GIS Mapping and Co-occurrence Analysis of Invasive Understory Plants in the Lillian Anderson Arboretum

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Abstract

Invasive plants are one of the greatest threats to an ecosystem's biodiversity. Managing environments which are invaded by multiple species is difficult without an efficient management plan that aims to control multiple species at once. To address this, we surveyed the Lillian Anderson Arboretum and measured invasive prevalence by species over 975 sampling sites. We further analyzed these species' prevalence with various abiotic factors as well as conducted co-occurrence analysis to show how the presence of each species affects the likelihood of another also being present. Our work provides an efficient management plan that considers all of these variables to better direct management with the aim of fostering biodiversity within the arboretum.

Introduction

The positive effects of biodiversity within an ecosystem range from increased productivity to supplying key ingredients of life such as oxygen and clean water (Cresswell & Murphy, 2017). But what happens to an environment characterized by low biodiversity and thus not privy to the benefits described above? Some studies have shown examples of environments being initially non-reactive to species loss, however, this does not come without environmental costs (Hooper et al., 2005). For example, environments with low biodiversity are more susceptible to loss to disease because the disease is more likely to infect a susceptible host if that host organism makes up a disproportionate amount of the environment's biomass (Young et al., 2017). Also, low diversity ecosystems are more prone to invasions (Knops et al., 1999). For these reasons, ecologists and management personnel strive to maintain or increase the biodiversity of their studies. However, this objective is not easily achieved as invasive species seek to inhabit new areas and overwhelm and/or outcompete the native fauna and flora.

Invasive species are those which are non-native to their environment, but rather are classified as highly-competitive while causing both economic and environmental harm; whether they are native or non-native. Due to their competitive capabilities invasive plants are the primary risk contributor for 42% of species classified as threatened or endangered (U.S. Forest Service, n.d.). To combat these invaders and maintain native populations, the United States spends ~$120 billion annually addressing these concerns (Pimental et al., 2005). Invasive plants cause the reduction of native plant populations thus cutting the environment's biodiversity leaving it more vulnerable disease, as well as, potential for a decrease in productivity. Also, invasive species can have detrimental impacts on pollination by forcing pollinator species to forage further and thus be less efficient (Ghazoul, 2004).

Determining mechanisms of specific invasions is a key step towards improving management strategies, and thus is a key objective of invasive species research. Global trade generally and agricultural and horticultural trades are key mechanisms of invasion of non-native plant species. For example, European soil, used as ballast in cargo ships, was transported to North America where it was dumped and replaced with cargo. This soil contained seeds of European-native plant species such as white champion (*Silene* alba) and Australian fireweed (*Senecio minimus*) which colonized the eastern coast of the United States and spread throughout the country (Baker, 1986). Invasions through the agricultural trade occur when seeds of invasive species are unintentionally included in crop seed and planted mistakenly. For example, *E. crus-galli* (a type of barnyard grass) is native to tropical Asia where it coexists with *Oryza sativa* (rice). For thousands of years, management of this invasive grass consisted of hand-picking out of rice fields. Through evolutionary mechanisms the grass' seed and vegetative growth stage are morphologically indistinguishable from *Oryza sativa's* (Ellstrand et al., 2010). Due to their resemblance, *Echinochloa crus-galli's* seeds are commonly included with rice seeds and the grass is able to grow and germinate before it becomes distinguishable from rice. *Echinochloa crus-galli* is now present in 49 states (excluding Alaska) and has been classified as invasive (EDDMapS, 2019).

The horticultural trade is the avenue through which most invasive plants move through. These plants are sold for aesthetic reasons and planted in personal and/or commercial gardens often without consideration of how their presence will affect the native environment. This is apparent when looking at Australia's flora compositions of which 57% was introduced via the horticultural trade (Reichard & White, 2001). Another example of horticulture leading to invasive plant populations is Japanese barberry, an invasive plant, which is popular in North American horticulture (Baksin, 2002).

Many invasive species were also introduced for a variety of landscaping purposes including livestock feed and soil erosion control. For example, *Pueraria montana* (Kudzu Vine), has been given the moniker “the vine that ate the south” as it now covers an estimated 220,000 acres in the southeastern United States. Kudzu was originally planted in the southern United States as foraging material for livestock and to combat agricultural soil erosion but has since been classified as invasive as it quickly spread to cover massive expanses of forest in the southern United States (Se-eppc, 2019). The economic damages caused by Kudzu is estimated at nearly $500 million per year when accounting for environmental productivity loss (Forseth et al., 2004).

Historically, the management of these invasive species has been single-factored; meaning one plant species is singled out and dealt with at a time (Ericson, 2009). Single-factored analysis is effective at single-species management, but when dealing with multiple invaders into the same space, this method proves to be inefficient (Januchowski et al., 2011). To proceed with management in these environments, we need to better understand the co-occurrence relationships between and among species to effectively manage multiple species at once. At its simplest, co-occurrence describes the likelihood of two species existing within the same space. This proves to be a powerful tool for those managing invasive plant species as understanding how the presence of one species affects the likelihood of presence of another allows for indirect management of multiple species via direct management of one. While co-occurrence analysis does not unveil the biological mechanisms behind the observed relationships, it provides direction for future research as well as a starting point for hypothesizing these biological mechanisms (Veech, n.d.).

I present an analysis of invasive species co-occurrence patterns in a natural area in southwest Michigan, USA. Our area of study was the Lillian Anderson Arboretum in Kalamazoo, Michigan. The Lillian Anderson Arboretum was originally inhabited by the Council of the Three Fires made up of the Ojibwe, Odawa, and Potawatomi; the three indigenous nations of the Great Lakes region (Kalamazoo College, 2019). Now, the arboretum is property of Kalamazoo College and is used as both a field site for study and a nature preserve open to the community. This area, however, is being threatened by invasive plant species.

The arboretum consists of 140-acres with varying ecosystems from wetlands to pine forests. We recorded the presence of thirteen different invasive understory plant species; *Celastrus orbiculatus* Thunb. (bittersweet), *Alliaria petiolate* M. Bieb (garlic mustard), *Rosa multiflora* Thunb. (multiflora rose), *Rhamnus cathartica* L. (buckthorn), *Elaeagnus umbellata* Thunb. (autumn olive), *Euonymus alatus* Thunb. (winged euonymus), *Lonicera* genus (honeysuckle), *Vinca minor* L. (creeping myrtle), *Ligustrum vulgare* L. (privet), *Hesperis matronalis* L. (dame's rocket), *Reynoutria japonica* Houtt. (Japanese knotweed), *Centaurea maculosa* Lam. (spotted knapweed), and *Berberis thunbergii* DC. (Japanese barberry). Some of these species, such as oriental bittersweet, were introduced to the United States via the horticulture trade. Others, such as multiflora rose and autumn olive were introduced purposefully to provide wildlife food and habitat (Haddad, 2018).

The management crew of the arboretum has been actively working on reducing certain invasive populations, but the sheer number and range of these species has made this task incredibly difficult. The first known target species for management was garlic mustard which was singled out by the management crew as it is easily identifiable and managed by simply pulling the plant and its root system. In 2013, management efforts were started to combat

Japanese knotweed populations and were focused on the area that is now the Batts pavilion; this management consisted of herbicide treatments. Before the pavilion construction, the area was used as a dumping ground for pulled invasives and other plant matter from around the arboretum as well as from the main Kalamazoo College Campus. The constant disturbances caused by the herbicide facilitated the recruitment of Japanese knotweed to this area and it quickly spread and outcompeted nearly all other plant species in this area. Before construction of the pavilion could start, this area had to be cleared and the entirety of the Japanese knotweed population in this area was managed. Since the construction of the pavilion, disposal bins have been placed along certain trails with instruction on how to identify and effectively pull garlic mustard, opening the management efforts to community members. While little data is available from before these management efforts, Sara Stockwood (Director of the Lillian Anderson Arboretum) asserts that these populations have been drastically reduced since the start of these management efforts.

Currently, management personnel are focused on near trail areas as they are easily accessible. Due to these near-trail areas also likely serving as a primary avenue of dispersal for these invasive species these management efforts may be slowing the spread of these invasives. Specifically, the management personnel have been focused on garlic mustard and bittersweet within the arboretum. The objective of my study was to accurately map these two species and additional invasives locations and prevalence as well as analyze their co-occurrence relationship to better inform management moving forward.

