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MANAGEMENT OF INVASIVE GARLIC MUSTARD POPULATIONS

by

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MANAGEMENT OF INVASIVE GARLIC MUSTARD POPULATIONS

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ABSTRACT:

The purpose of this study was to investigate current practices regarding known *Alliaria petiolata* (garlic mustard) populations in Lincoln, Nebraska and to determine the most effective management techniques in controlling garlic mustard invasions. *A. petiolata* is a shade tolerant, cool season growth plant invasive to North America. It is an allelopathic biennial whose established first year rosettes overwinter giving garlic mustard a head start on native annuals allowing it to outcompete indigenous species in the understory of woodland areas. Information regarding the histories and extent of invasions, management methods, and impacts on ecosystems was gathered from personnel at Fontenelle Forest Nature Center, Lancaster County Weed Control, Pioneers Park Nature Center, and Nebraska Department of Agriculture's Noxious Weed Program. Fontenelle Forest in Bellevue, NE

served as a case study for management efficacy as garlic mustard has demonstrated a prolific ability to spread throughout the area. The most effective method of controlling garlic mustard infestations has been to manually pull and bag the plants, taking care to completely remove the entire root. This treatment should be repeated multiple times throughout the growing season until the mature adults begin to seed to prevent further seed dispersal. Annual monitoring is crucial until the seed bank has been depleted to prevent reinvasion.

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To Zane & Morgan: Blood or not, we will always be family.

To Svend, Paxon, & Coco: The best of times lie ahead.

INTRODUCTION

Alliaria petiolata (garlic mustard), native to Europe, was introduced to the United States by European settlers in 1868 for medicinal and herbal purposes (Nuzzo, 1992). It can also be used as a flavoring agent in cooking or as a substitute for leafy greens as all parts of the plant are edible (“On the Lookout For...Garlic Mustard”). Since introduction to Long Island, New York, garlic mustard has spread to 37 U.S. states and five Canadian provinces (“*Alliaria petiolata* (M. Bieb.) Cavara & Grande garlic mustard”). More recently, garlic mustard has been documented at six sites in southwestern areas of Lincoln, NE: Col. Densmore Park, Jamaica Trail, Pioneers Park, Rock Island Trail, Standing Bear Park, and Wilderness Park (Pharris, 2011). The Pharris (2011) also gathered quantitative data on average plant height, average leaf width, plant density (per square meter), pod number (per plant), seed number (per pod), and estimated land cover at the Rock Island Trail site.

Because garlic mustard has the ability to quickly invade new areas, it is important to better understand its threat to existing ecosystems. As new populations are established, garlic mustard outcompetes native plant species by growing in dense groups that inhibit interspecific competition, (i.e., competition between different species) (Nuzzo, 2000). This has resulted in ecological and economic damages. The purpose of this study is to investigate current practices regarding known garlic mustard populations in Lincoln, NE and to determine the most effective management techniques in controlling invasions.

Biology:

Alliaria petiolata is a member of the Brassicaceae family, also known as the mustard family. Cruciferae, interchangeable with Brassicaceae, means “cross-bearing” and is

representative of the four petals of mustard flowers arranged in a cross shape. Garlic mustard has a “S”-shaped tap root that is visible when manually pulled.

Garlic mustard is a cool season, shade tolerant plant that inhabits wooded areas. It prefers damp soil (Gleason, 1963) with a pH between 5-7.2 (Byers & Quinn, 1998) and will grow in sand, loam and clay but avoids peat and muck (Nuzzo, 2000). *A. petiolata* also tends to inhabit disturbed areas near trails, paths, hedgerows, fences, roads and railroads (Nuzzo, 1992). The spatial association between man-made structures and garlic mustard populations indicate that anthropogenic processes are important for long distance dispersal of the plant. Deer and other wildlife contribute to short distance dispersal.

A. Petiolata has a biennial life cycle with a two season maturation period. Seeds germinate in early spring during late February and early March, followed by growth into the juvenile rosette which presents with three to five leaves in the spring (Scott, 2000). The rosette is between five to ten centimeters tall and five to 13 centimeters in diameter (Nuzzo, 2000). Vegetative growth has been documented in the cool fall months; some plants have been observed to add a new set of four leaves (Cavers *et al.*, 1979). The rosette leaves are heart shaped with scalloped leaf margins and deep leaf veins (Czarapata *et al.*).

