The University of Maryland
CONS670: Conservation Biology
Fall, 2014

**Invasive Species Survey, Frederick City Watershed**

Kiel Edson, Maira Bezerra, Robin Graber, Tiffany Kim,
Kristin Taddei, Anika Cartas, Jessie O'Connor

Under the supervision of Dr. Keryn Gedan

PALS--Partnership for Action Learning in Sustainability
A National Center for Smart Growth initiative at the University of Maryland

Gerrit Knaap, Executive Director
Uri Avin, PDC Director

## Contents

## Executive Summary

Invasive plant species are present within Frederick City Watershed and are a concern for ecosystem health. Research has shown that roads and trails often act as vectors for invasive species. Within Frederick City Watershed, there is a 9.5-mile sanctioned (legal) trail and over 100 miles of unsanctioned (illegal) trails. We addressed three questions to better understand the impact of roads and trails on invasive species prevalence within Frederick City Watershed. First, does invasive species prevalence differ near sanctioned versus unsanctioned trails? Second, does invasive species prevalence decrease with increasing distance from trails? Last, does invasive species prevalence increase closer to roads? To address these questions, we performed a survey of invasive species along transects running perpendicular to both sanctioned and unsanctioned trails. For each transect, we estimated a percent cover of invasive species within one-meter square plots at zero, five, 10, 15 and 20 meters on either side of the trail. In addition, we used GIS to determine transect distance from the nearest road. Our results show that invasive species cover increases with decreasing distance from both trails and roads. Our survey results also show that invasive species cover was greater near unsanctioned trails. However, due to the low sample size, it is unclear whether trail type or distance from the nearest road is responsible for this trend. Based on these results, we recommend closing trails farthest from roads to prevent the establishment of invasives in more remote areas of the Watershed, while focusing removal efforts along roads and trails closest to roads.

## Research Topic and Overarching Issue

Invasive species are widely recognized as one of the most significant threats to ecosystem stability and environmental health (Mooney and Hobbs 2000). Nearly 20 years ago, the Bureau of Land Management estimated that invasive plants infest 100 million acres and every year an additional three million acres are affected (BLM 1996). Globalization, rapid human population growth and increased development have facilitated the introduction, establishment and spread of invasive species around the planet (Hulme 2009). Approximately 5,000 non-native plants now exist in the United States' ecosystems and the collective cost of all invasive species has been estimated as $137 billion annually (Pimentel 2000). Invasive plants specifically are problematic because they displace native species, degrade ecosystem processes and productivity, hamper biodiversity and reduce wildlife habitat (Davies 2007, BLM 2010). There are two primary anthropogenic influences facilitating these invasions: the intentional and unintentional introduction of foreign species into novel environments, and the degradation of ecosystems, making them more susceptible to non-native species invasion (Davis 2009). Although human-induced invasions have occurred for centuries, it has only been in the past half-century that we have recognized the social, economic and ecological consequences of these introductions. As a result, invasive management has become an increasingly common practice (Davis 2009).

The term invasiveness refers to a species' ability to succeed as an invader (Colautti et al. 2006). Although ecologists disagree about the relative importance of each factor that influences invasions, they agree that three characteristics are important in predicting and managing invasions: (1) invasiveness, (2) invasibility and (3) propagule pressure (Colautti et al. 2006; Erfmeier & Bruelheide 2010; Shea & Chesson 2002; van Kleunen et al. 2010). Examples of characteristics that often increase invasiveness include rapid reproduction and development, asexual reproduction, resource consumption efficiency and the ability to withstand a wide range of physiological conditions. Invasibility refers to an ecosystem's susceptibility to invasion (Colautti et al. 2006). Ecosystems impacted by human disturbance or are otherwise degraded are much more susceptible to the establishment and proliferation of non-native species (Oswalt and Oswalt 2007, Hoffman et al. 2008). Unsurprisingly, the interactions between characteristics of the introduced species, such as growth rate and method of dispersal, combined with characteristics of the receiving ecosystem, such as resource availability or a lack of natural enemies, have been demonstrated as important in determining invasion success (Erfmeier & Bruelheide 2010). When considering the potential for invasion, propagule pressure, which is the number of individuals introduced or the number of introduction events, might arguably be the most important factor to consider (Colautti et al. 2006).

Anthropogenic activities have dramatically influenced biological invasions by either altering the receiving ecosystem (thus increasing invasibility) or by increasing propagule pressure. Non-native species can disperse easily along roads and trails. Trombulak and Frissell (2000) described three main ways in which roads can assist in dispersal and establishment of invasive species. First, roads cause habitat alteration and fragmentation, which can facilitate invaders. For example, Greenberg et al. (1997) found that soil modification due to roads can facilitate plant invasions. Second, roads can stress or remove native species and subsequently make the area more susceptible to invaders. These refer to changes in the environment that increase the ecosystem's invasibility. The third means of facilitation is the ease of movement—and introduction—of invasives by both wildlife and humans, thus increasing propagule pressure in the area (Trambulak and Frissel 2000). Other studies' findings support these three hypotheses by demonstrating that roads provide habitat for invasive plant species and act as conduit for introducing invasive species, facilitating their spread and establishment (Buckley et al. 2003).

## Local Context for Research Activities

Frederick Municipal Forest is a large, 7,006-acre forest tract, which encompasses 26 miles of perennial streams. It also includes a significant portion of Frederick City Watershed that ultimately drains into Fishing Creek reservoir. In 2005, the City released the Forest Stewardship Plan, which highlighted its primary management objective to maintain the area as a source of clean and reliable water, now and into the future. Secondary goals include protecting Frederick City Watershed's ecosystem from deleterious impacts such as fire, insects, pests and disease; protecting wildlife habitat and water quality for fish species; and providing recreational opportunities for the public (Pannill 2005). The perennial streams that wind through the landscape are important habitat for eastern brook trout, Maryland's only native trout species. The forest is also a popular recreational destination for hikers, mountain bikers and hunters. Forest managers and The City of Frederick aim to balance between protecting the forest's ecology and the City's water supply, while allowing open access for recreational use.

Invasive plant species can have severe consequences for forest health, and trails—like those throughout Frederick City Watershed—are known to not only serve as dispersal corridors for these non-native organisms, but also as an ideal habitat for their establishment and proliferation (Mortensen 2009). The introduction of invasive plant species was identified by the City as "one of the most serious threats to the [Frederick Municipal] forest." This is because invasives compete with native vegetation for scarce resources and can alter nutrient cycling, soil chemistry and interspecies symbioses (Pannill 2005). The Plan also notes that one particularly problematic species, Japanese stiltgrass (*Microstegium vimineum*), has spread throughout the forest via hikers and mountain bikers on trails, and by vehicles on roadways. Other invasive species of note within Frederick City Watershed are Mile-a-Minute (*Polygonum perfoliatum*), Multiflora Rose (*Rosa multiflora*), Japanese Barberry (*Berberis thunbergii*) and Tree-of-Heaven (*Ailanthus altissima*) (Pannill 2005).

