Contributed Paper

Effects of deer exclusion on the spread and diversity of invasive species on the Front Royal SIGEO Plot

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Abstract

The successful invasion of exotic plants is often attributed to the presence of white-tailed deer (Odocoileus virginianus). To test this hypothesis, we measured the concentration of four invasive plants— Wineberry (Rubus phoenicolasius), Multiflora rose (Rosa multiflora), Japanese honeysuckle (Lonicera japonica), and Japanese barberry (Berberis thunbergii)— inside and outside of a deer exclosure in Front Royal, Virginia. This work was conducted in a mature secondary mixed deciduous upland forest. We included degree of slope, concavity, aspect and stream presence in our analysis of invasive abundance. There was no significant relationship between these variables with respect to species abundance. We found that Berberis thunbergii and Rubus phoenicolasius were both less abundant inside the deer exclosure. By contrast, concentrations of Rosa multiflora and Lonicera japonica were the same on either side of the exclosure fence. Our results suggest that not all invasive plant species benefit equally from Odocoileus virginianus presence.

Keywords: invasive species, data collection, sampling effort, ANOVA, secondary forest

Introduction

Invasive species are a serious threat to several taxa, second only to humans (BirdLife 2000, Clavero 2005, Harrison & Stiassny 2004, McPhee & Flemming 2004, Miller et al. 1989).

Sometimes, the invasion of just one exotic species can destroy a local ecosystem. For example, the invasion of the brown treesnake (*Boiga irregularis*) led to the extinction of every vertebrate native to the island of Guam, with the exception of three lizard species (Fritts & Rodda 1998).

Invasive species are the primary reason why ~~around~~ 400 of the 958 species listed on the

Endangered Species Act are considered threatened or endangered (Wilcove et al. 1998). Specifically, invasive plants are cited as a threat to 410 species of plants and 19 species of birds in America (Gurevitch 2004). It is estimated that the US economy loses as much as $34.6 billion in damages, crop losses, and costs incurred while trying to control roughly 35,000 invasive plant species (Pimentel et al. 2005). In addition to economic losses, invasive species contribute to the loss of genetic diversity. Hybridization between native and invasive species diminishes natural biodiversity as invasive genes takeover the natives' gene pools (Bleeker et al. 2007). Computer modeling suggests that proactive, preventative measures would be the most efficient strategy to combat invasives (Leung 2002), but much species-specific research remains to be done to develop effective preventative plans.

There are several hypotheses for why introduced species can become problematic invaders. One hypothesis is that invasive species are less susceptible to the enemies of their native competitors. In a study involving 473 European species introduced to the United States, invasive species were infected by an average of 84% fewer fungi and 24% fewer viruses when brought to the United States (Mitchell & Power 2003). A case study of the weed *Silene latifolia* found that it was 17 times less likely to be damaged in the United States as an invader than as a native in Europe due to the absence of natural enemies (Wolfe 2002). Species that can afford to spend less energy on defense mechanisms, may be able to allocate more resources to growth and reproduction, also known as phenotypic plasticity (Willis et al. 2000). Another case study of *S. latifolia* demonstrated that the invasive North American strain germinated earlier, grew faster, produced more flowers, and produced a greater number of seeds than the European strain (Blair & Wolfe 2004). Similarly, the Chinese Tallow Tree (*Sapium sebiferum*) present in the Southern United States was significantly larger, had greater seed production, and had less defended leaves than its

counterpart found in China (Siemann & Rogers 2001). The increased fitness of invasive species could also be explained by evolutionary changes that occur after introduction in response to relaxed enemy pressure. Species who developed adaptations to allocate more resources to growth and reproduction rather than to defense, where they is not needed, would be more fit (Blossey & Notzold 1995, Daehler & Strong 1997, Leger & Rice 2003, Blair & Wolfe 2004).