The rosette stays green throughout winter into the second year and undergoes a period of rapid growth during March and April. Established rosettes have a head start on native annual plants, and are able to outcompete them for sunlight and resources. The mature plant can reach a height of 50-190 centimeters tall (Nuzzo, 2000) although the average plant height documented off of the Rock Island Trail site in Lincoln, NE was 130 centimeters (Pharris, 2011). The mature adult plant has white, four-petal flowers and

leaves that are triangular in shape with serrated leaf margins.

Flowering peaks in mid-May and can continue into early June when the leaves senesce and the petioles develop into seed pods which shed seeds in late June into mid-July (Scott, 2000). Each plant can have between four and 16 pods containing 10-20 seeds per pod (Nuzzo, 2000); however, the populations at the Rock Island Trail were reported to have an average of 44 pods per plant and 12-20 seeds per pod (Pharris, 2011).

Reproductive Potential:

Garlic mustard is a rapidly spreading, highly invasive species due to its high seed production. Garlic mustard has the ability to produce up to 24,600 seeds per square meter (Pharris, 2011). In its native range in Europe, garlic mustard has host specific pathogens and insects that control populations (Steinauer, 2002). Garlic mustard has no biological control in North America leaving population growth unchecked.

Garlic mustard seeds are also highly viable even after dormancy. Scott (2000) did a three year study on seed viability and dormancy in Ohio woods. He found that 61% of the seeds germinated the first spring after planting. After three year, 94% of the planted seeds had germinated. Viability after dormancy plays a key role in garlic mustard reproduction because seeds may remain dormant in the soil for up to seven years.

Allelopathic Advantage:

Garlic mustard produces allelochemicals that are toxic to soil microbes and mycorrhizal fungi of North American, which aid plants to fix nitrogen and other nutrients. In its native range, European species have coevolved resistance mechanisms and are able

to compete with garlic mustard. In North America, the indigenous plants do not have coevolved resistance mechanisms to combat the effects of the allelochemicals. Without native species to compete with, garlic mustard has more resources to grow.

Lankau *et al.* (2009) studied a 50 year chronosequence of garlic mustard with seeds from 44 sites. They found that plants grown from seeds of younger populations produced higher concentrations of allelochemicals which are more valuable in ecosystems with stronger interspecific competition. This enables garlic mustard to outcompete native species and become established in a new range. Plants grown from seeds of older populations produced lower concentrations of allelochemicals which are more valuable in ecosystems with stronger intraspecific competition (i.e., competition within a species). After establishing itself, the garlic mustard exhibits a trade off; energy saved by reducing allelochemical production can be put toward vegetative growth to increase surface area for photosynthesis.

Ecological Damage:

Garlic mustard invasions are considered a serious threat to woodlands (Czarapata *et al.*). Invasion is a process that involves three stages: arrival, establishment, and spread (Scott, 2000). As it implies, arrival is the introduction of garlic mustard seed(s) to a new range. As a biennial, young populations exhibit alternating years of reproduction until the seed bank has built up. Because garlic mustard seeds can stay dormant in the soil for years, once previous garlic mustard plants have inhibited native plants' mycorrhizae, a new set of rosettes are eventually able to germinate and survive every growing season. At this point,

the garlic mustard population is considered to be established and can begin to spread outwards.

Once abundant, garlic mustard reduces native plant diversity of the woodland understory by outcompeting indigenous plants for resources. Deer and other herbivores do not forage on garlic mustard because of the strong garlic scent given off by the plants, forcing the primary consumers to forage on the already reduced native populations. Established garlic mustard populations also change and reduce the habitats of several species of native fauna: salamanders, earthworms, insects, mollusks, ovenbirds, thrushes and whip-poor-wills (Steinauer, 2002).

METHODS

To determine the most effective methods of managing garlic mustard, the Fontenelle Forest Director of Science and Stewardship, Gary Garabrandt, was interviewed to determine the management methods that have worked best in controlling garlic mustard.

The following questions and topics were discussed:

1. When did garlic mustard first appear?
2. What is the current extent of invasion?
3. How did invasion spread, in biomass and local geography?
4. What is the history of management methods?
5. How has garlic mustard impacted local flora & fauna?
6. How has garlic mustard impacted aesthetics and human use of parks, trails, & education programs?
7. If resources were unlimited, what would be the best plan for control?
8. What suggestions would you give to control Lincoln's populations?