Frederick City Watershed has a 9.5-mile sanctioned (legal) trail network and over 100 miles of unsanctioned (illegal) trails (Pannill 2005). The sanctioned trail is approved and maintained by the Maryland Department of Natural Resources (DNR) and the Plan's recommendations include limiting recreational use to this trail along with the eradication of non-native, invasive plants along roadsides and permanent openings (Pannill, 2005). The abundance of unsanctioned, or 'rogue' trails, is a concern for the City and local foresters because they are unmaintained, largely unmonitored and could be drawing non-native species into areas from which they might otherwise be excluded. Our initial qualitative assessment was that these invasive species appeared more prominent along the sides of trails (both sanctioned and unsanctioned) and roads, and were more sparse or nonexistent in the interior forest. Combined with a growing body of literature demonstrating that roads and recreational trails facilitate the spread of invasive species in wilderness areas (see *Research Topic and Overarching Issue*), we hypothesized that the roads and trails within Frederick City Watershed are promoting the spread of invasive plants. This infers that we would observe higher percent cover of these species close to trail edges. The goals of this study are to determine whether there are correlations between percent cover of invasives, trail type (sanctioned or unsanctioned) and/or distance from trails; and to provide the City with management recommendations regarding trail maintenance and recreational use.

**Research Methods**

We organized our field survey of invasive plants into a set of 18 transect clusters, or locations within Frederick City Watershed. Each cluster was located at or near an intersection between a sanctioned and unsanctioned trail. These transect clusters were visually selected using the Frederick City Watershed Mountain Bike Trail Assessment map of trails (Figure 2). We then selected ten of these transect clusters using a random number generator. We focused the field studies undertaken on October 12 and October 25, 2014 on these ten transect clusters, but could ultimately only gather data for nine transect clusters.

*Data Collection*

At each transect cluster, we walked 100 meters down the unsanctioned or sanctioned trail, recorded the GPS coordinates at that site, then established perpendicular transects 20 meters wide on either side of the trail (Figure 1). Using a one square-meter PVC pipe quadrat, surveying plots were placed every five meters along each transect on either side of the trail. The first site was on the edge of the trail (at 0 meters), while the remaining sites were five meters, ten meters, 15 meters and 20 meters from the trail. We recorded the percent cover of invasive species within these plots (Figures 4 and 5). Our team used a plant guide provided by DNR to identify invasive species present in these plots (all species in Appendix A). Once data was collected at the first trail type (sanctioned or unsanctioned), we returned to the transect cluster (intersection) and repeated with the other trail type.

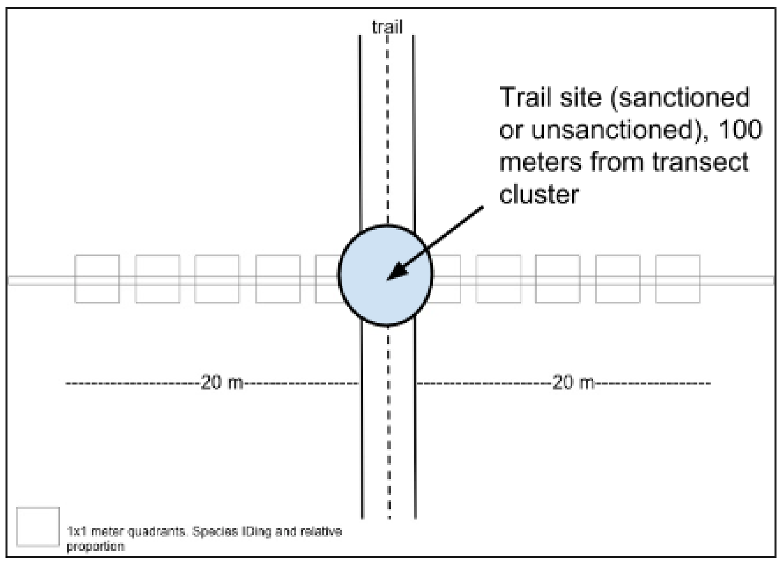


**Figure 1.** Transect design (not to scale).

Within the one square-meter quadrat, we recorded the percent cover of invasive plants by species. Once an invasive species was identified, our team visually estimated the percent cover for the species within the quadrat. We also obtained the coordinates for each transect site location using a GPS (Figure 6).

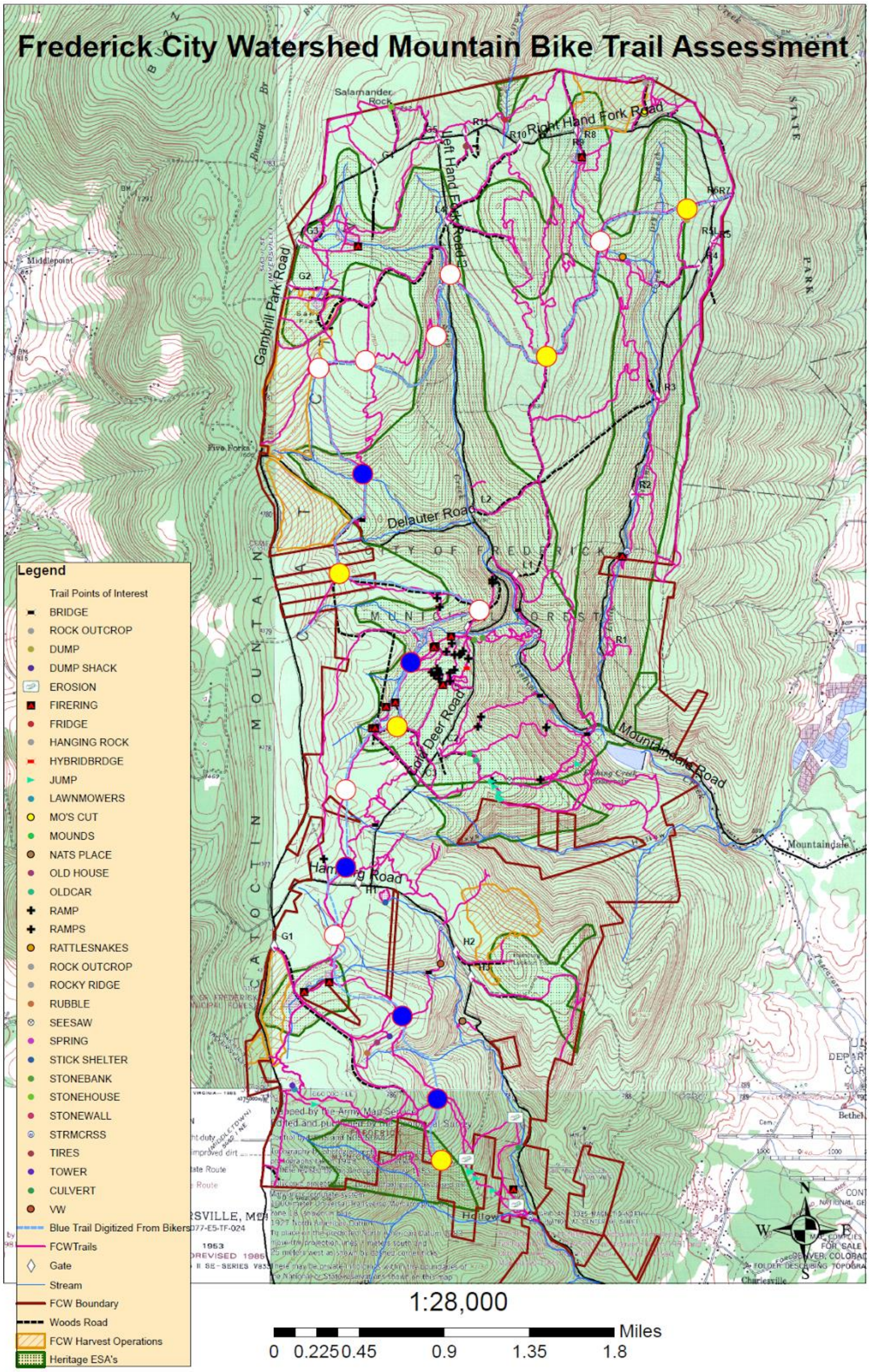
Frederick City Watershed Mountain Bike Trail Assessment
Legend
Trail Points of Interest
BRIDGE
ROCK OUTCROP
DUMP
DUMP SHACK
EROSION
FIRERING
FRIDGE
HANGING ROCK
HYBRIDBRDGE
JUMP
LAWNMOWERS
MO'S CUT
MOUNDS
NATS PLACE
OLD HOUSE
OLDCAR
RAMP
RAMPS
RATTLESNAKES
ROCK OUTCROP
ROCKY RIDGE
RUBBLE
SEESAW
SPRING
STICK SHELTER
STONEBANK
STONEHOUSE
STONEWALL
STRMCRSS
TIRES
TOWER
CULVERT
VW
Blue Trail Digitized From Bikers
FCWTrails
Gate
Stream
FCW Boundary
Woods Road
FCW Harvest Operations
Heritage ESA's
Right Hand Fork Road
Left Hand Fork Road
Gambrill Park Road
Delauter Road
Mountaindale Road
Hamburg Road
Salamander Rock
Five Forks
Middlepoint
Mountaindale
1:28,000
0 0.225 0.45 0.9 1.35 1.8
Miles