These co-occurrence relationships tell us how the presence of one invasive species affects the likelihood of finding another in the same space. This will be used to rank the species in order of management, with those species with the highest number of positive relationships being targeted primarily. This ranking system was used because positive relationships are indicative of biological mechanisms that allow these species to co-occur and removing one of the species from this relationship will likely reduce the presence of the other. Further understanding these biological mechanisms is incredibly important as this information tells us why these species are co-occurring. This can be used to create management strategies specific to each invasive species.

To better inform management efforts of these invasives, three abiotic factors (canopy coverage, elevation, and distance from the nearest trail) were recorded and compared to the prevalence of each invasive species. The influence of canopy cover on each invasive species' can better inform us on the species' niches, providing direction for management. Elevation's effect on invasive prevalence was observed because of its relationship to water and nutrient levels in the soil. Higher elevation typically leads to less water availability in the soil, as rainwater accumulates at low elevation points. Also, at higher elevation are characteristically lower in nutrients reducing the health and abundance of vegetation (Knoepp & Swank, 2002). Finally, distance from the nearest trail's relationship with invasive prevalence was observed because distribution of plant species is often mediated by humans. As we walk trails, we unknowingly spread invasive seeds and plant material increasing the dispersal of these species. (Davies & Sheley, 2007). For this abiotic factor analysis, plant co-occurrence was recorded as presence (1) or absence (0).

Materials and Methods

Field Methods

The field site was the Lillian Anderson Arboretum in Kalamazoo, Michigan, USA. Data collection took place from June – August 2018 and June – August 2019. Our objective was to sample the invasive plant population occurrences in a grid with 20 meters spacing between each point. Data collection started in the northeastern corner of the Arboretum. At this point the Trimble® Geo7x (Trimble, Sunnyvale, CA) system, atop a ~1.2-meter monopod was planted into the ground. With the Trimble system marking the center of the data collection site, a 5-meter radius circle was established as visualized (Fig. 1). Within the circle, the percentage abundance of each invasive species was estimated and recorded. Percentage abundance was estimated as the percentage of total living "stems" within the 5-meter circle. Abundance was observed for invasive understory plants only, and each species of invasive plant's percent cover was recorded as one of five categories (0%, 0-25%, 25-50%, 50-75%, and >75% abundance). The GPS unit was held as still as possible to allow for a minimum of 30 "pings" from the satellites in communication (at least 30 seconds). Once observations had been made and the minimum number of satellite pings had occurred, the data point was saved and using a tape measure the team moved 20 meters North / South (depending on if the column was started from the northern or southern end of the field site. In 2019, canopy and ground coverage were recorded using the categories mentioned above (0%, 0-25%, 25-50%, 50-75%, and >75%) with the addition of a "100%" cover category.

We assessed the relationship of three abiotic factors with invasive species' prevalence; light levels (via canopy coverage), elevation, and distance from the nearest trail. These three abiotic factors were compared to the species' prevalence in a logistic regression model.

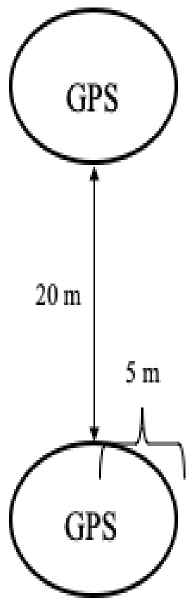

Figure 1. Visualization of data collection methodology. Each circle is representative of the 5-meter radius sampling sites. Sites were done in 20-meter transects.

Data Correction

Data from the Trimble® system (Trimble, Sunnyvale, CA) were transferred onto a computer using GPS Pathfinder Office (ArcGIS v 5.7, ESRI, Redlands, CA). The files were then differentially corrected using the Kalamazoo, Michigan (SOWR) continuously operating reference station (CORS) basefiles. Differential correction is used to correct for slight variations in satellite's orbits thus making the spatial data of each point more accurate. Once differentially corrected, each point was individually quality checked. Quality checking consisted of checking the standard deviation from the mean for each point. Points with a standard deviation above 0.2 meters were further corrected by looking at the individual "pings" for each site (done by temporarily deleting the point). Any "ping" that was one meter or more from the next nearest "ping" was manually deleted. Once all files were differentially corrected and quality checked, they were exported as shape files and combined into a single ArcMap layer (ArcGIS v 10.4, ESRI, Redlands, CA).

Analysis

Statistical analysis was conducted in R (Version 1.1.442 – © 2009-2018 Rstudio, Inc.) using the following packages; mosaic (Pruim et al., 2017), ggplot2 (Wickgam, 2009), and cooccur (Griffith et al., 2016). Co-occurrence analysis provided insight into the relationships between invasive species. Its purpose was to illustrate how the presence of one species affects the likelihood of another being present in the same area. For this analysis, each species was paired up with every other invasive present and their observed co-occurrence probabilities were compared to a random distribution.

These relationships are characterized as random, positive and negative. Random relationships are indicative of no significant co-occurrence relationship between species-pairs. Positive relationships are those in which the two species co-occur red more often than expected given random distribution. Inversely, negative relationships between species indicates that they co-occur red significantly fewer times than expected given a random distribution.

Results

Lillian Anderson Arboretum

Thirteen invasive understory plant species were identified, and their prevalence recorded across 975 sampling points (bittersweet, honeysuckle, autumn olive, multiflora rose, buckthorn, garlic mustard, winged euonymus, Japanese knotweed, spotted knapweed, dame's rocket, privet, creeping myrtle, and Japanese barberry (Figures 6-13).

Invasive Abundance Overview

Prevalence of each invasive species was separated into quartiles by estimated percent cover of each sample site (Table I). In order, the three most prevalent species in the Lillian Anderson Arboretum were bittersweet (48% of points), honeysuckle (38% of points)), and multiflora rose (35% of points) (Table I).

Table I. Abundance proportions of the six most abundant invasive understory plant species in the Lillian Anderson Arboretum, Kalamazoo, MI, USA. Prevalence is reported as the proportion of total (975) sampling sites in which each species was recorded. Data collection took place from Jun-Aug 2018 and Jun-Aug 2019.

Species	Not Present	Present 0-25%	Present 25.1-50%	Present 50.1-75%	Present 75.1-100%	Overall Presence
Bittersweet	0.52	0.36	0.08	0.03	0.01	0.48
Honeysuckle	0.62	0.27	0.07	0.03	0.00	0.38
Multiflora Rose	0.64	0.26	0.06	0.02	0.02	0.36
Buckthorn	0.81	0.16	0.014	0.00	0.00	0.18
Garlic Mustard	0.93	0.06	0.00	0.00	0.00	0.06
Autumn Olive	0.96	0.04	0.00	0.00	0.00	0.04

Bittersweet

The canopy cover of points which contained bittersweet did not differ from the overall distribution of canopy cover. While canopy cover over points with bittersweet slightly deviated from the expected, the overall shapes of the distributions were similar (Fig. 2)(χ^2 (3, N=245) = 5.80, p = 0.12). Elevation, however, did have a significant influence on the presence of bittersweet; as elevation increased, the probability of finding bittersweet decreased (p =0.001). Finally, we observed no relationship between distance from the nearest trail and bittersweet presence (p = 0.15).

Honeysuckle

The canopy coverage of points which contain honeysuckle did not differ from the overall canopy cover (Fig. 3)(χ^2 (3, N = 165) = 2.36, p = 0.50). Also, the relationship between honeysuckle and elevation was not significant (p = 0.19). In addition, distance from trail did not influence honeysuckle presence (p = 0.40).

Multiflora Rose

The canopy cover of points containing multiflora rose did not significantly differ from the overall canopy coverage (Fig. 4)(χ^2 (3, N=176) = 5.10, p = 0.16). Elevation also had no effect on multiflora rose presence (p = 0.47) nor did distance from the nearest trail (p = 0.50).

Co-occurrence Analysis

Of the 78 pairwise combinations analyzed, 45 pairs were disqualified because their expected co-occurrence was less than or equal to only one sampling site (not enough for statistical analysis), and five were disqualified due to their occurrence being too minimal for statistical power. Of the 28 eligible pairs; 14 species pairs were random, 10 positive, and four negative.

