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Biology and Management of *Alliaria petiolata* (Garlic Mustard) in Woodland Communities of North America

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Introduction

Alliaria petiolata is a non-indigenous herbaceous plant species that is invading several types of woodland ecosystems within the continental United States and Canada. *A. petiolata* invasion displaces native plant populations (especially spring ephemerals) and limits the vegetative resources of native flora available to wildlife (George, 2000). *A. petiolata* has been found to be readily invasive in both low quality and high quality woodland ecosystems, making it a critical conservation problem. Due to the invasiveness of this species and the ill effects that it currently has on woodland ecosystems within the United States and Canada, it is imperative that *A.*

petiolata be managed to lessen these negative effects. Three techniques for management of *A. petiolata*, including weeding, prescribed burning, and herbicide treatment, will be discussed following a background on the history, geography, habitat needs, and biology of the herb.

History and Geography

Alliaria petiolata is a biennial herb native across many parts of Europe and Asia. The herb was brought to North America by European settlers in the mid 1800's as a culinary and medicinal herb (Nuzzo, 1991). As a culinary herb, *A. petiolata* has been prepared as an accompaniment to meat dishes and eaten raw in salads in both Europe and North America (Guest, 1997). As a medicinal herb, *A. petiolata* has been used internally as a cure for dropsy and coughs, while being applied as a compress externally for sores and gangrene (Guest, 1997).

Within the United States and Canada, the range of *A. petiolata* is expanding, with existing populations from Ontario through the northeastern United States west into Minnesota and south to Missouri and Virginia (Guest, 1997). It has also been documented from parts of the Pacific Northwest and Utah (Guest, 1997). The first recorded presence of the herb in the United States dates back to 1868 in Long Island, New York (Nuzzo, 1991). By 1950, *A. petiolata* was found in at least 13 other states. In 1990, the herb was reported present within 29 states, predominantly in the Midwest and Northeast regions of the United States but also including Utah, Oregon, and the District of Columbia (Nuzzo, 1991). In Canada, the herb was first documented in Toronto in 1879, found in two provinces by 1950, and in 1990 was found in southern Ontario, the St. Lawrence Valley in Quebec and southern Vancouver, British Columbia (Nuzzo, 1991).

Habitat

In a typical North American woodland ecosystem there are three significant layers of vegetation: the overstory, the understory and the groundlayer. The overstory is made up of trees greater than 10.5 meters in height. The understory is made up of trees and shrubs ranging from approximately 2 meters to 10.5 meters. The groundlayer consists of herbaceous and woody plant species that range from ground level up to approximately 2 meters (The Kestrel Group, 1999). Within North American woodland communities, *A. petiolata* is found in the groundlayer vegetation layer.

In North America, *A. petiolata* is quickly creating a niche for itself in a variety of woodland ecosystems and has become a dominating element in many natural areas, displacing native woodland species. In woodland communities, *A. petiolata* is most frequently found growing under a partial shade canopy (Nuzzo, 1991). However, it is important to note that *A. petiolata* plants are also frequently found growing in sites that have light penetration ranging from full sun to full shade (Nuzzo, 1991). The plant may have greater growth under full sun conditions, but will be less invasive when either full sun or full shade conditions exist (Cavers et al. 1979). In terms of soil, *A. petiolata* has been found growing in a variety of soil substrates ranging from clay to gravel, but the herb has not been documented in peat soils or soils with high acid content (Cavers et al. 1979). *A. petiolata* is most invasive within disturbed woodland communities, and rapid invasion and dominance of the herb can occur within such sites (Nuzzo, 1991). *A. petiolata* has been observed to invade and dominate the herbaceous ground layer within 10-20 years in

disturbed and degraded woodland communities (George, 2000). Due to the tolerance of many growing conditions, and the plant's ability to invade and dominate a site rapidly, *A. petiolata* has the possibility of making a severe impact on the long-term natural history of woodland ecosystems throughout North America (George, 2000).