**Figure 2.** Each point represents a selected set of transect clusters (intersection of sanctioned and unsanctioned trails) in Frederick City Watershed. The ten survey sites in yellow (primary) and blue (secondary) were randomly selected as focus sites. [map source: Maryland DNR]

**Figure 3.** 20-meter transect extending into forest from trail edge.

**Figure 4.** Recording the percent cover of invasive species in one square meter quadrats, spaced at five-meter intervals from trail edges.

**Figure 5.** Recording the percent cover of invasive species in one square meter quadrats, spaced at five-meter intervals from trail edges.

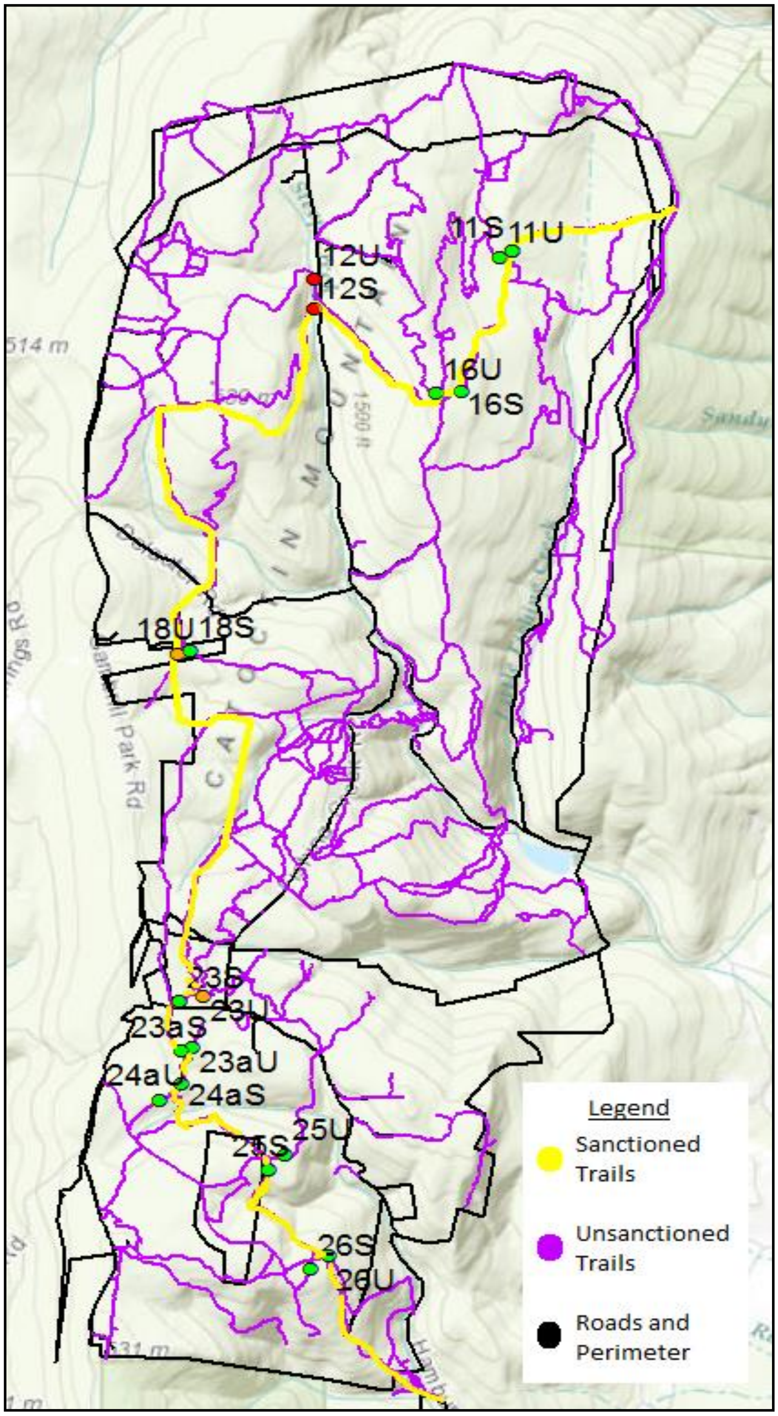


**Figure 6.** Map of northern Frederick City Watershed with plotted GPS coordinates for each unsanctioned and sanctioned transect location from the October 12 and October 25, 2014 field surveys. Green points indicate that no invasive species were observed along these transects, while orange points indicate that some invasive species were observed along these transects. Transects denoted by red points were where the most invasive species were observed.

*Data Analysis*

To ascertain whether percent cover of invasives is higher closer to the trail edge and whether trail type influences the spread of invasive plants, we graphed mean percent cover of invasive species at each distance from the trail for both unsanctioned and sanctioned trails. A statistical analysis was not performed due to the low number of observations of invasive species.