While most of the species-pairs demonstrate a random relationship, there were several positive and negative relationships between invasive plant species. Bittersweet positively co-occurs with four other invasive species; garlic mustard, multiflora rose, honeysuckle, and autumn olive; meaning that these species co-occurred with bittersweet significantly more times than a random distribution. Positive co-occurrence relationships were also observed between garlic mustard and both honeysuckle and multiflora rose. Multiflora rose occurred more often than a random distribution with both honeysuckle and autumn olive. The final two positive co-occurrence relationships are between honeysuckle with autumn olive, and Japanese barberry and buckthorn. Winged euonymus demonstrates no positive associations and negatively co-occurs with buckthorn, autumn olive, and honeysuckle. A negative co-occurrence relationship was also observed between buckthorn and multiflora rose (Fig. 5)

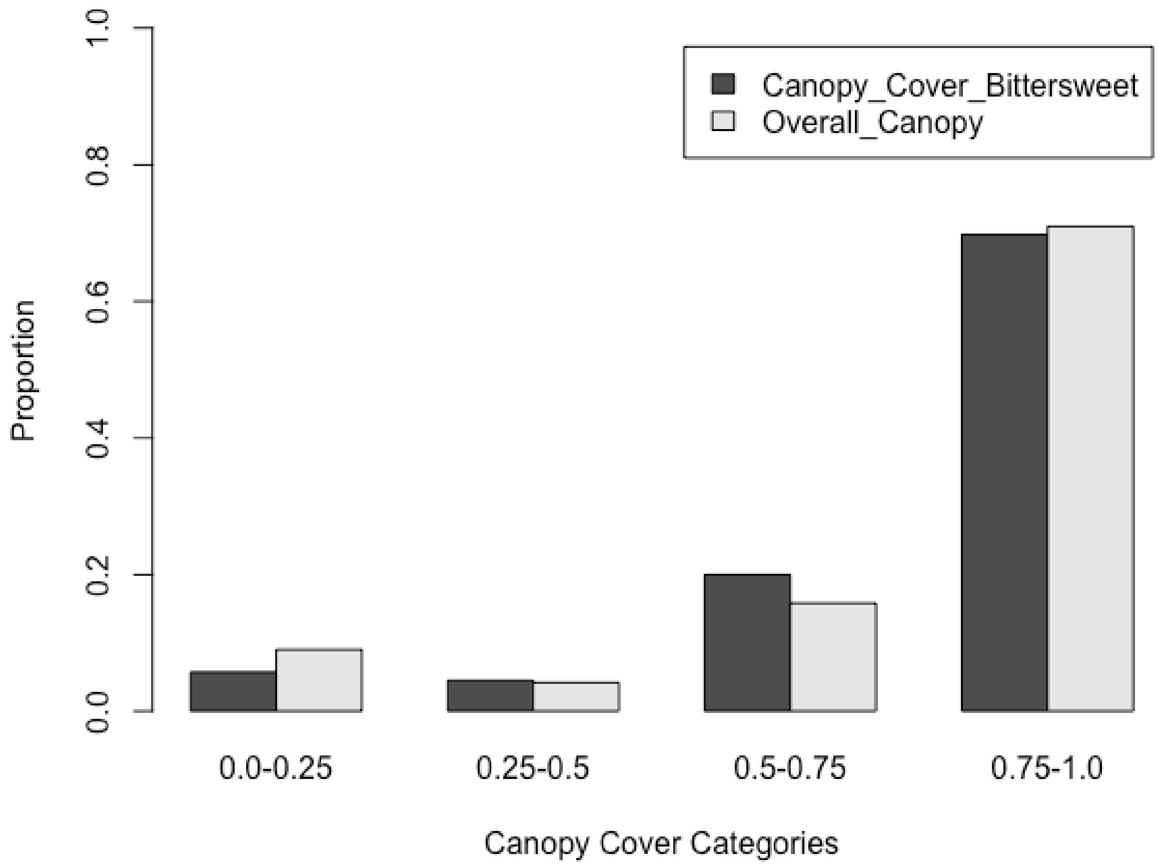

Figure 2. Proportion of points in canopy cover categories for sites with and without bittersweet. The distribution of canopy cover of points where bittersweet was found (black bars) did not differ from the overall distribution of canopy cover within the study area ($\chi^2 = 5.80$, df=3, p = 0.12). Data collected from Jun-Aug 2018 and Jun-Aug 2019 in the Lillian Anderson Arboretum, Kalamazoo, MI, USA.

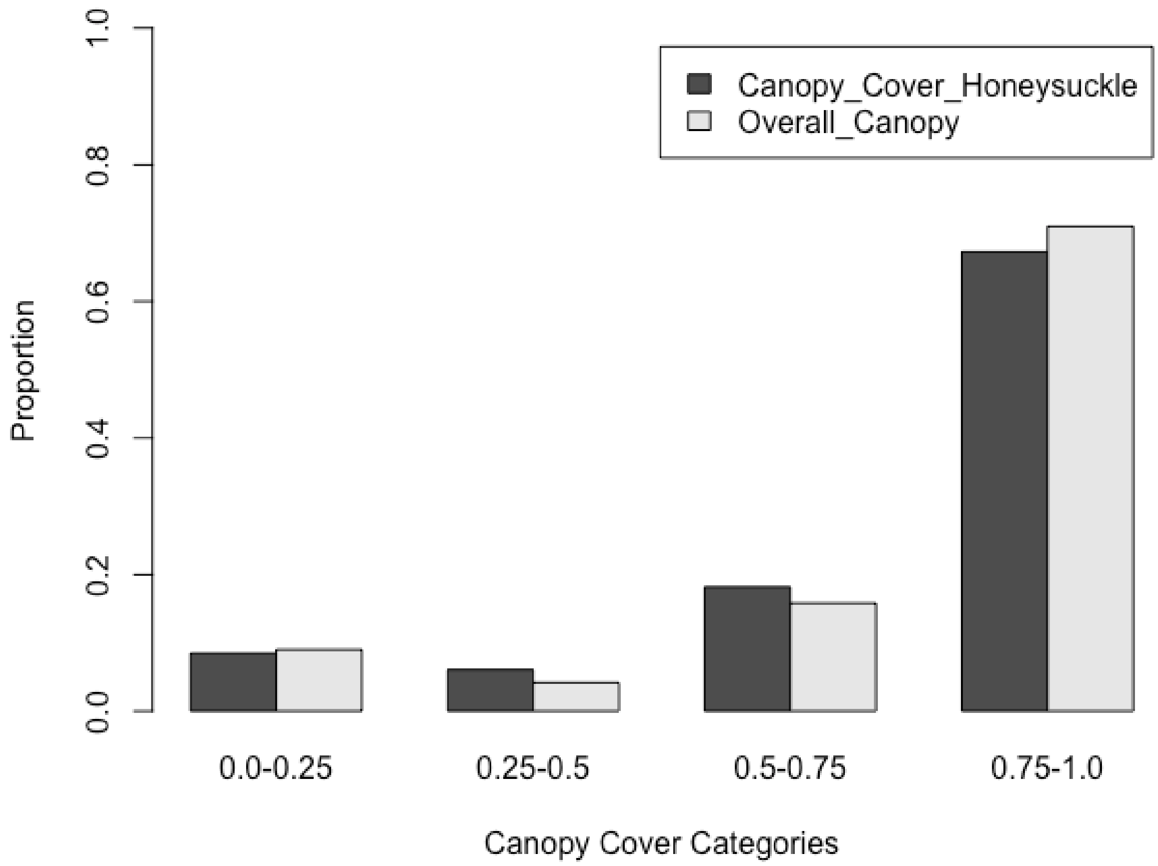

Figure 3. Proportion of points in canopy cover categories for sites with and without honeysuckle. The distribution of canopy cover of points where honeysuckle was found (black bars) did not differ from the overall distribution of canopy cover within the study area ($\chi^2 = 2.36$, df=3, p = 0.50). Data collected from Jun-Aug 2018 and Jun-Aug 2019 in the Lillian Anderson Arboretum, Kalamazoo, MI, USA.