The purpose of focusing on these questions was to follow the progression of the invasion in Fontenelle Forest and gauge the success of the subsequent management techniques. The goal was to learn from the events at Fontenelle Forest and determine if the same progression of events could occur in Lincoln, NE.

The second set of interviews dealt with the current invasions observed in Lincoln. The Lancaster County Weed Superintendent, Brent Meyer, and the Pioneers Park Nature Center Land Manager, Aaron Druery, were interviewed. The following questions and topics were discussed:

1. Is Garlic Mustard being monitored?
2. When did populations first appear?
3. What is the current extent of invasion?
4. How is the invasion spreading, in biomass and local geography?
5. What management methods, if any, are being employed?
6. What are the current impacts, if any, on local flora and fauna?
7. What are the current impacts, if any, on aesthetics and human use of parks or trails?

An evaluation of Lincoln's garlic mustard populations was compared to the history of the invasions at Fontenelle Forest. The successes and failures at Fontenelle Forest were integrated with other literature to construct a management plan for the known infestations in the Lincoln area documented in the Pharris 2011 study.

RESULTS

To learn about a well established garlic mustard population, an interview was conducted on March 10th, 2013 with Gary Garabrandt, the Fontenelle Forest Director of Science & Stewardship. Garlic mustard was first identified in 1988. A rapid spread was observed by 1992 and by 1996, a portion of Fontenelle Forest in the Neale Woods area was coined, “Mustard Heaven”, because garlic mustard had complete take over the understory. Throughout this time, Garabrandt observed garlic mustard spreading from flood plains to hills. Flood waters during 1984 are speculated to having introduced the seeds. At one point during seasonal flooding the seeds were submerged in eight feet of water and again germinated after the retreat of the flood waters, showing remarkable resilience in times of unfavorable conditions. He reported that seeds on deer fur and turkey plumage may contribute to garlic mustard dispersal within the park. He also noted that deer will not feed on the garlic mustard like many of the other native plant species present at Fontenelle Forest. Currently, garlic mustard has spread throughout the 2000 acres of Fontenelle Forest and Neale Woods. The infestation continues to be a testimony to the ecological and aesthetic damage an invasive species can have once introduced.

Garabrandt has tried many management methods. Cutting and weed eating have proven somewhat ineffective as the garlic mustard plants grow back from the severed stalk. A propane-powered flame thrower was used for controlled burnings but with the root of the plant still intact, the shoots exhibited the ability to continue growing. Herbicide was applied, which killed the established plants but new plants surfaced in their place. The most effective method seems to be manually pulling and bagging garlic mustard. He

emphasized the importance of completely removing the root to prevent regrowth and ceasing pulling once the mature adults begin to seed to prevent further seed dispersal. The pulled plants are bagged, removed and burned. Pulled plants left in the understory have been observed to continue producing seed pods and disperse seeds. He noted that multiple treatments over the same area are sometimes necessary.

Fontenelle Forest and Neale Woods cover nearly 2000 acres. In 2011 alone, employees and volunteers put in nearly 600 man hours between April 20th and June 16th. Limited resources have forced Garabrandt to focus on the 200 acres surrounding the Fontenelle Forest Nature Center and let the rest of the grounds “go”. In the event a biological control agent is identified, he has set up two control plots. One is protected from herbivores and the second is not. The native species in the unprotected plot have experienced deer grazing resulting in decreased populations of native species and an increased population of garlic mustard. Top down regulation shows the increased pressure garlic mustard, who has no predators, puts on the native species to compete.

To inquire about current practices regarding garlic mustard in Lincoln, NE and Lancaster County, an interview was conducted on March 6, 2013 with Brent Meyer, the Lancaster County Weed Superintendent. He reported that garlic mustard is not considered “noxious” by Lancaster County or the state of Nebraska but is currently on Lancaster County’s “watch list”. Aside from the six sites documented in the Pharris 2011 study, the current extent of invasion is still unknown in Lincoln. It is unknown when the garlic mustard first appeared and how the species is spreading. The impacts on local flora and fauna are also unknown as the current infestations are relatively small compared to the

garlic mustard populations found at Fontenelle Forest. The infestations haven't impacted the aesthetics and human use of parks and trail as many pedestrians are unaware of its presence.