As discussed in *Research Topic and Overarching Issue*, roads have been shown to act as vectors for invasive plant species. Therefore, we decided to determine the distance between the focal points of our survey to the nearest paved road, to investigate whether the location with respect to paved roads could be an important factor in determining the presence of invasive species. We used the *near* function in ArcGIS 10 to calculate the distance in meters from each transect site to the nearest road. With the near function, we were able to calculate the distance from each focal point to the nearest paved roads. Again, no statistical analysis was performed due to a small sample size.

**Results**

Mean percent cover of invasive species was greater for all plots in unsanctioned trails than for all plots in sanctioned trails (Figure 7). On unsanctioned trails, the mean percent cover of invasives was highest in the plot closest to the trail (at 0 meters) and decreased but remained relatively constant in the 5, 10, 15 and 20 meters plots. On sanctioned trails, the mean percent cover of invasives was also highest in the plot at 0 meters but decreased continually with increased distance from the trail.

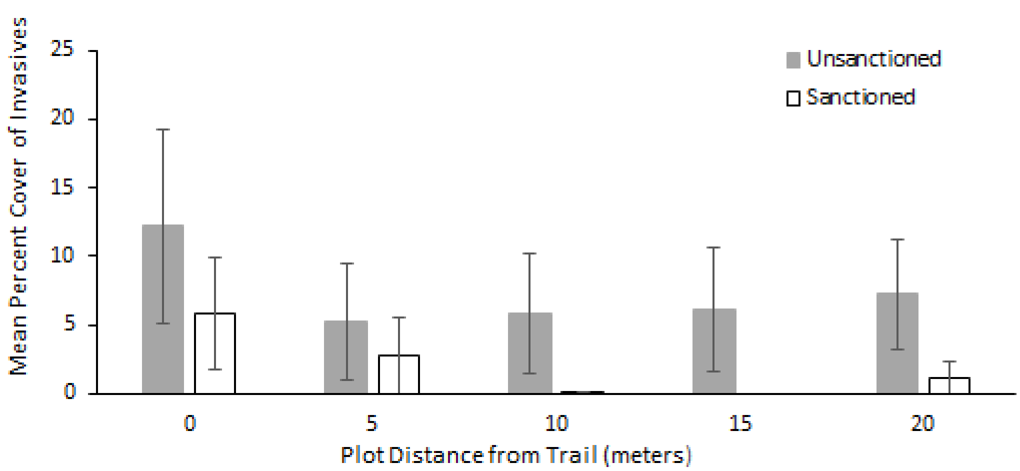


**Figure 7:** Mean percent cover of invasive species for each plot as a function of distance from sanctioned or unsanctioned trail edges (n =18 for each mean). Bars depict standard error (SE).

We found four invasive species in transects from unsanctioned trails and two invasive species in transects from sanctioned trails (Appendix A). Invasives found in unsanctioned trail transects were Japanese stiltgrass (*Microstegium vimineum* [Figure 8]), Japanese barberry (*Berberis thunbergii*), bush honeysuckle (*Lonicera maackii*) and multiflora rose (*Rosa multiflora*), while only Japanese stiltgrass (*Microstegium vimineum*) and Japanese barberry (*Berberis thunbergii*) were found in sanctioned trail transects.

**Figure 8.** Invasive species Japanese Stiltgrass (*Microstegium vimineum*) (bottom left corner) observed along a trail edge in the Frederick City Watershed.

Based on our GIS analysis, transects containing invasive species were closest to a road on both sanctioned and unsanctioned trails (Figure 9). Transects on sanctioned trails ranged from approximately 35 to 857 meters from the nearest road, and invasives were only found in the transect 35 meters from a road. It is worth noting that, of the nine sanctioned trail transects, only one was found to be impacted by invasives – a positive sign for the forest's health overall. Transects on unsanctioned trails ranged from approximately 41 to 726 meters from the nearest road and invasives were found in the three transects closest to roads at 41, 84 and 99 meters from a road. For unsanctioned transects, the mean percent cover of invasives decreased with increasing distance from roads; at 41 meters from a road, mean invasive cover was 57.5 percent, at 84 meters from a road, mean invasive cover was 5 percent and at 99 meters from a road, mean invasive cover was 3.5 percent.

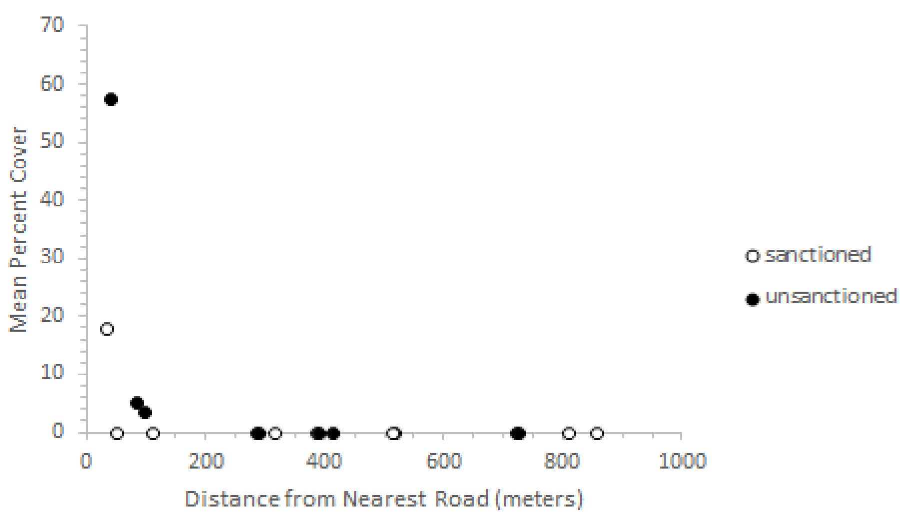


**Figure 9:** Each point represents mean percent cover of invasive species at each site as a function of distance from the nearest road.

## Final Considerations

Though it is encouraging that only four of the eighteen sites surveyed showed any presence of invasive species, this study had some limitations. With the increasingly cold fall weather, many plants had begun to die by our second field visit on October 25, 2014. Most of the area we surveyed was covered with leaf litter, so it is possible that the percent cover assessments are underestimates and that our team did not encounter certain species due to the late survey start date. However, this suggests that the observations of occurrences and estimates of cover are conservative, meaning that the prevalence of non-native plants throughout the trail network may be higher than our data suggest. To reach more robust conclusions regarding the relative importance of sanctioned and unsanctioned trails in the spread of invasives into the forest, more surveying should be conducted earlier in the year.

Another challenge was the time constraint of this project. The window for data collection was limited, due to the short semester and the seasonal changes; as a result, our survey was limited and our data preliminary. In addition, because of our constrained site visit opportunities, the survey locations were all within reasonable walking distance from a trailhead, so locations in the deepest areas of the forest were not surveyed.

Finally, identifying some of the plant species can be difficult (especially given the season); some seedlings of different species look similar and do not have the distinguishing characteristics of mature plants. However, DNR provided an invasive plant guide before the survey began, along with a site visit to familiarize ourselves with the species we would be encountering regularly. In addition, some of our group members have botanical survey experience (including in Maryland), which was helpful in plant identification.

