leaf axils. Like all members of the mustard family, the flowers have four petals. They bloom from late April into early June.


Suzan Campbell, MNFI

Fruits/Seeds:

Garlic mustard's seeds are small, shiny, dark brownish-black, and they are held in long narrow capsules. A single plant can produce thousands of seeds. The seeds are viable within a few days of flowering and remain viable for many years.

Habitat:

Garlic mustard is found in upland and floodplain forests, savannas, along trails, roadsides and disturbed areas. It is shade tolerant but is also found in full sun.


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Root

The slender, white taproot of garlic mustard is distinctive, forming an S- or J-shape near the top, just below the stem.

Similar Species

Garlic mustard seedlings can be confused with the basal leaves of kidney leaf buttercup (*Ranunculus abortivus*); however, garlic mustard leaves are more evenly round-toothed on their margins. Upon bolting, the upper leaves of garlic mustard are triangular and sharply toothed, whereas those of buttercup are smooth edged and lanceolate or divided.

Kidney leaf buttercup basal leaves (left); whole plant (right)

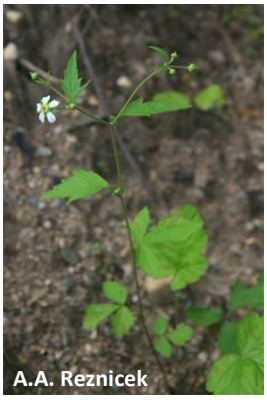
Henbit (*Lamium purpureum*) and creeping Charlie (*Glechoma hederacea*) have similary shaped leaves, but they are typically smaller with opposite leaves and square stems. Henbit leaves are usually more pointed or triangular while creeping Charlie leaves have more broadly rounded, larger teeth. Large creeping Charlie leaves closely mimic garlic mustard—check for the creeping stem. Unlike garlic mustard, neither of these species send up tall flowering stalks and their flowers are purple and irregular.

Henbit (*Lamium purpurea*)

Creeping Charlie (*Glechoma hederacea*)

Many violet (*Viola spp*.) leaves are similar; however, most are not so regularly kidney-shaped and have acute tips and shallower teeth. Their roots are not white and lack the characteristic S-shape.

Dog violet



Occasionally, white avens (*Geum canadense*) can be mistaken for garlic mustard before the leaves are fully mature. However, the basal leaves of avens are typically trifoliate and on long petioles. The white flowers have 5 petals.

Other small, white-flowered woodland herbs are sometimes confused with garlic mustard, including toothwort (*Dentaria spp*.) and sweet cicely (*Osmorhiza spp*.). Toothwort flowers have four petals like garlic mustard, but the leaves are divided, with three leaflets. Sweet cicely flowers have five petals and the leaves are divided with many leaflets.

Two-leaved toothwort

Sweet cicely

Garlic mustard can be distinguished from all other woodland herbs before fall by the characteristic garlic odor of the leaves when crushed. If in doubt, checking for the white, S-shaped taproot can usually rule out other species.

Reproduction/Dispersal

Garlic mustard is a biennial herb that reproduces by seed. It emerges early in the spring from a slender, white tap root and produces basal rosettes of rounded kidney-shaped leaves over the summer. The leaves remain green during the winter and bolt rapidly the following spring to produce flowering stems. These reach about 2-4 feet in height and bear alternate, triangular leaves. Flowers are produced from May through June. Garlic mustard can reproduce by both

cross- and self-pollination, but self-pollination is probably more common. Flowers mature into long, slender capsules filled with a row of many, tiny brown to black seeds by mid-summer. They burst when they are mature, and the seeds rain down onto the ground from July to October, leaving the empty, light brown capsules. The plant dies by late fall.

The seeds get buried where they fall or are dispersed by animals, humans, vehicles, equipment and possibly wind moving through the population. Garlic mustard colonizes floodplain forests as well as upland forests, and seeds can also be dispersed through water flow. They can be distributed upstream as well as downstream by seeds becoming lodged on animals, vehicles or watercraft that travel in many directions. Seed production is very high, and seeds can remain viable in the seedbank for many years.