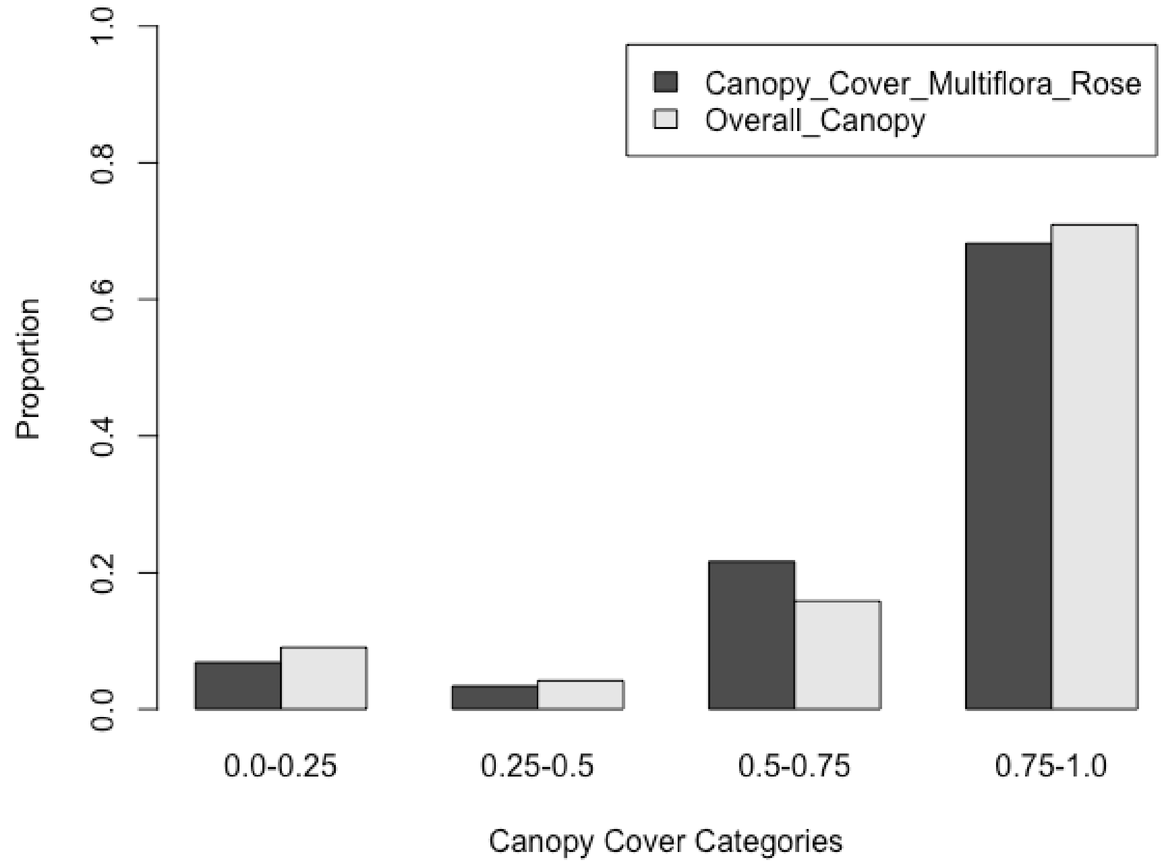

Figure 4. Proportion of points in canopy cover categories for sites with and without multiflora rose. The distribution of canopy cover of points where multiflora rose was found (black bars) did not differ from the overall distribution of canopy cover within the study area ($\chi^2 = 5.10$, df=3, p = 0.16). Data collected from Jun-Aug 2018 and Jun-Aug 2019 in the Lillian Anderson Arboretum, Kalamazoo, MI, USA.

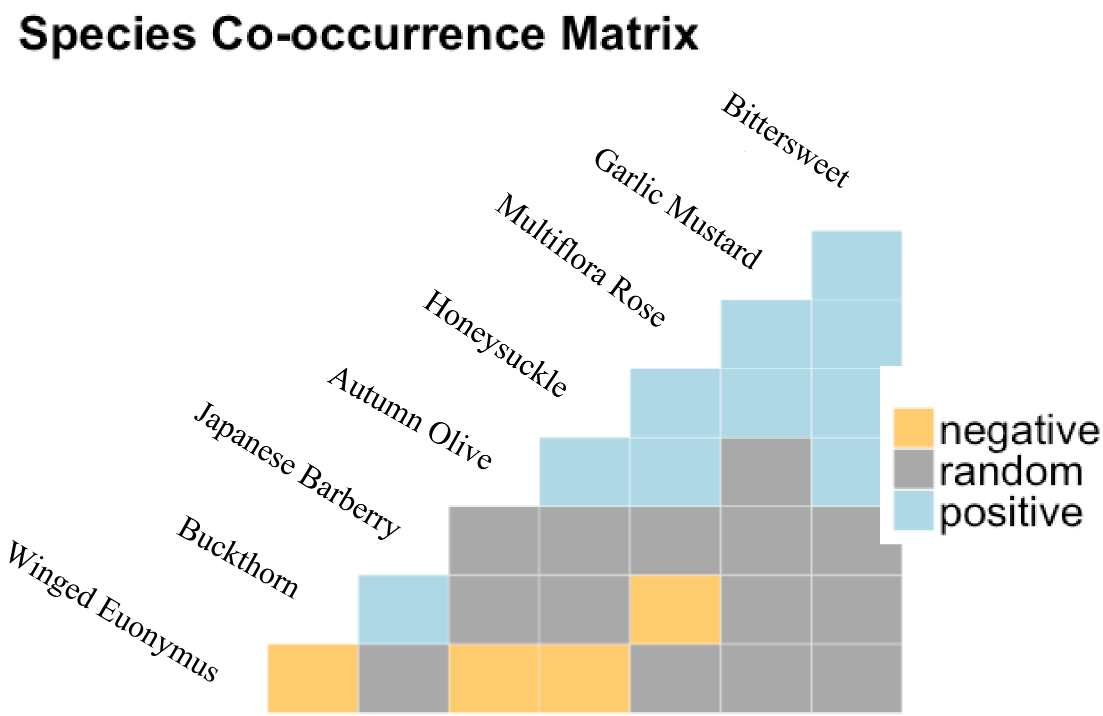

Figure 5. Matrix visualizing the positive, negative, and negative relationships between invasive understory plant species. Species names are positioned representatively of their pairwise co-occurrence relationships.

Discussion

Over two summers (2018-19) we mapped understory invasive plant specie's spatial location and prevalence. During this time 975 sample sites were used to cover the 140-acre Lillian Anderson Arboretum. We observed 13 individual invasive species ranging from 0.003% (spotted knapweed) to 48% prevalence (bittersweet) of sampling sites. We found that the three most prevalent invasives in the arboretum were bittersweet, honeysuckle and multiflora rose. We also found that of the three abiotic factors tested, elevation only had an effect on bittersweet prevalence. Canopy coverage and distance from trail had no effect on either of the three invasive prevalence's. Co-occurrence analysis revealed the positive, negative, and random co-occurrence relationships between the invasive species.

As the objective of this research was to more effectively and efficiently manage the invasive population at the Lillian Anderson Arboretum, the first step was knowing where each species was located within the arboretum and how prevalent they are. To achieve this, spatial maps were created to visualize exactly where and how prevalent each species is within the arboretum and to act as baseline data to assess management efforts in the future. From these maps, we gain insight into the range of each invasive plant. Interestingly, we see that winged euonymus is found only in the southwestern area of the arboretum. Furthermore, bittersweet, honeysuckle, and multiflora are found nearly everywhere but are most prevalent in the northern area of the arboretum (Figures 12, 15, and 17).

Management personnel can use these maps to direct their efforts to either manage the "hotspots" where invasive prevalence is high or to the perimeter of each species range to control their spread. Also, the prevalence of each species can be used to direct management towards the most abundant species within the arboretum. We found that bittersweet, honeysuckle, and multiflora rose were most prevalent, however we must also understand how each species' prevalence is related to certain abiotic factors to create a more effective management plan.

We chose to look at the relationship of three abiotic factors with the three most prevalent invasive species' prevalence; percent canopy coverage, elevation, and distance from the nearest trail. Bittersweet's occurrence did not have any significant relationship with canopy coverage. This result was expected as bittersweet is both shade and light tolerant, meaning it can grow and thrive in all light ranges (McNab & Meeker, 1987). Interestingly, bittersweet prevalence decreased as elevation increased. We were unable to determine if this is moisture or nutrient-mediated, or more likely a combination of the two, but this is useful for management as lower elevation areas should be higher priority when managing bittersweet. Finally, distance from trail showed no relationship with bittersweet. This may be a combination of both management efforts being focused on near trail areas, as well as trails serving as the vector for invasion (Davies & Sheley, 2007). Either way, this informs us that this management has not affected the bittersweet population, as it is still found in proximity to the trails.

Honeysuckle, being the second most prevalent invasive within the arboretum showed no significant relationship with any of the abiotic factors. Similar to bittersweet, honeysuckle was found under every category of canopy cover from open areas to those completely shaded by the canopy. Furthermore, honeysuckle is characteristically shade-tolerant, so the non-significance of canopy coverage is not surprising (Hutckinson & Vankat, 1997). The relationship between honeysuckle and elevation is non-significant likely due to honeysuckle being a generalist; meaning it is able to thrive equally within a wide range of various abiotic factors (Hutckinson & Vankat, 1997). We observed no significant relationship between distance from the trail and honeysuckle prevalence, however this may be due to past management efforts of honeysuckle being focused on trail perimeters thus reducing these populations in proximity to the trail system.