## Management Recommendations

Our results suggest roads are the most important factor in the spread of invasive plant species in the Frederick City Watershed. All sites within 100 meters of a major road with the exception of one had invasive species present, and the mean cover of invasives generally decreased with increasing distance from the nearest road. Although we found invasive species on three unsanctioned trail sites and only one sanctioned trail site, we are reluctant to draw any conclusions about differences between trail types because of the small sample sizes and because, in our survey, there were more unsanctioned trail sites within 100 meters of a road. Our data also indicate that where invasive species have been established along trails edges, they have spread fairly far into the forest (at least 20 meters), though at low densities. We recommend closure of trails farthest from roads to prevent establishment by invasive species in more remote areas, and focusing management efforts on removing invasives along roads, and along trails closest to roads. The most abundant invasive species by far was the Japanese stiltgrass; we include several eradication methods for this and other local invasive species in Appendix A.

Although we could not conduct a statistical analysis, open, disturbed areas also seem to be a crucial determinant in the presence of invasive species. For example, during our second survey on October 25, 2014, the only site in which we observed invasive species was a clearing with evident disturbance (trash was present) adjacent to what appeared to be a younger forest (the canopy was less dense, and young trees were growing closer together compared to other sites; Figure 10). If this is the case, we recommend communicating with landowners whose properties are adjacent to the forest with actions they can take to mitigate the spread of invasive species.

**Figure 10.** A clearing adjacent to younger forest. Japanese stiltgrass is apparent in the center of the clearing.

## References

Bella, E. M. (2011). Invasion Prediction on Alaska Trails: Distribution, Habitat, and Trail Use. *Invasive Plant Science and Management, 4*(3), 296–305. doi:10.1614/IPSM-D-10-00083.1

Buckley, D. S., Crow, T. R., Nauertz, E. A., & Schulz, K. E. (2003). Influence of skid trails and haul roads on understory plant richness and composition in managed forest landscapes in Upper Michigan, USA. *Forest Ecology and Management*, *175*, 509–520.

Bureau of Land Management (1996). Partners against Weeds - An Action Plan for the Bureau of Land Management. Retrieved from https://archive.org/stream/partnersagainstw27unit#page/n0/mode/2up

Bureau of Land Management (2010). Why are Invasive Species a Problem? Retrieved from http://www.blm.gov/wo/st/en/prog/more/weeds/problems.html

Colautti, R. I., Grigorovich, I. a., & MacIsaac, H. J. (2006). Propagule Pressure: A Null Model for Biological Invasions. *Biological Invasions, 8*(5), 1023–1037. doi:10.1007/s10530-005-3735-y

Davies, K.W. & Sheley, R.L. (2007). A Conceptual Framework for Preventing the Spatial Dispersal of Invasive Plants. *Weed Science, 55(2),* 178-184.

Davis, Mark A. (2009). *Invasion Biology*. Oxford University Press, Oxford England.

Dickens, S. J. M., Gerhardt, F., & Collinge, S. K. (2005). Recreational Portage Trails as Corridors Facilitating Non-Native Plant Invasions of the Boundary Waters Canoe Area Wilderness (U.S.A.). *Conservation Biology*, *19*(5), 1653–1657. doi:10.1111/j.1523-1739.2005.00232.x

Erfmeier, A., & Bruelheide, H. (2010). Invasibility or invasiveness? Effects of habitat, genotype, and their interactions on invasive Rhododendron ponticum populations. *Biological Invasions*, *12*, 657–676.

Harrison, S., Hohn, C., & Ratay, S. (2002). Distribution of exotic plants along roads in a peninsular nature reserve. *Biological Invasions*, *4*, 425–430.

Greenberg, C. H., Crownover, S. H., & Gordon, D. R. (1997). Roadside soil: a corridor for invasion of xeric scrub by nonindigenous plants. *Natural Areas Journal*, 17, 99-109.

Hoffman, J.D., Narumalani, S., Mishra, D.R., Merani, P. & Wilson, R.G. (2008). Predicting Potential Occurances and Spread of Invasive Plant Species along the North Platte River, Nebraska. *Invasive Plant Science and Management, 1*(4), 359-367.

Hulme, P. E. (2009). Trade, transport and trouble: managing invasive species pathways in an era of globalization. *Journal of Applied Ecology*, *46*(1), 10–18. doi:10.1111/j.1365-2664.2008.01600.x

Jodoin, Y., Lavoie, C., Villeneuve, P., Theriault, M., Beaulieu, J., & Belzile, F. (2008). Highways as corridors and habitats for the invasive common reed Phragmites australis in Quebec, Canada. *Journal of Applied Ecology*, *45*(2), 459–466. doi:10.1111/j.1365-2664.2007.01362.x

Mooney, H.A. & Hobbs, R.J. (2000). Invasive Species in a Changing World. Island Press, Washington, D.C., pp 457.

Mortensen, D.A., Rauschert, E.S.J., Nord, A.N., & Jones, B.P. (2009). Forest Roads Facilitate the Spread of Invasive Plants. *Invasive Plant Science and Management*, *2*(3), 191–199. doi:10.1614/IPSM-08-125.1

Nemec, K. T., Allen, C. R., Alai, A., Clements, G., Kessler, A. C., Kinsell, T., Stephen, B. J. (2011). Woody Invasions of Urban Trails and the Changing Face of Urban Forests in the Great Plains, USA. *The American Midland Naturalist*, *165*(2), 241–256. doi:10.1674/0003-0031-165.2.241

Oswalt, C.M. & Oswalt S.N. (2007). Winter leaf disturbance facilitates the spread of the nonnative invasive grass *Microstegium vimineum* (Trin.) A. Camus. *Forest Ecology and Management, 249,* 199-203.

Pannill, P., & Eriksson, P. (2005). Forest stewardship plan for Frederick City watershed.

Pimentel, D., Lach, L., Zuniga, R. & Morrison, D. (2000). Environmental and Economic Costs of Nonidigenous Species in the United States. *BioScience, 50(1),* 53-65.

Shea, K., & Chesson, P. (2002). Community ecology theory as a framework for biological invasions. *Trends in Ecology & Evolution*, *17*(4), 170–176.

Trombulak, S. C., & Frissell, C. a. (2000). Review of Ecological Effects of Roads on Terrestrial and Aquatic Communities. *Conservation Biology*, *14*(1), 18–30. doi:10.1046/j.1523-1739.2000.99084.x

Van Kleunen, M., Weber, E., & Fischer, M. (2010). A meta-analysis of trait differences between invasive and non-invasive plant species. *Ecology Letters*, *13*(2), 235–45. doi:10.1111/j.1461-0248.2009.01418.x

**Appendix A.**
*Invasive Species Control Methods*

<u>Japanese Stiltgrass</u> (*Microstegium vimineum*)

- Spring
  - **Chemical:** Use a corn-based, pre-emergence herbicide (Thompson 1999).
- Summer
  - **Mechanical:**
    - Mowing is most effective after June or in early fall, regardless of the window between flowering and seed set. Best for areas with high risk of reinvasion (e.g. roadsides). Repeated mowing in the same year unnecessary (Shelton 2012).
    - Pull before seed set; waiting until late summer allows for the growth of late emergent. Best for small infestations (Wallace 2012).
  - **Chemical:**
    - Season-long use of fenoxaprop-P over 3 years in NC has resulted in increased reestablishment of native plants and no increase in exotic plant cover (Judge 2008).
    - Acetic acid has been as effective as glyphosate after two years and resulted in higher native cover in CT. Optimal application is unknown (Ward 2012 2012).
    - Other options include glyphosate, imazapic, and sethoxydim (Wallace 2012).
- Fall
  - **Mechanical:** Fire is most effective just before seeds set in (Flory 2009). Use prescribed burns or direct flame via propane torch.
- **Other considerations:**
  - Yearly maintenance necessary until seed bank is exhausted (at least three years).
  - Seeding with native annual rye after the stiltgrass has been suppressed is recommended (Thompson 1999).