Garlic mustard does not reproduce by rhizome fragments, but if the root crowns are left in the ground during hand pulling, they may grow new stalks and produce flowers and seed. *If flowering plants are pulled, they can often still produce seed and must be disposed of properly.*

Best survey period

Detecting garlic mustard is easiest in early spring and late fall because they green-up earlier and senesce later than most native plants. After native species have emerged, it is easiest to detect garlic mustard when in flower during May and June. The distinctive knee-high clusters of leafy, flowering stalks topped with small white flowers stand out. It can be distinguished later in the season by the long, slender capsules; however, these are more difficult to see than flowers.

Planning a control program

Resources for invasive species control invariably fall short of the actual need, so it is important to prioritize sites for treatment and plan carefully. Assessing the scope of the problem is a critical first step:

- Map known populations.
- Identify leading edges and outliers.
- Is the species widely dispersed throughout the region or is it just beginning to appear?
- How is the species behaving in your area? Is it spreading rapidly?
- Identify potential dispersal pathways and monitor them; is the population along a pathway or stream?
- Does it lie in the path of road-mowing crews that might spread it further? Are there construction sites in the area where it might be introduced in fill dirt?
- Does it occur in high-quality habitat or on important recreational, hunting or fishing lands?

Given this information, develop a strategy for control:

1. Prioritize high-value sites where treatment success can be achieved.
2. Prevent further spread by monitoring leading edges and outliers; focus on second year plants before they go to seed.
3. Choose appropriate control methods given site conditions and available resources.
4. Determine whether any permits are required (e.g., herbicide application in wetlands, prescribed burning).
5. Eradicate smaller, satellite populations.
6. Treat larger, core infestations.
7. Monitor to ensure desired results are being achieved; adapt management to improve success.

Documenting occurrences

In order to track the spread of an invasive species on a landscape scale, it is important to report populations where they occur. The Midwest Invasive Species information Network (MISIN) has an easy-to-use interactive online mapping system. MISIN I-phone and android phone apps are also available. Links to MISIN and its phone apps are provided in the "Online Resources" section. Herbaria also provide a valuable and authoritative record of plant distribution. The University of Michigan Herbarium's database can be searched online for county records of occurrence, for example. When garlic mustard is first encountered in a county where it has not been documented previously, specimens should be submitted to the Herbarium to document its presence. Check the "Online Resources" section for links to both of these resources.

Control

Garlic mustard control has been occurring for decades with differing levels of success, primarily tied to the amount of resources available to do the work and the ability to maintain treatment over many years. The primary goals are to prevent second-year plants from producing seed, prevent new seeds from arriving from nearby populations and deplete the seed bank.

Using a variety of techniques including mechanical and chemical control is usually more efficient and effective, and should be tailored to the specific conditions of the site. It is critical to monitor treatment sites for many

years, perhaps indefinitely in some situations, to ensure depletion of the existing seed bank and prevention of seed bank replenished from nearby populations.

Some studies show that initiating garlic mustard control without the ability to maintain the effort over time may do more harm than good. Disturbance from short term control efforts may directly harm native species and facilitate germination of garlic mustard seeds that will compete with native species. Most studies show short-term control efforts do not result in long-term control. Do not get fooled by years in which garlic mustard appears to be in low abundance. As a biennial, it only flowers during the second year of its life cycle and is a good seed banker. More plants are likely to emerge in the following year. Vigilant monitoring is required.

Hand pulling

Hand pulling over repeated years can be an effective means of control, particularly for small populations. It has also been employed for larger populations with remarkable success, when there are adequate resources for long term control and maintenance.

Hand pulling is typically done in spring and early summer and should target second year plants before they go to seed. Second year plants are easier to pull than first year rosettes and are more important because they are the seed producers. Pulling seedlings usually is not cost-effective except for very small infestations because many seedlings fail to survive.