Multiflora rose also had no significant relationships with any of the abiotic factors studied. As with the bittersweet and honeysuckle, multiflora rose is characteristically shade and light-tolerant, so canopy cover having no effect on multiflora prevalence was expected (Klimstra, 1951). Elevation also had no effect on multiflora presence. Finally, distance from trail showed no relationship with multiflora rose likely because of the combination of management efforts and trail-mediated dispersal mentioned above.

Historically, invasive plant management has relied on spatial and single-factor analysis for direction on both which species to manage and where to focus efforts (Ericson, 2009). However, in an area such as the Lillian Anderson Arboretum where management resources are sparse, management of one species at a time is not efficient. To enhance our management's effectiveness and efficiency, we calculated the co-occurrence relationships of all invasive species. This analysis allows us to rank the species in order of management necessity (Table II).

Ranking species for management relies on the co-occurrence relationships of each species. Bittersweet tops the rankings as the primary management focus due to it being most prevalent overall at the Arboretum and it positively co-occur ring with four other species and negatively co-occur ring with none. Therefore, decreasing the population of bittersweet would have negative effects on the co-occur ring species. This could be done through herbicide application of bittersweet or through hand-pulling of the vines, both of which would have negative impacts on the positively co-occurring invasive plants. Honeysuckle and multiflora rose are combined as the second focal species for management because they both exhibit four positive co-occurrence relationships while only negatively co-occur ring with winged euonymus. The rest of the rankings follow this same line of thinking in which species with more positive relationships are ranked higher. While this analysis allows us to rank each species in order of management necessity, it does not unveil the biological mechanisms behind the relationships and because of this we put forth mechanistic hypothesis for each of these observed relationships.

One important potential reason for the observed positive relationships is spatial autocorrelation. In short, spatial autocorrelation highlights that because the sampling sites are not independent (some are next to each other and some are not) they are likely to affect each other. For example, sampling sites next to each other are more likely to share species prevalence's simply because they are next to each other and the two sites are not indicative of two different populations. In the future, this could be controlled for using specific modelling strategies not explored within this study.

Management Plan

Using these analyses, we created a management plan for the arboretum. This plan incorporates co-occurrence, abiotic factor, and spatial analyses to comprise a plan that aims to effectively and efficiently direct management to restore the biodiversity of the Lillian Anderson Arboretum.

Primary management efforts should be focused on bittersweet because it positively co-occurring with four other invasive species while negatively co-occurring with none. Due to bittersweet being so highly prevalent (present in 48% of points) management should be focused on controlling the spread of bittersweet rather than focusing on areas of high prevalence. This is done by managing the population edges and working inward towards the center of the population's range. These edges are points of lower prevalence (0-25%) that surround areas of high prevalence. Managing these areas specifically will control the range that bittersweet occupies and thus reduce it dispersal range. From there, management personnel should work inward towards the points of high prevalence to further decrease the population. Due to the negative relationship between bittersweet and elevation, areas of low elevation should be targeted first.

After bittersweet, management should be focused honeysuckle. While honeysuckle and multiflora rose both show four positive co-occurrence relationships and one negative, honeysuckle is more prevalent. Similar to bittersweet, honeysuckle should be managed from its population edges inward but no abiotic factors affected honeysuckle's prevalence so canopy cover, elevation, and distance from trail should be ignored when selecting points to manage. Following honeysuckle, multiflora rose should be targeted in the same way; focusing on edges and ignoring the three abiotic factors mentioned above.

Following our ranking order (Table II) garlic mustard should be managed next because it has three positive and no negative co-occurrence relationships. Unlike bittersweet, honeysuckle, and multiflora rose, which range from 35%-48% prevalence, garlic mustard was only found in 6% of points. Due to its prevalence, garlic mustard is likely not going to spread quicker than management efforts and points of highest prevalence should prioritized.

After garlic mustard, management should focus on autumn olive, Japanese barberry, and buckthorn in the same way; prioritizing points of highest prevalence to eliminate large portions of the populations as quickly as possible. Finally, winged euonymus should be targeted last. This is because winged euonymus only exhibits negative co-occurrence relationships. So, while winged euonymus inhabits a large portion of points in the southwestern area of the arboretum, it occurs with other invasive species less frequently than if they were randomly dispersed.

In order to accurately assess management efforts, the arboretum should be re-mapped on a regular 5-10 year cycle. This will inform us to the effectiveness of our management and allow us to update the population ranges regularly. Furthermore, future studies could utilize our data to investigate invasive plant impacts on pollinator habitats or conduct further analysis on other abiotic factors such as ground coverage and disturbance presence to measure their impact on invasive plant prevalence.

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Appendix

Table II. Ranking of invasive species in order of management necessity. Rankings were based on co-occurrence relationships and overall prevalence.

Ranking Order for Management	
1.	Bittersweet
2.	Honeysuckle
3.	Multiflora Rose
4.	Garlic Mustard
5.	Autumn Olive
6.	Japanese Barberry
7.	Buckthorn
8.	Winged Euonymus

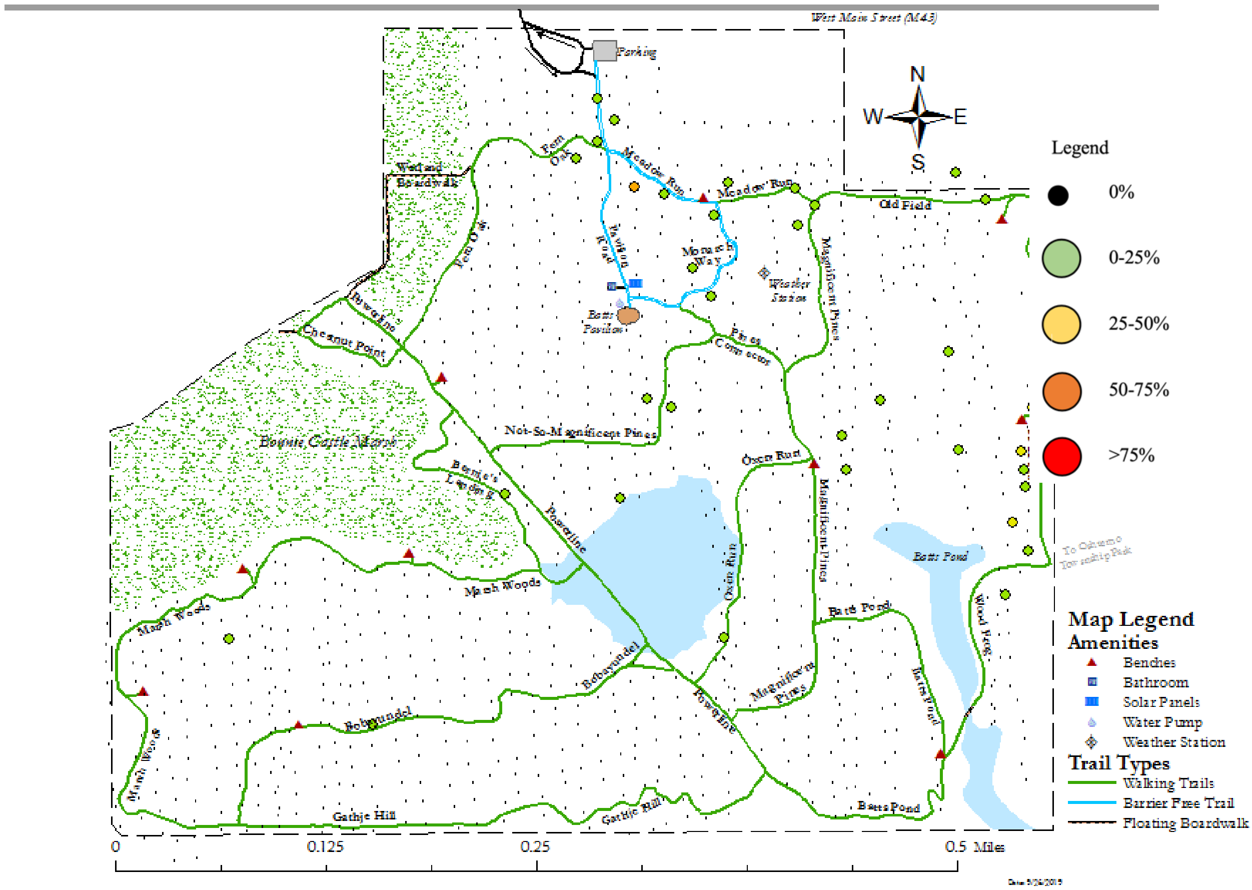

Figure 6. Spatial map of autumn olive prevalence in the Lillian Anderson Arboretum. Data collected from Jun-Aug 2018 and Jun-Aug 2019 in the Lillian Anderson Arboretum, Kalamazoo, MI, USA.