Recently, Lancaster County has implemented the Weed Watcher Program through which private citizens and organizations can educate themselves on weeds of concern, identify new populations, and report them to Lancaster County Weed Control for site mapping and removal. The goal of this program is to detect new populations early for eradication before the infestation becomes too severe. It is clear from the state of the known sites that garlic mustard has overtaken areas of the woodland understory.

Another interview was conducted on March 7, 2013 with Aaron Druery, the Pioneers Park Land Manager. Garlic mustard rosettes were first identified by an employee in the spring of 2011. The infestation is localized to a 100 foot by 60 foot area near the pond and raptor cages close to the Pioneers Park Nature Center. The population is in close proximity to an asphalt trail used by park goers and hiking tours. The invasion began in a centralized area that has since radiated outwards. The center of the population has become a dense monoculture. It appears to inhabit the same elevation along a lowland area but doesn't encroach upon the water front.

Efforts were made to remove some tree cover in hopes of inhibiting the plants' growth by exposing them to excessive sunlight. Herbicides (Roundup and Grazon) were applied and some plants were manually pulled and bagged. Because management techniques were done recently (in the last one to two years), effects on the population are not yet evident. Druery reported that no herbivores had eaten off the garlic mustard while

many native species in Pioneers Park are food for wildlife. He also stated that although garlic mustard had little to no detrimental effect on aesthetics and human use of the park, the invasion is used as an educational tool for 12,000 children that tour the park annually.

The last contact, Mitch Coffin of the Nebraska Department of Agriculture Noxious Weed Program, was made on March 8, 2013 through email exchange. He provided a list of Nebraska counties and their respective amount of reported garlic mustard in acres (Table 1). At the time of contact only 79 of the 93 counties had reported to Coffin for the 2012 State Weed Survey. 66 of the 79 counties reported zero acres to Coffin.

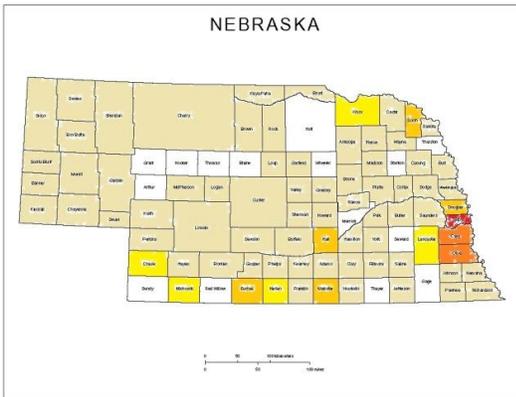
Table 1. 2012 State Weed Survey Counts for Garlic Mustard. Counties that reported a current garlic mustard population and their respective number of acres are shown. Counties that reported 0 acres have been excluded.

County	Estimated Population Area (in acres)
Cass	500
Chase	2
Dixon	15
Douglas	30
Furnas	15
Hall	14
Harlan	5
Hitchcock	10
Knox	10
Lancaster	1
Otoe	200
Sarpy	1020
Webster	40

This left 14 counties without data: Arthur, Blaine, Dundy, Gage, Grant, Holt, Hooker, Merrick, Red Willow, Seward, Thayer, Thomas, Thurston, and Wheeler. The reported count for garlic mustard totaled 1862 acres statewide.

The data from the State Weed Report was categorized by the severity of the infestation. A county map of Nebraska was used to visually show the distribution of garlic mustard (Figure 1).

Figure 1. 2012 State Weed Survey Map for Garlic Mustard. The distribution of garlic mustard populations according to the number of acres reported for the 2012 State Weed Survey is shown. (Original map before shading taken from <http://www.yellowmaps.com/map/nebraska-labeled-map-120.htm>)



Legend
 White: No report
 Beige: 0 acres
 Light Yellow: 1-10 acres
 Dark Yellow/Marigold: 11-101 acres
 Orange: 101-1000 acres
 Red: 1000+ acres

Many of the states reporting garlic mustard are situated in proximity to flowing water. The southern counties are along the Republican River and the eastern counties are along the Platte and Missouri Rivers. This indicates that not only may garlic mustard seeds be spread downstream by the flow of the current but also upstream if water craft are transported over land and put in upstream areas of the river.