<u>Japanese Barberry</u> (*Berberis thunbergii*)

- Year-long
  - **Biological:** Tephritid flies (*Rhagoletis spp.)* have been effective in Europe, which can reduce seed production, but has not been studied in the U.S. yet (Silander 1999).
- Spring
  - **Mechanical:**

        - In early spring, pull out, cut, or dig out larger individuals, making sure to remove root systems as well. Use a spading fork or root wrench to help with root removal. Best if used on smaller populations due to being labor intensive (Ward 2009).
        - In early spring, controlled burns can be effective. Use more direct flames with a propane torch (Ward 2009).
        - After cutting, pulling, or burning in early spring, use drum chopper or bulldozer to flatten leftovers (Ward 2009).
        - Once in bloom, trim off all flowers. Bag and dispose of them either by burning, or in a landfill. Careful not to further spread seeds (Thompson 1999).
    - **Chemical:** Use glyphosate in early spring before most other plants are out. Apply after cutting or pulling for increased effectiveness. Can be used via spot or broadcast application (Silander 1999, Ward 2009).
- **Other considerations:** (Silander 1999)
    - Focus efforts on small, newly expanding populations for best control
    - Try to limit new recruitment
    - After removal, native species are slow to recover

<u>Multiflora Rose</u> (*Rosa Multiflora*)

- Year-long
    - **Biological:** A fungal pathogen rose rosette disease (RRD) attacks *Rosa spp.* There are five rose species native to MD, but the majority of these are resistant to this pathogen. The pathogen is endemic to North America and is transmitted best through grafting. Eriophyid mites serve as vectors. When used, only found spread to be about 100 meters and did not find symptomatic roses more than 150 meters from initial site (Epstein 1999, Hindal 1988).
- Spring
    - **Mechanical:**
        - Pull seedlings or dig up larger individuals, being sure to remove roots to at least six inches in depth (Thompson 1999).
        - Controlled burning can be used, but may need to be repeated over several years. It should be followed by glyphosate application in the fall (Thompson 1999).
    - **Chemical:** Apply glyphosate to cut stems or foliage when the plant is flowering. Metsulfuron is another herbicide that can be effective in control, but is more successful in the spring than fall (Thompson 1999, Derr 1989).
- Winter

- **Chemical:** Glyphosate should be applied to leaves in late fall or early winter while other plants are dormant. This should be done before the first frost of the season, while the ground is still unfrozen (Thompson 1999).

<u>Tree of Heaven (TOH)</u> (*Ailanthus altissima*)

- Year-long
  - **Biological:** A strain of fungus *Verticillium alboatrum* causes near 100 percent mortality of TOH after 5-6 years with no effect on other plant cover (Harris 2013).
  - **Mechanical:** Must remove all roots and fragments when digging up seedlings in moist soil.
- Spring
  - **Chemical:** Basal bark application of a mixture of 20 percent oil-soluble triclopyr product/80 percent oil is most effective in early spring (mid-Feb. to mid-April) for trees less than six inches diameter (Swearingen 2009).
- Summer
  - **Mechanical:** Cut stump and apply an herbicide to the stump immediately (Glyphosate has poor results) (Thompson 1999).
  - **Chemical:** The hack-and-squirt method is most effective in mid-late summer (Imlay). Cut trunk with an ax, then squirt a water-soluble triclopyr product into cut and repeat. (See source for more details.) Follow-up with herbicide following year (Swearingen 2009).

<u>Bush Honeysuckle</u> (*Lonicera maackii*)

- Year-long
  - **Mechanical:** Mow or cut back three times a season (Thompson 1999).
- Spring
  - **Mechanical:**
    - Cut immediately after first leaves appear; this time period is when the plants' energy reserves are lowest (Cipollini 2008).
    - Pull seedlings and dig out larger plants, making sure to remove root systems (Thompson 1999). Moist soil and plants less than three years old are the best conditions for pulling out entire plants, as these allow for the easiest root removal (Hartman 2004).
    - Controlled burns during growing season can be effective if repeated over several years. Follow burns with fall application of glyphosate (Mcmurray 2001, Thompson 1999).
  - **Chemical:** Apply glyphosate within fifteen minutes of cutting or spray late in growing season (late spring) (Cipollini 2008, Thompson 1999). Glyphosate can also be injected into the plants stems themselves. This mechanism of application is

    less labor intensive than cutting and pasting of the herbicide, but it is difficult when the plant stems have extremely small diameters (Hartman 2004).

- **Other considerations:**
    - Removal of these plants often precedes an invasion of garlic mustard (Gorchov 2005).
    - Focus efforts on edges of invasion front (Gaston 2009).

<u>Mile-a-minute</u> (*Persicaria perfoliata*)

- Year-long
    - **Biological:** Weevil specie (*Rhinoncomimus latipes*) from China have been released in ten states, including Maryland and all of its surrounding states, as of 2010. This biocontrol program was first instituted in 1996 and has been closely monitored since. This species of weevil is host specific and has shown no significant effects on non-target plants, while decreasing the occurrence of mile-a-minute plants (Hough-Goldstein 2009, Hough-Goldstein 2012).
    - **Mechanical:** Mow and cut back three times a season (Thompson 1999).
- Spring
    - **Chemical:**
        - Sulfometuron methyl and atrazine can be used as pre-emergence herbicides. They must be applied before germination, which occurs in early spring. (Oliver 1996)
        - Apply glyphosate to foliage and flowers if in bloom. (Thompson 1999)
- Summer
    - **Mechanical:** Mow, cut, or pull out plants before their seeds set. Be careful not to leave seeds behind. Remove any leftovers or late emerging plants later in the season (Oliver 1996, Thompson 1999).
- **Other considerations:**
    - Planting native seeds and perennials as invasive mile-a-minute plants are removed will increase chances for re-establishment of native plant communities (Hough-Goldstein 2012).
    - Ideal habitats are dead and decaying plant matter, such as brush and tree piles. Limiting these areas will minimize ideal habitat (Oliver 1996).

<u>Japanese Honeysuckle</u> (*Lonicera japonica*)

- Year-long
    - **Mechanical:** Mow or cut back three times a season (Thompson 1999).
- Spring
    - **Mechanical:** Pull seedlings or dig out larger plants, making sure to remove root systems (Thompson 1999).