The presence of other exotic species impacts the structure of the woodland community and can thus have implications for *A. petiolata*'s success at germination and development. For example, as non-native earthworm populations increase in many woodland communities, the duff layer on the forest floor is reduced or completely depleted. This unnatural condition provides an optimal habitat for *A. petiolata* as the species prefers a highly mineral soil with little leaf cover to shade it during germination (Gillette, 2000). If non-native earthworms were not changing soil and surface structure in this way, *A. petiolata* may have reduced success at germination and dominance of the groundlayer (Gillette, 2000).

It is important to note that within its native range, *A. petiolata* has been found to occur at much smaller densities in more isolated populations than in invaded ecosystems of North America (Reston Association, 2000). Also, throughout the herb's native range there are over 30 different insect species that have a direct impact on the plant and associated plant functions through stem, leaf and seed damage (Reston Association).

Biology

Alliaria petiolata is a cool-season biennial herbaceous plant within the Brassicaceae family. Typical of the Brassicaceae family, flowers are small and white with four petals per flower. Flowers are generally grouped in small clusters at the terminal end of the main stem. Flowers of *A. petiolata* are self-compatible and thus capable of self-pollination, but they are also adapted to cross-pollination by insects including syrphid flies, midges, and bees (Nuzzo, 1991). An implication as a self pollinating species includes the possibility of a single plant being capable of pollinating an entire site (Nuzzo, 1991).

As a biennial herb, *A. petiolata* has a distinct growth development pattern. In the first year a basal rosette develops. During this developmental stage, the plant can be easily overlooked as the leaves lie close to the forest floor and may be covered with leaf litter. In the second year a flowering stalk is produced and the plant flowers, sets seed and dies. Biennial plants generally are prolific seed producers due to the fact that all of the plant's reproductive energy is used to produce seed. As a flowering adult plant *A. petiolata* produces an average of 350 seeds (Guest, 1991) in its one flowering season. Seeds are held in erect siliques and ballistically dispelled for a distance of up to several meters (Nuzzo, 1991). Seeds are also dispersed with the aid of a variety of mobile elements within the woodland community. Current observation has concluded that seeds are typically dispersed via deer, rodent, and human movement (Gillette, 2000). Deer carry the seed for long distances on their hooves depositing the seed on and along trails, while rodents such as raccoon and squirrel have been observed depositing seed under roosting trees (Glass, 2000). Human dispersal of *A. petiolata* can occur over great distances if seed is attached to hikers' clothing and footwear, or on tire treads of bicycles, off-road vehicles, and on-road vehicles such as cars and motorcycles. Human movement posses the largest threat to long range spread of the herb in the shortest period of time (Gillette, 2000).

Water movement through the ground plane of woodland communities, particularly in the floodplain woodland communities, may also disperse seeds. Seed dispersal has also been observed to follow storm water flow paths (Glass, 2000). However, seeds are not typically wind dispersed (Nuzzo, 1991).

Seed dormancy lasts approximately 20 months from the time when the seeds are dispelled from the parent plant to when the seeds germinate (Baskin, 1992). Cold stratification is required for seed germination to occur, and, once dormancy has broken, seeds are capable of germinating at low temperatures (Baskin 1992) thus allowing early spring germination of A. petiolata seeds. This factor is an import element in the invasiveness of the species since A. petiolata can then out-compete native species for early spring light before the forest canopy develops (George, 2000).

Typically seed germination occurs in the early spring, often after the first or second warm spring rain (Nuzzo, 1991). A second germination may occur in autumn, though in much smaller quantities (George, 2000). Most germination occurs within the two years following dormancy break (Nuzzo, 1991), but seeds may remain viable in the soil for up to four years (Baskin, 1992) with decreasing germination success rates as the seed ages.

Management Practices

A. petiolata has been known as an invasive species and managed as such since the early 1980's (Callahan, 2000). Twenty years of management of *A. petiolata* in woodland situations has resulted in the development and refinement of a few fairly effective management techniques: prescribed burning, weeding/ cutting, and herbicide treatment. Each one of these techniques has associated limitations, including environmental concerns or repercussions.