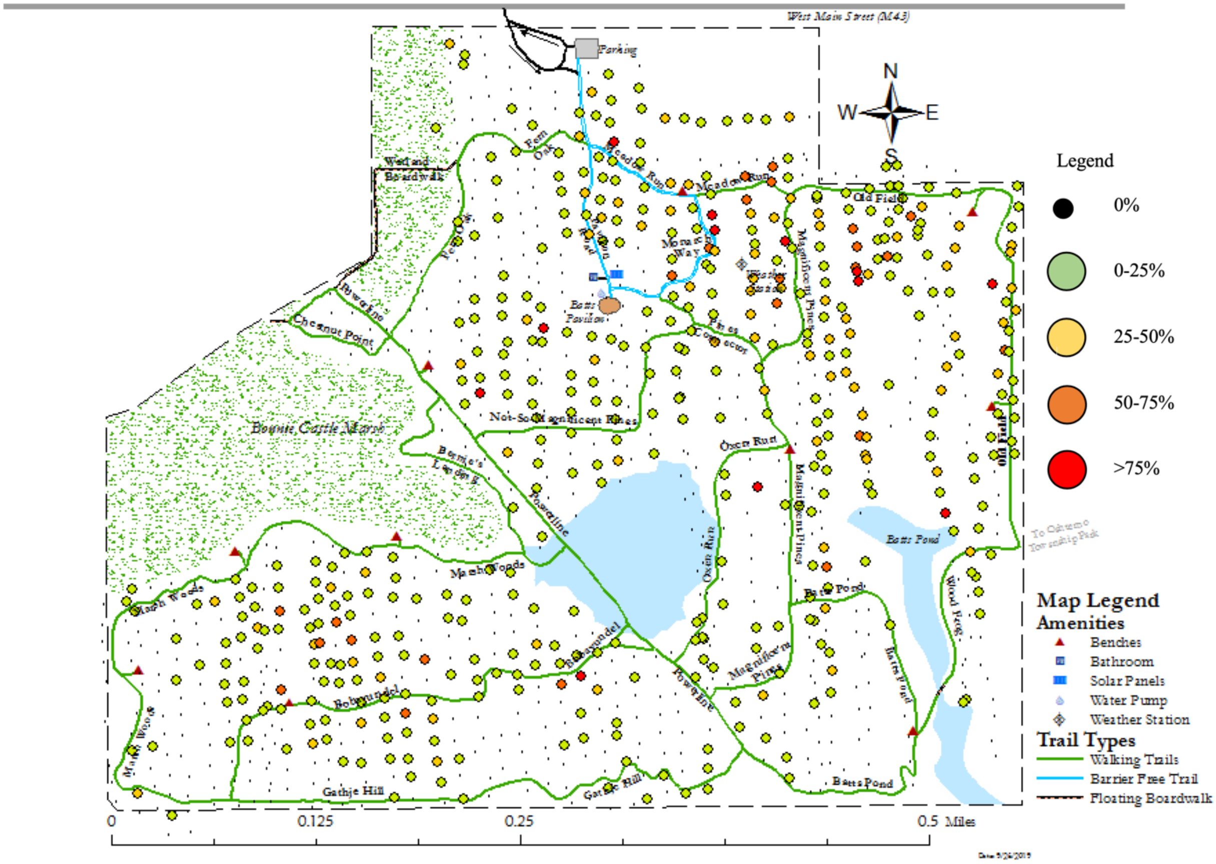

Figure 7. Spatial map of bittersweet prevalence in the Lillian Anderson Arboretum. Data collected from Jun-Aug 2018 and Jun-Aug 2019 in the Lillian Anderson Arboretum, Kalamazoo, MI, USA.

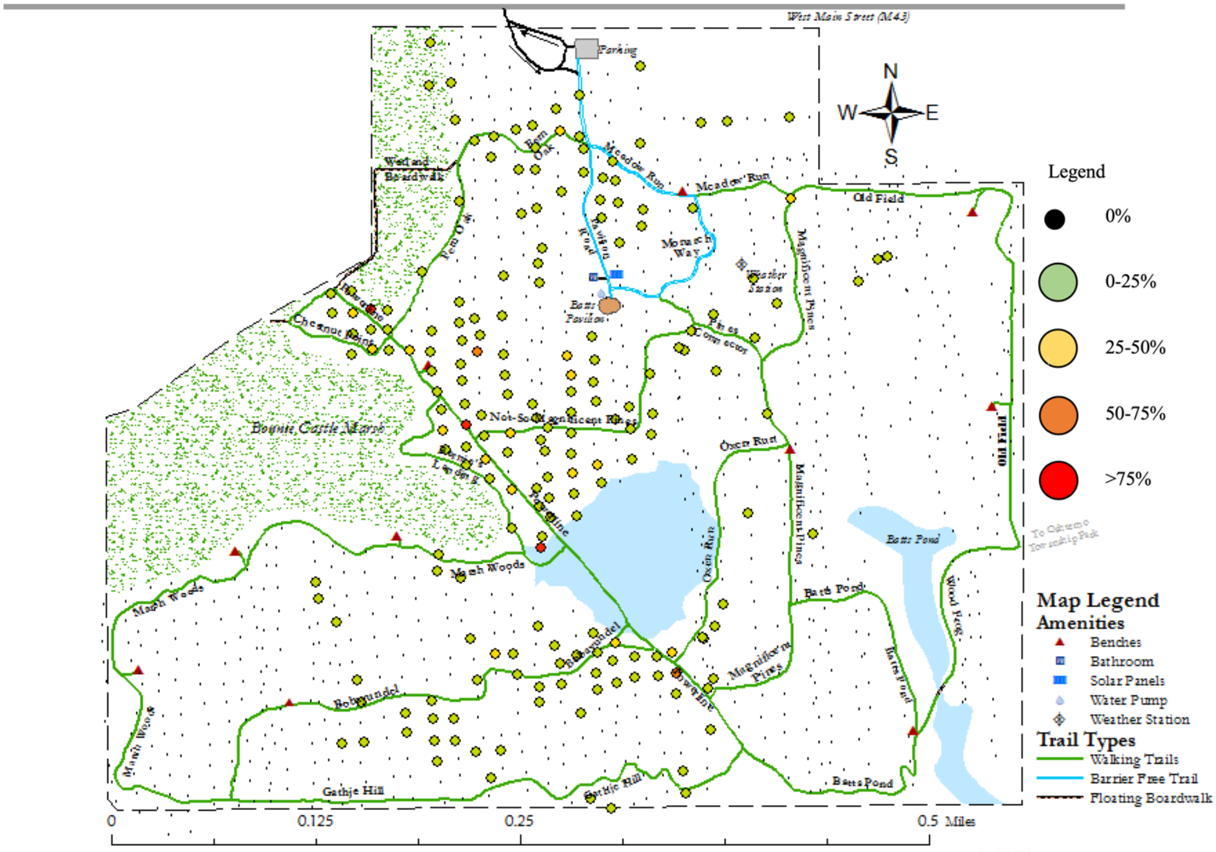

Figure 8. Spatial map of buckthorn prevalence in the Lillian Anderson Arboretum. Data collected from Jun-Aug 2018 and Jun-Aug 2019 in the Lillian Anderson Arboretum, Kalamazoo, MI, USA.