    - **Chemical:** Apply glyphosate, triclopyr, clopyralid, or metsulfuron herbicides early in the spring before non-target plants emerge. Apply directly after cutting or to foliage, especially when flowering (Williams 1998, Thompson 1999).
- Fall
    - **Chemical:** Apply glyphosate or dichloroprop in late fall/early winter. Best if done when most plants are already dormant, but before the first frost of the season. Effective at killing treated vines, but does not prevent all regrowth. These herbicides decrease target species, while causing minimal damage to most native trees (Regehr 1988).
- **Other considerations:**
    - Can survive most fires, so controlled burns are not a useful management tool (Schierenbeck 2004).
    - No known diseases or possible biocontrol (Schierenbeck 2004).

Oriental Bittersweet (*Celastrus orbiculatus*)
- Spring
    - **Mechanical:**
        - Pull seedlings and dig up larger individuals, making sure to remove root systems (Thompson 1999).
        - Remove and bag or dispose of all fruits as they appear. Recruitment from their seed bank is minimal, so if possible, remove seeds and kill established individuals before seeds ripen; recruitment should be significantly reduced (Ellsworth 2004).
    - **Chemical:** Use the cut and paint method of applying herbicide to this invasive. Use triclopyr instead of glyphosate. Follow up by clipping any regrowth or applying additional herbicide when necessary (Thompson 1999).

Autumn Olive (*Elaeagnus umbellata*)
- Unspecified
    - **Mechanical:**
        - Pull or dig up plants up to four-inch diameter, removing all roots (Thompson 1999).
        - Cut stump and apply 20 percent glyphosate (IPSAWG, VNPS).
    - **Chemical:** Basal bark application with 2 percent triclopyr mixed with oil. Multiple treatments may be required (IPSAWG).
- **Other considerations:** Do not mow or burn (IPSAWG, VNPS).

Princess Tree (*Paulownia tomentosa*)
- Spring

- **Mechanical:**
    - Pull seedling and small saplings, making sure to remove entire root systems. For larger individuals, cut down the tree (Kuppinger 2010, Thompson 1999).
    - Without having to cut the tree down, one can girdle it, which means to cut through the bark and the growing layer around the trunk. This can also be performed in the summer (Thompson 1999).
  - **Chemical:** Apply glyphosate to trunk or stump after cutting tree down, and spray on the foliage of any regrowth or small trees (Thompson 1999).
- **Other considerations:**
  - Princess Tree is a pioneer tree species, so invades best in disturbed areas. Should not be controlled through burns, as it is an early-successional species and can re-invade (Kuppinger 2010).
  - A time lag between establishment and treatment of the invasive may be more effective. Wait to treat until after post-successional competition has reduced invasive densities somewhat, but before the tree has reached reproductive age (Kuppinger 2010).

<u>Garlic Mustard</u> (*Alliaria petiolata*)

- Year-long
  - **Biological:** Weevil species of the genus *Ceutorhynchus*. A combination of *C. scrobicollis* and *C. alliariae*, which attack the rosettes and stems of the plant, seem to be most effective (Davis 2006).
- Spring
  - **Mechanical:**
    - Before they flower, pull seedlings and dig up larger plants. Remove roots and tamp down soil after removal (Thompson 1999).
    - After they flower, cut off flowers and seeds, but make sure not to scatter the seeds. Bag and burn or dispose of them (Thompson 1999).
- Fall
  - **Chemical:** Applying glyphosate treatments will reduce the adult cover and survival of adults, but not rosettes. Treatment needs to be continued yearly or else the population will recover. Treatment is more successful in years of high precipitation in June (Slaughter 2007).
- **Other considerations:**
  - Seed bank has the ability to re-establish the population (Pardini 2009).
  - Better to focus on control in concentrated areas and attempt to cause complete eradication, rather than more spread out control. Focus on complete mortality (Pardini 2009).

Mullein (*Verbascum Thapsus*)

- Spring
  - **Mechanical:** Pull or dig up plants. When removing plant, if seed capsules are not brown yet, there is a low chance of them becoming viable, so they do not need to be treated with care. However, if seed capsules have already turned brown, they should be handled and disposed of carefully, as they are likely to be viable (Wilbur 2012).
  - **Chemical:** Foliar applications of herbicides, such as glyphosate, should be applied in the early growing season. Need to be mixed with surfactants in order to stick to plant leaves (Brown 2005).
- **Other considerations:** Focus efforts on plant while it is still in the rosette stage. Control is much more challenging once plant has bolted (Brown 2005, Wilbur 2012).

Beefsteak Plant (*Perilla frutescens*)

- Spring
  - **Mechanical:** Pull seedlings and dig up larger individuals. Remove flowers, seeds and fruit, being careful not to unintentionally spread seeds. These should be burned or bagged and disposed of in a landfill (Thompson 1999).
  - **Chemical:** Apply glyphosate either via foliar application or by the cut and paint method. Follow up by clipping any regrowth or with additional herbicide if necessary (Thompson 1999).

Burning Bush (*Euonymus alatus*)

- Spring
  - **Mechanical:** Pull seedlings, dig up individuals, or cut down bush if necessary. Be sure to remove all root systems. Trim flowers as they appear. Bag and dispose of the flowers properly (Thompson 1999).
  - **Chemical:** Apply glyphosate to stump or stems after cutting or clipping (Thompson 1999).

**Native alternatives** (Thompson 1999)

- Shrubs (Japanese barberry, multiflora rose, bush honeysuckle, burning bush, garlic mustard, beefsteak plant)
    - Spicebush (*Lindera benzoin*), strawberry bush (*Euonymus americanus*), maple-leaf viburnum (*Viburnum acerifolium*), arrowwoods (V*iburnum dentatum, V. recognitum, V. nudum*), wild hydrangea (*Hydrangea arborescens*), highbush blueberry (*Vaccinium corymbosum*) and lowbush blueberry (*V. vacillans*)
- Vines (Mile-a-minute, Japanese honeysuckle)
    - American bittersweet (*Celastrus scandens*), trumpet honeysuckle (*Lonicera sempervirens*), native wisteria (*Wisteria frutescens*), trumpet vine (*Campsis radicans*), Virginia creeper (*Parthenocissus quinquefolia*) and native grapes (*Vitis spp.*)
- Shade trees (Tree of heaven)
    - White oak (*Quercus alba*), northern or southern red oak (*Q. rubra, Q. falcata*), mockernut hickory (*Carya tomentosa*) and black or sour gum (*Nyssa sylvatica*)
- Ornamental trees or hedges (Princess tree, autumn olive)
    - Serviceberry (*Amelanchier spp.*), fringetree (*Chionanthus virginicus*), black haw (*Viburnum prunifolium*) and red chokeberry (*Aronia arbutifolia*)
    - American hazelnut (*Corylus Americana*) and slippery elm (*Ulmus rubra*)
- Grasses (Japanese stiltgrass)
    - Indian grass (*Sorghastrum nutans*), big bluestem (*Andropogon gerardii*), purple top (*Triodia flava*), bluestem (*Schizachyrium scoparium*), bottlebrush (*Hystrix patula*) and wild oats (*Uniola latifolia*)

## Appendix A References


Brown Jasa, L. (2005). *Crop Watch*. No. 2005-22, September 30, 2005.