Information about management practices has been contributed by a variety of sources including Cary George of the Minneapolis Park and Recreation Board, Larry Gillette of Hennepin Parks, and Steve Glass of the Wisconsin Arboretum at Madison.

Due to the longitivity of seeds within the seedbank and the possibility of a single plant being capable of producing seed in sufficient quantity to start an invasive colony, persistence and thoroughness are key to proper management of the herb in woodlands throughout North America.

Prescribed Burning

Prescribed burning is most often used in large areas when time is limited and labor intensive techniques such as hand pulling are too resource intensive for practical use (Gillette, 2000). Prescribed burning is used as a tool for general woodland ecosystem management in some areas and, thus, control of *A. petiolata* can be a beneficial result of a larger scale management plan (Gillette, 2000). What is necessary for prescribed burning to work as a management technique for *A. petiolata* is consistency. Burning must occur in infested areas once a year for a minimum of 3-4 years in order to exhaust the seed bank. Burning must also occur prior to the surviving second year plants' seed development, so that the seed bank is not replenished (Glass, 2000).

Experiments have shown that fires need to be of mid-intensity (flame length up to 15 cm) to effectively destroy *A. petiolata* (Nuzzo, 1991). Low-intensity fires (flame length up to 3 cm) have been proven to be ineffective in destroying *A. petiolata* (Nuzzo, 1991). Fires are conducted in early spring when *A. petiolata* first appears or in autumn when native plants have gone into dormancy but *A. petiolata* is still green. Burning in the spring risks negatively affecting early emerging spring ephemeral species but results in better density reduction of *A. petiolata* in comparison to autumn burning (Nuzzo, 1991). Autumn burns reduce the possibility of damage to native plants since burning can be done after native plants have gone into dormancy. However, autumn is usually too late to effectively reduce *A. petiolata* since seed has already set and replenished the seed bank. The viability of seeds of *A. petiolata* in the seedbank that remain after exposure to fire is unknown.

Fuel for a mid-intensity fire is essential. If fuels are not sufficient for a mid-intensity fire throughout the infested area, survival of individual plants and groups of plants is likely to result in a continuation of seed production from surviving plants and ultimately a continuation of the problem. Furthermore, fuel availability for a minimum of 3-4 prescribed burns in consecutive years can pose an even larger problem. A growing concern about the reduction of leaf litter by non-indigenous earthworm populations has been speculated to limit the potential to sustain prescribed fire (Gillette, 2000).

With this in mind, it is of essential importance that, if prescribed burning is being used as the sole management technique for control of *A. petiolata*, fuel must be sufficient for a minimum of 3-4 years of annual mid-intensity burning. It is also important to note that some land managers believe that the seedbank can persist much longer than research data has shown, up to 10 years (Glass, 2000). Management practices must incorporate this time period if necessary.

Weeding/Cutting

Weeding and cutting is most effective in small areas where sufficient labor is available for this time intensive, but highly effective, control method (Gillette, 2000). It is most typically used when volunteer labor forces are available, or in cultivated landscapes where weeding is a regular part of the landscape management. There are three commonly used techniques that fall under the weeding and cutting management method. With all of the techniques, plants must be removed or cut back before seeds have set so as not to repopulate the area with a new generation of seed

(Glass, 2000).

The first technique commonly used under the weeding and cutting is to remove *A. petiolata* plants in their entirety. (Gillette, 2000). Since new shoots can develop from root fragments remaining in the soil, it is important to remove as much of the root system as possible (George, 2000). Removal of the entire plant is the most time consuming technique since each plant must be hand dug. It is also the most invasive technique in regards to soil and adjacent plant disturbance.

The second technique involves cutting the plants at the base of the stems at ground level. This technique involves some adjacent plant disturbance as tools used for cutting the stem at the base

may also cut non-target plant species tissues (Nuzzo, 1991). As well, soil disturbance or soil compaction may occur as laborers kneel on the forest floor to reach the base of the plant and tools inadvertently penetrate the soil surface. Cutting at the base is generally only a temporary remedy as new shoots may develop from the base of the plant, and the plant may restore itself to reproductive capacity. Although this technique may not result in complete annihilation of *A. petiolata* populations in infested areas, it is less time consuming than weeding, and can be used in situations where time or labor is limited.