Plants should be pulled only if the entire root can be removed. Roots remaining in the ground can re-sprout and produce flowers and seed. *Plants may also flower and produce seed after they have been pulled.* They should be bagged and taken to a landfill or dried and then burned or buried deep in the ground.

If second year plants are pulled too close to seed maturation, it will facilitate seed dispersal. Soil disturbance by hand-pulling also stimulates seed germination. Deliberate stimulation in this way, may expedite depletion of the seed bank thereby speeding up long-term control. However, this will only be effective if follow-up management of new sprouts is undertaken before new seeds are produced. Follow-up treatment will be required until the seed bank is exhausted.

A recent study supports the hypothesis that second year garlic mustard plants are important competitors with juvenile garlic mustard plants by shading them and taking up space and nutrients. Extensive management of adult garlic mustard early in the season may increase survival of juveniles that might otherwise be out-competed by second year plants. They will then have to be managed the following year. Some practitioners recommend hand pulling adult plants later in the season to take advantage of this natural control. Further study is needed to ascertain whether shifting pulling efforts to later in the season provides a significant advantage.

Root slicing

A sharp spade can be used to slice the taproot completely, approximately 1-2” below the surface. However, this will be even more labor intensive than hand pulling as the roots are small and difficult to target. This method can sometimes provide an alternative where plants cannot be easily pulled. It is important to slice the root below the crowns and remove the sliced plants with the root crowns and properly dispose of them.

After slicing roots, monitoring for and treating new sprouts is critical. It is difficult to get all plants during the initial treatment, and even tiny, overlooked plants with only a few flowers will produce new seeds.

Clipping

For small populations, the flowering tips can be clipped, bagged and removed. However, this is also more labor intensive than hand pulling and must be conducted multiple times during the growing season to capture all the flowers before seed production. Monitoring and clipping additional flowers as they emerge is critical.

Mowing

Mowing is not usually suitable for garlic mustard infestations, because it will harm associated native species and increase risk of spreading seeds.

Chemical control

Chemical controls are typically used for large garlic mustard infestations where hand pulling alone is impractical. It is often employed in conjunction with hand pulling or spot treatment with chemicals or hand-held propane torches.

General considerations

Anyone applying herbicides as part of their employment must become a certified pesticide applicator. In addition, certification is required for the use of some herbicides under any circumstances. The exam is administered by the Michigan Department of Agriculture and Rural Development and a link to their website is included in the “Online Resources” section.

A permit from the Michigan Department of Environmental Quality is usually required to apply herbicide where standing water is present—in wetlands, along streams, rivers or lakes, or over open water. A permit is also required for herbicide use below the ordinary high water mark along the Great Lakes or Lake St. Clair shoreline, whether or not standing water is present. A link to their website is included in the "Online Resources" section.

A number of adjuvants or additives may be used with herbicides to improve their performance including mixing agents, surfactants, penetrating oils and dyes. Some are included in premixed products while others must be added. Adjuvants do not work with all products; consult the product label to determine which adjuvants may be used with a specific herbicide formulation.

Dyes are useful in keeping track of which plants have been treated, as well as detecting spills on clothing or equipment. Some premixed herbicides include dyes. Clothing dyes such as Rit® can be added to water soluble herbicides, while other products require oil-based dyes. Consult the product label for specific instructions.

Crop Data Management Systems, Inc. (CDMS) maintains a database of agro-chemicals that includes herbicide labels for specific products. Herbicide labels contain information on application methods and rates, specific weather conditions, equipment types, nozzles etc., to provide the desired coverage and minimize the potential for volatilization or drift. They also contain critical information about the potential for damage to valuable non-target species. A link to the CDMS website is included in the "Online Resources" section.

Read the entire pesticide label before use. Follow all directions on the label.