Cipollini D, Stevenson R, Enright S, Eyles A, Bonello P (2008). Phenolic metabolites in leaves of the invasive shrub, *Lonicera maackii*, and their potential phytotoxic and anti-herbivore effects. *Journal of chemical ecology*, 34, 144–52.

Davis, Adam S., et al. (2006). Demographic models inform selection of biocontrol agents for garlic mustard (Alliaria petiolata). *Ecological Applications*, 16(6), 2399-2410.

Derr, Jeffrey F. (1989). Multiflora rose (*Rosa multiflora*) control with metsulfuron. *Weed Technology*, 381-384.

Ellsworth, Joshua W., Robin A Harrington, James H Fownes. (2004). Seedling emergence, growth, and allocation of Oriental bittersweet: effects of seed input, seed bank, and forest floor litter. *Forest Ecology and Management*, 190(2-3), 255-264.

Epstein, A. H., and J. H. Hill. (1999). Status of rose rosette disease as a biological control for multiflora rose. *Plant disease*, 83(2), 92-101.

Flory, S. Luke, and Jason Lewis. (2009). Nonchemical Methods for Managing Japanese Stiltgrass (Microstegium Vimineum). *Invasive Plant Science and Management* 2.4, 301–308.

Gaston, KJ (2009). Geographic range limits: achieving synthesis. *Proceedings of the Royal Society B: Biological Sciences*, 276, 1395–406.

Gorchov, David L. (2005). Control of forest invasives and responses of native forest-floor plants: case studies of garlic mustard and Amur honeysuckle. *Ohio Invasive Plant Research Conference*.

“Invasive Alien Plant Species of Virginia: Autumn Olive (*Elaeagnus umbellata* Thunberg), Russina Olive (*Elaeagnus angustifolia* L.)” *Virginia Native Plant Society (VNPS)*. Web. 9 Dec. 2014.

“Invasive Plant Species Fact Sheet: Autumn Olive (*Elaeagnus umbellata*).” *Invasive Plant Species Assessment Working Group (IPSAWG)*. 2006. Web. 9 Dec. 2014.

Harris, P. T., Cannon, G. H., Smith, N. E., & Muth, N. Z. (2013). Assessment of plant community restoration following Tree-of-Heaven (*Ailanthus altissima*) control by Verticillium albo-atrum. *Biological Invasions*, *15*(9), 1887–1893.

Hartman, Kurt M., and Brian C. McCarthy. (2004). Restoration of a forest understory after the removal of an invasive shrub, Amur honeysuckle (*Lonicera maackii*). *Restoration Ecology*, 12(2), 154-165.

Hindal, Dale F., and Sek Man Wong. (1988). Potential biocontrol of multiflora rose, *Rosa multiflora*. *Weed Technology*, 122-131**.**

Hough-Goldstein, Judith, et al. (2009). Monitored releases of *Rhinoncomimus latipes* (Coleoptera: Curculionidae), a biological control agent of mile-a-minute weed (*Persicaria perfoliata*), 2004–2008. *Biological control,* 51(3), 450-457.

Hough-Goldstein, J., E. Lake, and R. Reardon. (2012). Status of an ongoing biological control program for the invasive vine, *Persicaria perfoliata* in eastern North America. *BioControl,* 57(2), 181-189.

Judge, C. A., Neal, J. C., & Shear, T. H. (2008). Japanese Stiltgrass (*Microstegium vimineum*) Management for Restoration of Native Plant Communities. *Invasive Plant Science and Management*, 1(2), 111–119.

Kuppinger, D. M., Jenkins, M. A., & White, P. S. (2010). Predicting the post-fire establishment and persistence of an invasive tree species across a complex landscape. *Biological Invasions, 12*(10), 3473-3484.

Mcmurry, ER, et al. (2001). Initial effects of prescribed burning and thinning on plant communities in the southeast Missouri Ozarks. *Proceedings of the 15th Central Hardwood Conference*, e-GTE-STS1.

Oliver, J. Douglas. (1996). Mile-a-minute weed (*Polygonum perfoliatum L.*), an invasive vine in natural and disturbed sites. *Castanea,* 244-251.

Pardini, Eleanor A., et al. (2009). Complex population dynamics and control of the invasive biennial *Alliaria petiolata* (garlic mustard). *Ecological Applications* 19(2), 387-397.

Regehr, David L., and David R. Frey. (1988). Selective control of Japanese honeysuckle (*Lonicera japonica*). *Weed Technology,* 139-143.

Schierenbeck, Kristina A. (2004). Japanese honeysuckle (*Lonicera japonica*) as an invasive species; history, ecology, and context. *Critical reviews in plant sciences,* 23(5), 391-400.

Shelton, A. L. (2012). Mowing Any Time after Midsummer Can Manage Japanese Stiltgrass. *Invasive Plant Science and Management,* 5(2), 209-216.

Silander, John A., and Debra M. Klepeis. (1999). The invasion ecology of Japanese barberry (*Berberis thunbergii*) in the New England landscape. *Biological Invasions,* 1(2-3), 189-201.

Slaughter, Bradford S., et al. (2007). Response of *Alliaria petiolata* (garlic mustard) to five years of fall herbicide application in a southern Ohio deciduous forest 1. *The Journal of the Torrey Botanical Society,* 134(1), 18-26.

Swearingen J, Pannill P (2009). Least wanted: *Ailanthus altissima*. Plant Conservation Alliance. http://www.nps.gov/ plants/alien/fact/aial1.htm. Accessed 1 Dec 2014
Thompson, L. (1999). Control of Invasive Non-Native Plants A Guide for Gardeners and Homeowners in the Mid-Atlantic Region. *Maryland Native Plant Society, Silver Spring, MD*.

Wallace, R.D. “Japanese Stiltgrass (*Microstegium vimineum* (Trin.) Camus).” *New York Invasive Species Information*. Cornell University Cooperative Extension, 2012. Web. 10 Dec. 2014.

Ward, J. S., & Mervosh, T. L. (2012). Nonchemical and Herbicide Treatments for Management of Japanese Stiltgrass (*Microstegium vimineum*). *Invasive Plant Science and Management*, *5*(1), 9–19.

Ward, Jeffrey S., Thomas E. Worthley, and Scott C. Williams. (2009). Controlling Japanese barberry (*Berberis thunbergii*) in southern New England, USA. *Forest ecology and management,* 257(2), 561-566.

Wilbur, H. D., & Hufbauer, R. A. (2012). Timing control efforts to limit seed set of common mullein (*Verbascum thapsus*). *Invasive Plant Science and Management*, *5*(3), 390-394.

Williams, Peter A., Susan M. Timmins, and Nigel Mountford. (1998). Control of Japanese honeysuckle (*Lonicera japonica*), climbing dock (*Rumex sagittatus*), and bone-seed (*Chrysanthemoides monilifera*). *Science for conservation (Wellington, NZ),* 100.632.580993: 20.