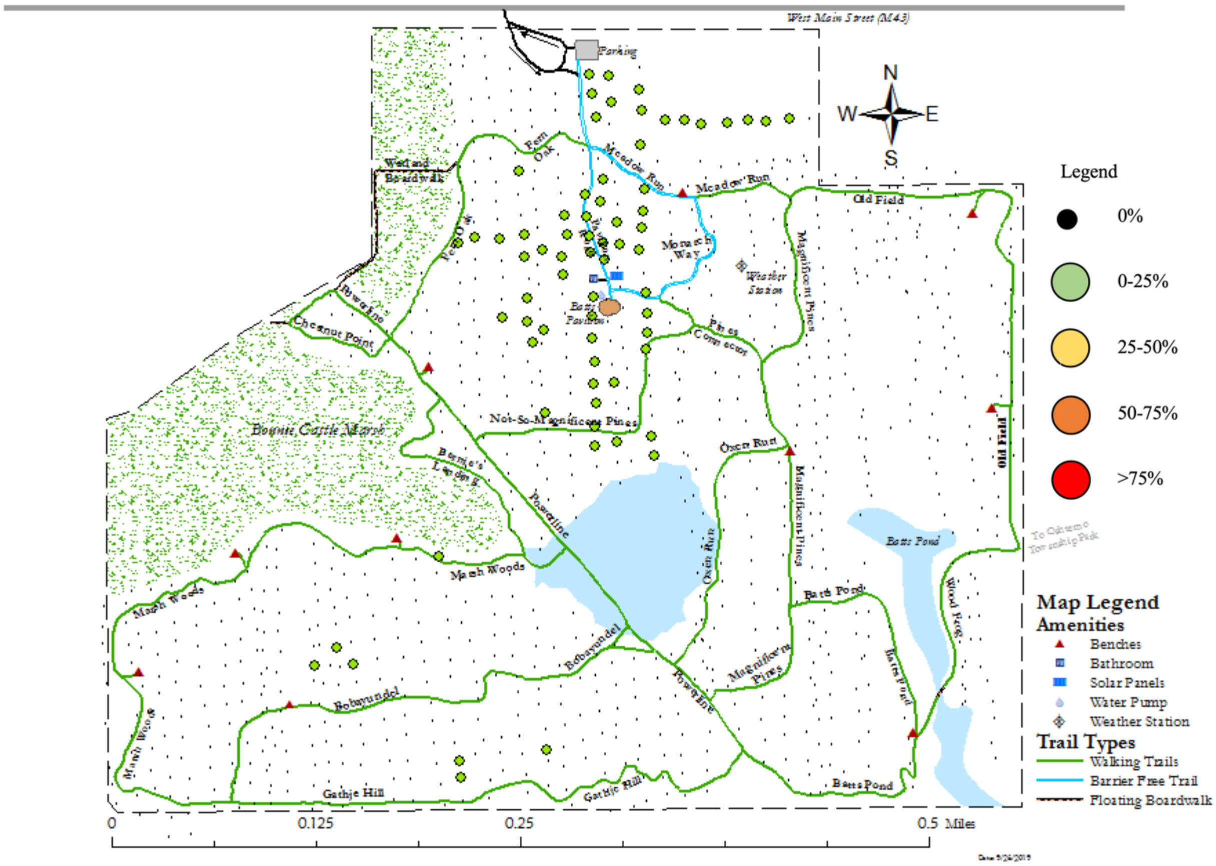

Figure 9. Spatial map of garlic mustard prevalence in the Lillian Anderson Arboretum. Data collected from Jun-Aug 2018 and Jun-Aug 2019 in the Lillian Anderson Arboretum, Kalamazoo, MI, USA.

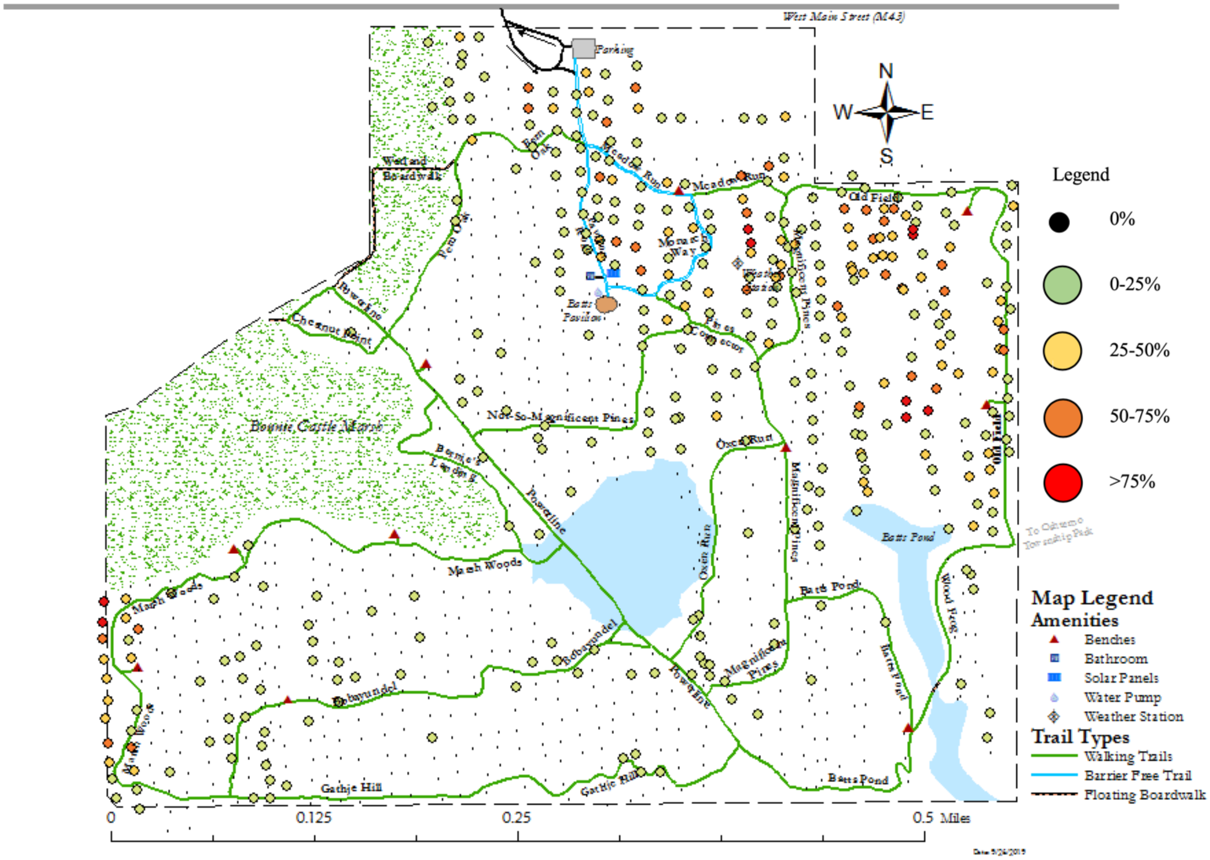

Figure 10. Spatial map of honeysuckle prevalence in the Lillian Anderson Arboretum. Data collected from Jun-Aug 2018 and Jun-Aug 2019 in the Lillian Anderson Arboretum, Kalamazoo, MI, USA.