Herbicide specifics

Glyphosate (e.g., Roundup®, Rodeo®, Accord®) can provide effective control of garlic mustard. It should be applied as a foliar spray in the spring to rosettes and bolting plants, well before seeds ripen. It can also be applied to first year rosettes in the fall. Fall treatment will not control seedlings that emerge in the spring and dry conditions may inhibit translocation of herbicide to roots. Fallen leaves can also limit effectiveness. Non-target impacts will be minimized if applications are made while native species are still dormant or after they have senesced.

Glyphosate should be used with a vegetable oil-based, multi-purpose adjuvant (e.g. SprayTech® Oil) on upland sites or a wetland-approved, non-ionic surfactant (e.g., Cygnet Plus®) in wetlands. Glyphosate is not selective and will kill desirable non-target species through over-spray and drift, in some cases leading to increased erosion on site. Glyphosate works best at temperatures above 50 degrees.

Triclopyr provides effective control of broad-leaved plants including garlic mustard but does not kill grasses or some conifers, making it particularly useful in grasslands, pastures and old fields. It is available in both amine (e.g., Garlon 3A®) and ester (e.g., Garlon 4 Ultra®) formulations. The amine formulation can be safely used in wetlands.

Triclopyr can be used as a foliar spray once per season. The ester formulation should be used with a vegetable oil-based, multi-purpose adjuvant (e.g. Spray- Tech® Oil), and the amine formulation should be used with a wetland-approved non-ionic surfactant (e.g., Cygnet Plus®).

Do not apply herbicides during a drought, as plants will not translocate chemicals effectively.

Foliar application

The product label for the specific herbicide being used provides essential information on coverage - how much of the foliage should be treated and how wet it should be. Herbicide labels also contain information on specific weather conditions, application modes, equipment types, nozzles, etc., to provide the desired coverage and minimize the potential for volatilization or drift.

The herbicide applicator is responsible for managing drift and damage to non-target vegetation. Wind speeds between 3 and 10 miles per hour are best for foliar herbicide spraying. At higher wind speeds, herbicide may be blown onto adjacent vegetation or water bodies.

At lower wind speeds, temperature inversions can occur, restricting vertical air movement. Under these conditions, small, suspended droplets of herbicide can persist in a concentrated cloud and be blown off-target by variable gusts of wind. Ground fog indicates the presence of a temperature inversion, but if no fog is present, smoke movement on the ground can also reveal inversions. Smoke that layers and remains trapped in a cloud at a low level indicates an inversion, while smoke that rises and dissipates indicates good air mixing.

In hot, dry weather, herbicide can evaporate rapidly. Setting equipment to produce large droplets can help compensate for this. If wind and temperature conditions allow, use a finer spray for larger patches. In contrast, spot treatment should occur with a confined spray pattern in order to minimize impacts to adjacent native plants. In general, follow all directions on the label of the specific herbicide being used in order to prevent damage to non-target vegetation or water bodies.

Prescribed Fire

General considerations

Permits are usually required before a prescribed fire. The Michigan Department of Natural Resources (DNR) is responsible for issuing burn permits in the Upper Peninsula and Northern Lower Peninsula unless a municipality wishes to do so. Municipalities located in the Southern Lower Peninsula issue burn permits under authority of the state law. A link to the DNR local fire contacts web page is included in the "Online Resources" section. In the Southern Lower Peninsula, contact the local fire marshal for permits and more information. In many situations, insurance is required before a permit is issued to cover the cost of damages if the fire should escape.

Before initiating a program of prescribed fire, a written burn plan establishing the criteria necessary for starting, controlling, and extinguishing a burn is required. The burn plan includes details such as specific weather conditions, locations of fire control lines, ignition pattern, equipment and personnel needed, contingency plans and important phone numbers. The burn plan is essentially the prescription for how to conduct the burn safely while accomplishing the management objectives.