Herbivores threaten the growth of exotic and native plants, yet, invasives seem to benefit from their presence (Ashton 2008). There is generally a linear relationship between deer density and plant diversity, species height, and species diversity (Horsley 2003). Deer density begins to have negative effect on vegetation composition as low as 8 deer/km² (Horsley 2003). Invasives may survive herbivory better than natives because they are less palatable or more tolerant to damage (Ashton 2008). Deer can also change the composition of a forest by preferentially browsing and delaying growth of their preferred species. High deer density can increase Japanese Barberry's (*Berberis thunbergii*) relative dominance by heavy browsing of other species (Ehrenfeld 1997). Deer browsing has a large effect on new growth forests in which saplings are. When there was no deer exclosure after a ~~failed~~ clearcut, there were almost 30% fewer desirable species and just over 30% fewer commercial species (Marquis & Grisez 1978).

White-tailed deer disperse seeds of both native and invasive species (Bartuszevige & Endress 2008, Myers *et al.* 2004, Vellend, 2002). However, invasive seeds are favored deer dispersion. Myers' (2004) found that 95% of successfully germinated seeds found in deer feces were from invasives. Two species that we surveyed, Multiflora rose (*Rosa multiflora*) and *B. thunbergii*, were found in deer pellets (Myers *et al.* 2004). The superior viability of invasive seeds dispersed in feces suggests the importance of deer for invasive migration and distribution.

We are studying the effect that deer presence has on the abundance and distribution of invasive species. By doing so, we hope to elucidate mechanisms in which invasives can be better controlled.

Methods

Invasive Species

We studied Japanese barberry (*Berberis thunbergii*), Wineberry (*Rubus phoenicolasius*), Multiflora rose (*Rosa multiflora*), Japanese honeysuckle (*Lonicera japonica*).

Japanese Barberry (*Berberis thunbergii*) is an East Asian native. It is a spiny, dense shrub that grows to be 1-2 meters. Individuals tend to be evenly spaced, and each consists of several stems (Ehrenfeld 1999). *B. thunbergii* have been found growing in environments as harsh as wastelands (Swearingen 2002). *B. thunbergii* is also a very shade-tolerant species, only showing significant drops in survival rates below 1% of full sun exposure (Silander & Klepeis 1999). *B. thunbergii* grows best in wetter summer and warmer spring seasons (Li et al 2008). *B. thunbergii* grow very well in post-agricultural settings if introduced before the area is reforested (DeGasperis & Motzkin 2007). The small red berries produced by *B. thunbergii* are often ignored by birds because of their low nutritional value (Stiles 1980). The majority of seedlings are found under or next to the adult (Silander & Klepeis 1999). Barberry leaves its berries on the branch over winter when forage sources are slimmest (Ehrenfeld 1999). Turkey, grouse, deer, and chipmunks have all been reported to act as seed dispersal agents. *B. thunbergii* is cited as a plant rarely damaged by deer populations (Fargione 1991). According to all of these findings, *B. thunbergii* is predicted to grow very well in the studied plot because it can tolerate low levels of

shade, post-agricultural land, and there is a stream running through the plot, suggesting a wet soil. We also predict that *B. thunbergii* should be more abundant outside of the exclosure because deer may eat berries, especially during winter when other food sources are depleted, and disperse their seeds.

Wineberry (*Rubus phoenicolasius*), from East Asia, has an appearance similar to native blackberry plants, with long stems covered in red bristles. It most commonly grows in moist habitats, in open woods, or on the boundaries between defined habitats. It sometimes grows so robustly that it pushes out native species (Swearingen 2002). It has also been suggested that tree -falls are necessary for sunlight exposure and successful growth of *R. phoenicolasius* in forests (Gorchov et al. 2005). In the aftermath of Hurricane Isabel in 2003, the frequency of *R. phoenicolasius* increased three times as quickly in spots where high sunlight was exposed compared to places that remained in low sunlight (Snitzer et al. 2005). *R. phoenicolasius* seeds are commonly spread by birds, mammals, and even people, but it can also grow new shoots from root buds or by arching over and touching the ground (Swearingen 2002). *R. phoenicolasius* is predicted to grow well by the stream on the study plot because of the moist soil and coincidental large treefalls along the streams bank that allows more intense sun exposure. The effect of deer exclusion on *R. phoenicolasius* is predicted to be less than that for *B. thunbergii* because birds disperse their seeds.