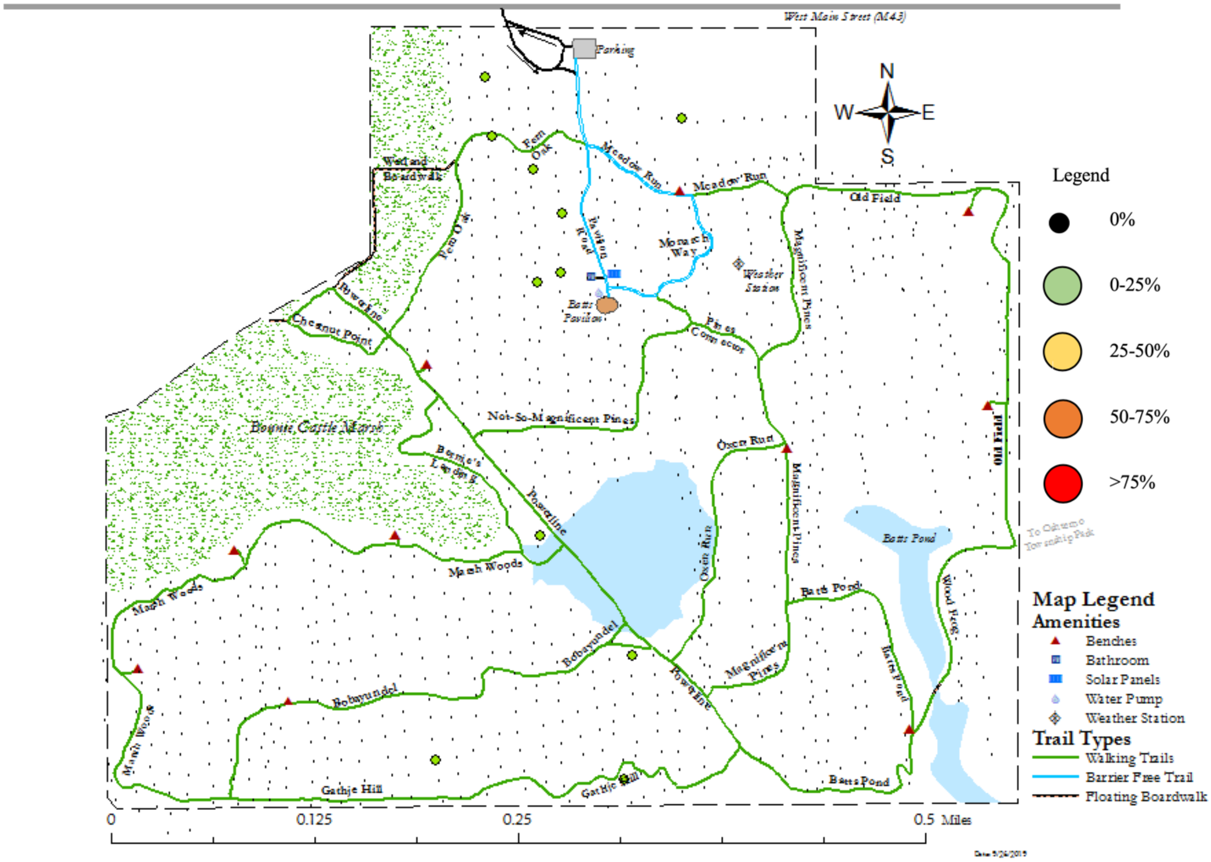

Figure 11. Spatial map of Japanese barberry prevalence in the Lillian Anderson Arboretum. Data collected from Jun-Aug 2018 and Jun-Aug 2019 in the Lillian Anderson Arboretum, Kalamazoo, MI, USA.

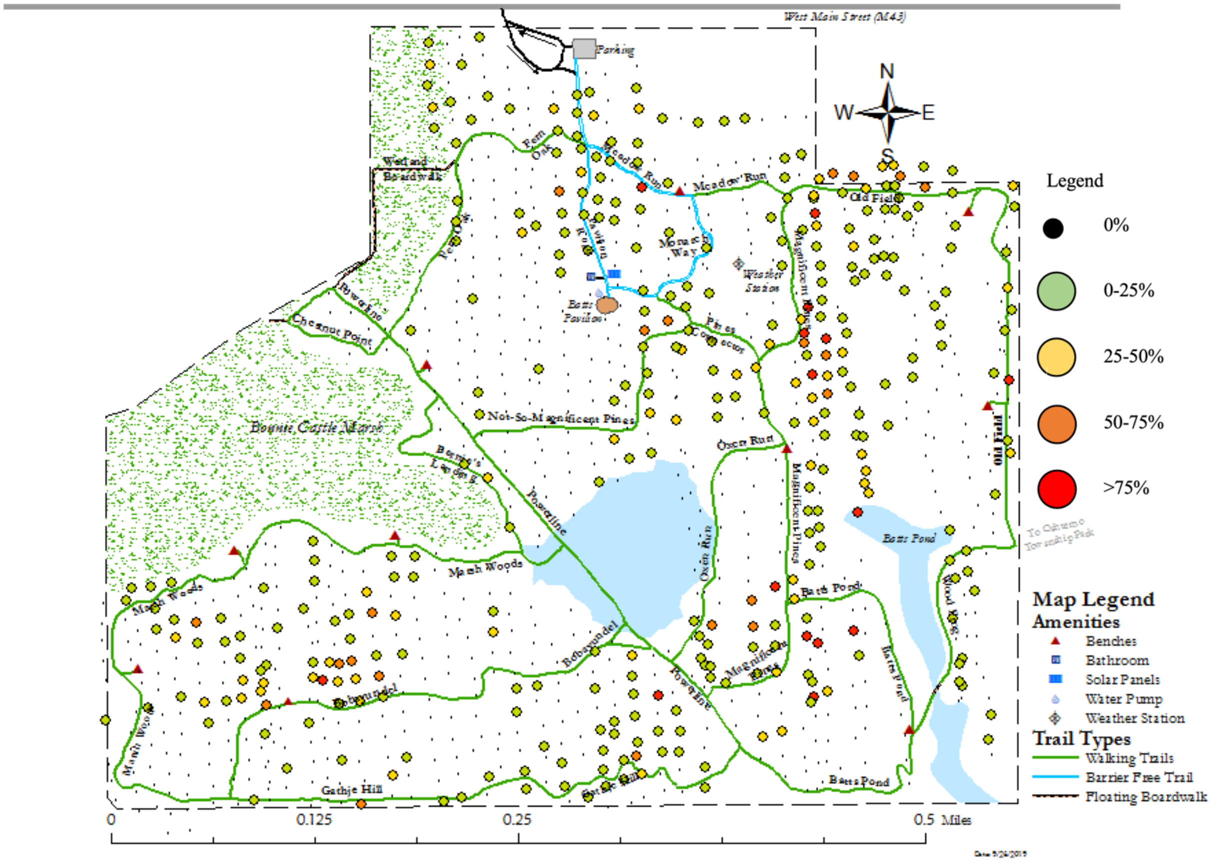

Figure 12. Spatial map of multiflora rose prevalence in the Lillian Anderson Arboretum. Data collected from Jun-Aug 2018 and Jun-Aug 2019 in the Lillian Anderson Arboretum, Kalamazoo, MI, USA.

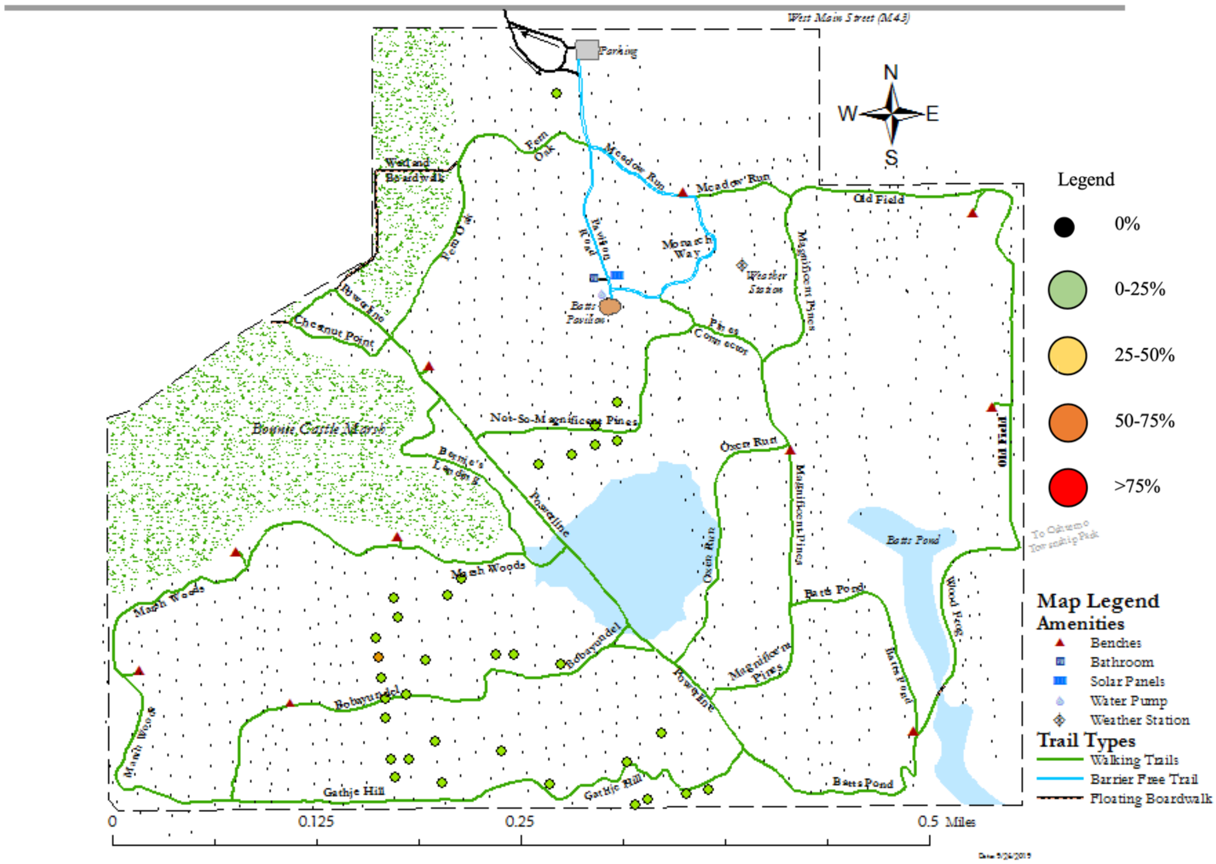

Figure 13. Spatial map of winged euonymus prevalence in the Lillian Anderson Arboretum. Data collected from Jun-Aug 2018 and Jun-Aug 2019 in the Lillian Anderson Arboretum, Kalamazoo, MI, USA.