Fire specifics

Spring burning of garlic mustard can be useful in fire-adapted communities, but prescribed burning alone does not provide effective control of garlic mustard. Fire will typically control seedlings; however, its impact to rosettes and second year plants is variable, depending upon fire intensity and specific burn timing. If fire intensity is not high enough, seedling management will be necessary until the seed bank is exhausted.

Fire also stimulates seed germination, ultimately increasing garlic mustard competition with desirable native species. However, deliberate planning to manage seedlings intensively after a burn can be an effective means of more rapidly depleting the seed bank. Seedlings can be managed by hand-pulling, spot treatment with herbicide or burning with a hand-held torch.

Prescribed fire is best conducted in spring after garlic mustard seedlings have emerged but before desired vegetation begins growth.

Prescribed burning should be implemented to meet specified management goals in accordance with specific site conditions. Fire may pose a risk to desirable plants; however, it may benefit other fire-adapted species such as prairie grasses, resulting in improved competition with garlic mustard. This should be considered during planning.

Hand-held propane torch

Freshly emerged seedlings can be quickly killed with a handheld propane torch, but this should be done when conditions are not too dry, to minimize risk of unintended fire. As the first-year plants develop taproots, this method becomes less effective.

Interseeding

In some situations, native seeding may improve success of garlic mustard control by increasing competition with garlic mustard seedlings. Assessment of the native seed bank prior to control efforts will help determine whether interseeding may be useful.

Manipulation of the forest canopy

Garlic mustard typically gets a foothold in forests where the canopy is disturbed, and it can take advantage of increased light penetration. It can be advantageous to manage these openings by restoring the canopy quickly. However, garlic mustard is shade tolerant and will persist under full canopy once established.

Biological control

Currently, four weevil species are being tested for potential use as garlic mustard biocontrol agents: two stem-miners (*Ceutorhynchus alliariae, C. roberti),* a root-miner (*C. constrictus*) and a crown-miner (*C. scrobicollis*). Studies are currently underway to determine the specificity of these agents and likelihood of impact to native species in North America.

Integrated control

Integrated control first requires understanding the site management goals, the biology of garlic mustard and the environment in which it is growing to select a combination of actions that collectively reduces its impact. Removal of garlic mustard is but one action amidst other changes that likely need to occur to

increase biological integrity or ecological health of the area.

An effective approach is to hand pull outliers and work along the leading edges of an infestation first, pushing the infestation back towards its core, thereby concentrating the infestation and subsequent seed production into a smaller area. Depending upon time and resources available, the site can continue to be hand pulled, or chemical treatment can be applied to the smaller core area, minimizing non-target impacts. Repeated follow-up spot treatments of surviving plants by hand pulling, spot treatment with herbicide, or burning with a hand-held propane torch will be needed.

Vigilance is required to manage any live plants in the kill zone and ensure that other invasive species do not emerge or colonize. Native seeding may improve success, particularly in sites where garlic mustard has been long-established.

Disposal of plant parts

Root crowns and pulled plants should not be left on site or composted as they may re-sprout and still produce seed. They should be disposed of in a manner that will ensure that their roots will dry out completely. If flowers are present, they should be burned or bagged and placed in a landfill. Where this is not possible, any resulting seedlings will require monitoring and control.

Although landscape waste cannot generally be disposed of in landfills, Michigan law permits the disposal of invasive species plant parts. See the "Online Resources" section for a link to the relevant legislation.