Multiflora rose (*Rosa multiflora*), native to Asia, tolerates many different soil, water, light, and habitat conditions, and is listed as a noxious weed in five states (Swearingen 2002). *R. multiflora* grows best on formerly residential land and with high sunlight exposure (Lundgren et al. 2004). When spots of higher sunlight were exposed by Hurricane Isabel, *R. multiflora*

frequency increased nearly three times as quickly as it did in the spots with no new exposure (Snitzer et al. 2005). Each rose plant produces an estimated one million seeds per year that can remain dormant in the soil for twenty years (Swearingen 2002). *R. multiflora* retains its fruit over winter (Swearingen 2002). While its fruit is available, *R. multiflora* draws as many migratory birds as native species meaning that dispersal agents are halved for competing native shrubs (Aksamit 2008). The winter range of the Mockingbird (*Mimus polyglottos*) has been largely altered simply by the availability of *R. multiflora* winter fruits (Stiles 1982). *R. multiflora* can also reproduce like *R. phoenicolasius* by sprouting anew when a cane arches back to the ground (Swearingen 2002). It is also listed as a species that is occasionally severely damaged by deer suggesting some feeding (Fargione 1991). It is predicted that *R. multiflora* will grow nearly as well as Berberis thunbergii because of its plentiful seed production, highly invasive qualities, and ability to capitalize on treefalls. Because of birds' high affinity for the berries, the deer exclosure is predicted to have a small effect on *R. multiflora* abundance.

Japanese Honeysuckle (*Lonicera japonica*) is a perennial vine that climbs along the ground and up standing vegetation. *L. japonica* can survive and spread slowly in high-shade conditions, waiting for a spot of sunlight (Aksamit 2008). *L. japonica* also grows during the winter when most other plants are unable to compete (Swearingen 2002). Its vigorous growth has been shown to topple saplings of native species (Aksemit 2008). *L. japonica* produces a large number of seeds in the form of berries that are dispersed by birds (Swearingen 2002). Their berries are also browsed by white-tailed deer (Aksemit 2008). *L. japonica* is predicted to grow well in our forest plot because of its shade tolerance and ability to climb to sunlight. The effect of the deer exclosure is predicted to be similar to that of *R. phoenicolasius* because birds will play a large part in their seed dispersal.

Field Site

This experiment studied a portion of the SIGEO plot established at the Center for Research and Conservation (CRC) of The Smithsonian Institution. The CRC property is in Front Royal, VA (38°54N, 78°09W) at approximately 170 meters above sea level. The field site consists of mature secondary mixed deciduous upland forest including White Oak (*Quercus alba*), Black Oak (*Quercus velutina*), Shagbark Hickory (*Carya ovata*), White Ash (*Fraxinus Americana*), Yellow Poplar (*Liriodendron tulipifera*), and Flowering Dogwood (*Cornus florida*). A stream runs through the plot between two slight hills. The site was originally private farmland, but it has been left to grow naturally since 1911. The 640m x 400m plot is divided into a 20 x 20 m² grid system.

Deer Exclosure

White-tailed deer (*Odocoileus virginianus*) are excluded from a 200 x 200 m² zone in the plot by a deer exclosure. The deer exclosure consists of a fence barrier built in 1991 that is roughly 3 meters tall. The lower two meters of the barrier is metal square-celled fencing, and the upper 1 meter is made with six strands of high tensile steel wire attached to wooden spacer extensions. Small to medium vertebrates and bears travel through or over the barrier. Outside the exclosure, deer density has consistently been greater than 25 deer/km² since a 1992 survey (McShea et al 2000). The continued presence of deer density since 2000 at this level is confirmed by unpublished data from the same author.