DISCUSSION

From Garabrandt's 25 years of experience with garlic mustard, it seems that the most effective means of controlling the garlic mustard populations is to manually pull and bag the plants. This was also confirmed by Krista Lang, an employee of Indian Cave State Park, who I spoke with at the monthly Five Rivers Weed Management Area meeting on April 10th, 2013 after giving a presentation of my thesis. Lang first started at Indian Cave State Park, comprised of oak woodlands, in 2011 and was solely responsible for removing approximately 30 known patches of garlic mustard. As she began exploring areas along trails she observed that garlic mustard had spread to many new areas of the park. During the 2012 growing season she was helped by two technicians to continue garlic mustard removal but reported that they had barely made a dent in areas taken over by the invader.

This questions the accuracy and implications of the reports from the 2012 State Weed Survey. Indian Cave State Park is located in Nemaha County which reported zero acres of garlic mustard. This differs greatly from the testimony of Lang. It seems that the 1862 acres of garlic mustard reported statewide may be a gross underestimate of the actual population area of garlic mustard in Nebraska. Much of Nebraska is rural and landowners may not report a new plant species unless they know it poses a clear, foreseeable threat to their land. In many cases, the landowners may not be aware of the presence of garlic mustard; or if they are, they may not know its spreading capabilities.

The potential errors in reports for the State Weed Survey also make it difficult to accurately monitor the increases or decreases in garlic mustard populations to gage the rate at which it spreads. While acreage is a good measurement of population area, it isn't a

good measurement of the extent of populations with respect to each county. Counties vary in size and larger counties that reported a great number of acres of garlic mustard may actually have a smaller percentage of garlic mustard land coverage. Likewise, smaller counties that reported fewer acres may actually have a higher percentage of garlic mustard land coverage.

Another factor regarding the spread of garlic mustard is the proximity to densely populated metropolitan areas. The populations seen in Lincoln, NE and at Fontenelle Forest are located in areas of high human traffic (hikers, bikers, joggers) along trails and in parks. Not only is it likely that seeds become stuck to boots, clothing, and pets but it is also possible that garlic mustard is spread by commercial mowers and weed eaters that are used by county and park personnel. This may account for the proximity to public bike paths in Lincoln or long distance dispersal in parks.

During the interview with Druery, it was discovered that the employee who first identified the rosettes at Pioneers Park lives at the house that appears to be “ground zero” for the Standing Bear population. The employee’s backyard, overtaken by garlic mustard, is just feet from a foot/bike path. When questioned about garlic mustard, the employee stated he had had previous experience with garlic mustard in his backyard which is why he knew how to identify the rosettes. This suggests the employee may have unintentionally transported garlic mustard seeds to Pioneers Park after working in his yard.

CONCLUSION

Because there are no biological control agents and herbivores that have been observed feeding on garlic mustard in North America, prevention and early detection are the best ways to control younger garlic mustard populations with higher allelochemical concentrations from taking over a new range. Preventative measures should be taken to thoroughly wash clothing, boots, pets, vehicles and any machinery (i.e., mowers, ATVs, weed eaters) after exposure to an area invaded by garlic mustard. While herbicides can be effective at temperatures above 50 degrees Fahrenheit, the most effective method of control appears to be manually pulling and bagging the plants, taking care to completely remove the entire root to prevent regrowth. Mature adults should not be pulled after the plant begins to seed to prevent further dispersal. Treatment should be done multiple times during the growing season to ensure all plants that begin to emerge are removed. In older populations with decreased allelochemical concentrations, measures should still be taken to decrease garlic mustard populations but efforts would be most valuable in attempting to rehabilitate the native populations by rebuilding the native seed bank.

Lancaster County should continue to promote the Weed Watchers Program and encourage citizens to become educated, not only about garlic mustard but all weeds on the noxious weed list and watch list. Early detection gives the best chance for eradication. The county should continue to monitor known garlic mustard sites annually until the seed bank is depleted to prevent reinvasion. The known garlic mustard sites in Lincoln are currently small in comparison to the size of the populations at Fontenelle Forest and may still be able

to be eradicated if the county concentrates on the infestations and follows through with multiple treatments over several years.

On a larger scale, the Nebraska Department of Agriculture should increase garlic mustard awareness and push counties to report more accurate estimates of garlic mustard population areas. By doing so, if garlic mustard has indeed invaded more land than previously thought, the state should conduct a scientific Weed Risk Assessment (WRA) to determine if garlic mustard should be considered “noxious”. As mandated, county weed personnel are required to make noxious weeds the first priority. As seen in Fontenelle Forest, established garlic mustard is extremely difficult to eradicate. Being proactive is the best approach for garlic mustard because it is such a prolific spreader.

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