Online resources:

CDMS - herbicide labels
http://www.cdms.net/LabelsMsds/LMDefault.aspx?t=v

Fire Effects Information System, *Alliaria petiolata*
http://www.fs.fed.us/database/feis/plants/forb/allpet/all.html

Invasive.org
http://www.invasive.org/

Michigan Department of Agriculture and Rural Development—Pesticide Certification
http://www.michigan.gov/pestexam

Michigan Department of Environmental Quality—Aquatic Nuisance Control
http://www.michigan.gov/deqinlandlakes http://www.michigan.gov/deq/0,4561,7-135-3313_3681_3710---,00.html

Michigan Department of Natural Resources—Local DNR Fire Manager contact list
http://www.michigan.gov/dnr/0,4570,7-153-30301_30505_44539-159248--,00.html

Michigan Invasive Species Coalition:
http://www.michiganinvasives.org/

Michigan Invasive Species Program:
http://www.michigan.gov/invasives

Michigan's Invasive Species Legislation
Natural Resources and Environmental Protection Act 451 of 1994, Section 324.4130
http://legislature.mi.gov/doc.aspx?mcl-324-41301

Michigan Legislation—landscape waste, disposal of invasive species plant parts
Natural Resources and Environmental Protection Act 451 of 1994, Section 324.11521, 2 (d)
http://legislature.mi.gov/doc.aspx?mcl-324-11521

Midwest Invasive Species Information System:
https://www.misin.msu.edu/

MIPN Invasive Species Control Database
https://mipncontroldatabase.wisc.edu/

MISIN Mapping Phone Apps:

http://www.misin.msu.edu/apps/

The Nature Conservancy's Weed Control Methods Handbook: Tools and Techniques for Use in Natural Areas
http://www.invasive.org/gist/handbook.html

University of Michigan Herbarium - Michigan Flora Online
http://michiganflora.net/

Quick reference - Garlic mustard

This chart has been provided as a convenience, to summarize the pros and cons of each herbicide and to present details on adjuvants, concentrations, etc., that do not fit into the discussion in the preceding sections. Although every attempt has been made to ensure accuracy, the product labels for the listed herbicides are the ultimate authority for their usage. Where there are conflicts, always follow the label directions. Techniques are listed in order of general preference by MDNR Wildlife Division staff but not all are suitable for wetlands or sensitive sites. Site conditions vary—choose a method that is best suited to conditions on the site being treated.

Anyone using herbicides in the course of their employment is required to be a certified pesticide applicator. Treatment in wetlands or over open water requires a permit from the Michigan Department of Environmental Quality.

These chemicals are available in a variety of formulations and concentrations. Concentration is listed below as a percentage of the active ingredient (AI) to facilitate use of different products/brands. Always follow all directions on the product label including mixing instructions, timing, rate, leaf coverage and the use of personal protective equipment.

	Herbicide	% A.I.	Adjuvant	Timing	Pros	Cons
Foliar Spray	Triclopyr ester (e.g., Garlon 4 Ultra®)	1.5-3%	Use a vegetable oil based multi-purpose adjuvant (e.g., SprayTech® Oil)	Target rosettes (first year plants) in October-November if there aren't too many fallen leaves, or in March- April, prior to emergence of natives. Best at temperatures above 50 degrees.	Broad-leaf specific--will not harm sedges and grasses. Extremely effective.	Not approved for use in wetlands.
Foliar Spray	Triclopyr amine (e.g., Garlon 3A®, Renovate®)	2-3%	Use a multi-purpose adjuvant (e.g., SprayTech® or Cygnet Plus in wetlands)	Target rosettes (first year plants) in October - November if there aren't too many fallen leaves, or in March-April, prior to emergence of natives. Best at temperatures above 50 degrees.	Safe for use in wetlands. Broad-leaf specific--will not harm sedges and grasses.	May be slightly less effective at a given percentage than the ester formulation.
Foliar Spray	Glyphosate (e.g., Roundup®, Rodeo®, Accord®)	1-3%	Some products already contain a surfactant - if not, add one (e.g., Cygnet Plus®, NuFilm IR®).	Target rosettes (first year plants) in October-November if there aren't too many fallen leaves, or March-April, prior to emergence of natives. Best at temperatures above 50 degrees.	Some products approved for use in wetlands.	Non-selective! Use only when few or no natives are present.
Note: Hand-pull survivor seedlings in May or June, whether you apply herbicide in spring or fall. Be sure to remove the entire root.						