The third technique is to cut off only the flowering section of the plant. This technique is the most time efficient and may have the least impact on soil structure and neighboring plant health. However, it is not as effective in reducing flowering plant populations (Nuzzo, 1991) due to possible regeneration of reproductive capacities. As with cutting at the base, this method is useful in situations where time or labor is limited but some management of *A. petiolata* is desired on a site.

With all three weeding and cutting techniques, disturbance of soil and neighboring groundlayer plants will occur as laborers walk through the infested area to carry out their duties. Also, as laborers move through the woodland to remove or cut back *A. petiolata* they may also be effectively transporting any seed from the soil surface to their next destination (Glass, 2000), aiding in the plant's dispersal. Therefore, it is important that laborers remove clothing and footwear before entering a non-infested site. Lastly, weeding and cutting techniques, as with burning, must be performed on an annual basis for a minimum of 3-4 years to effectively remove existing populations of *A. petiolata*.

Chemical application

Herbicide treatment is an effective management strategy for both small and large populations of *A. petiolata*. The most common herbicide used is a 2-3% solution of glyphosate (George, 2000), which can be found under various trade names. This herbicide is non-specific and will destroy any plant tissue that comes in contact with it. This non-specificity limits the use of the herbicide as a management method because it should only be applied at times of the year when native plant's foliage is dormant and therefore unaffected (Glass, 2000). The result is that herbicide treatment typically occurs in early spring or autumn. Spot treatment, however, can occur all throughout the growing season if necessary (George, 2000). Additionally, the herbicide should be applied to individual plants or groupings of target plants manually to insure that application to non-target species is avoided (George, 2000). Thus, application can require extensive amounts of time and labor if treatment involves large areas.

Herbicide treatment can be very effective as a management technique if care is taken to treat all *A. petiolata* plants of an infestation. Problems can arise when foliage of *A. petiolata* plants is covered by leaf litter on the forest floor in early spring and autumn resulting in missed plants.

Missed plants can potentially parent an entire population and ultimately generate a reinfestation of the area (Baskin, 1992).

Conclusion

A. petiolata is a highly invasive plant within woodland communities of North America due to many factors. These factors include its adaptability to a wide variety of growing conditions, its prolific seed production, its early germination capabilities, and its successful seed distribution via mobile elements within the environment. Interactions of other exotic species with the environment may also be impacting the success of *A. petiolata* as an invasive species, as with non-native earthworm populations and their impact on soil structure.

Currently, three management techniques are commonly in use for control of *A. petiolata*. These techniques include prescribed burning, weeding/cutting, and chemical application. Each technique has positive and negative attributes as well as a tendency to work more effectively within certain parameters. Prescribed burning is most effective in large areas, but can be difficult to pursue if there are insufficient quantities of leaf litter. Weeding and cutting works well when a large labor force is available, but can disturb soil and plants as laborers move through the woodland. Chemical application is very effective if applied correctly and can be carried out by a single person over a substantial area. Still, if chemical application is carried out incorrectly, or during the growing season, non-target plants are at risk of being damaged. Even after the seedbank has been exhausted from use of one or more of these management techniques, annual surveying for new invasions must be done, and management must be incorporated for eradication of those developments before seeds set.

In the future, use of biological control may open up possibilities for more extensive and long-term management options. Natural enemies of *A. petiolata*, including several species of Ceutorhynchus weevils, are currently being researched at Cornell University in Ithaca, New York (Blossey, 2000). Within the next ten years it is possible that biological control methods will be available for use in managing *A. petiolata* (Gillette, 2000). Until then resource managers and concerned citizens managing *A. petiolata* populations on public and private lands can benefit from the use of one of, or a combination of, the management techniques mentioned herein.

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