Survey Techniques

Two hundred twenty-nine of the 20 x 20 m^2 grid squares were examined between March 8th and 10th, 2009. Roughly 115 of those regions represented deer-excluded zones. The invasive species ($n = 4$) that were counted on 20 x 20 m^2 plots. Variables – including the degree of slope, concavity, and aspect – were determined at the middle of each grid square. Aspect was measured with a handheld compass. The presence or absence of stream was noted, as was each quadrants' location inside or outside the deer exclosure.

Statistical Analysis: ANOVA

Using the data collected at the Front Royal SIGEO plot, statistics were run on JMP Version 7. Using the "Analysis of a Variation Technique," henceforth referred to as "ANOVA," the distributions of each species were examined according to their averages. The variables used are all nominal. Group averages were compared in order to ascertain whether a statistically significant difference between the two existed. In this case, as in many cases, the ANOVA is used to gauge treatment effects. There are two possible outcomes to an ANOVA: a finding of significant treatment effects (also referred to as statistically significant differences), or no detection of treatment effects. A lack of treatment effects indicates that the null hypothesis is indeed true, as deemed by the α-level.

Statistical Analysis: Mantel Test

The data was also subjected to the Mantel Test. The Mantel Test is a tool used to directly compare two matrices for correlation (Legendre, 1998). Its output is a z statistic:
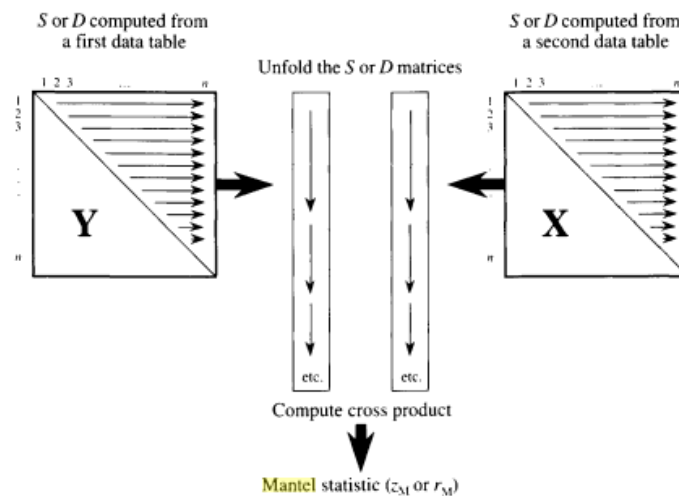
$$Z \square \square \square A_{ij} B_{ij}$$
$$\substack{n \quad n \\ i \square 1 \; j \square 1}$$

in which A and B are the distance matrices.

This is accomplished by first creating two distance matrices, one comparing the distances on an X-Y plot, and the second comparing the presence and amount of individuals of a specific species.

Second, permutations are used to assess the similarity of the two matrices. This similarity coefficient is the most important part of the Mantel test, as it reveals how the independent value – in our case, the amount of an invasive species in each quadrant – is related to an X-Y plot. In other words, how does the data on the invasive plant correlate spatially? Can one predict the presence or absence of a plant based on its location in the plot?

The distance matrices and Mantel permutation tests were performed in the R statistical language and programming package, developed by Pierre Legendre (Legendre 1998) ~~and available for free download on the internet~~. The ~~hard~~ data collected at the Front Royal SIGEO plot was converted into a CSV (Comma Delineated Values), and imported into the R package's memory. Next, the X-Y coordinates were treated as vectors in order to create a distance matrix, using a traditional geometric measure of distance – in other words, the distance added by the earth's curvature was not accounted for. This extra distance would have little effect on such a small plot, though in the case of larger plots longitude and latitude could be used to accurately reflect distances.

Results

Throughout the 229 plots assessed, the most common specie was *B. thunbergii*, with 1345 instances reported. The second most common species was *R. phoenicolasius* (692 individuals), and the third most common species was *L. japonica* (342 individuals). The most rare species was *R. multiflora*.

Table 1. Total Instances of Each Species.

R. multiflora	*L. japonica*	*B. thunbergii*	*R. phoenicolasius*
173	342	1345	692

Next, the effect of deer exclosure was tested by an ANOVA comparing quadrants inside the exclosure (*n*=108) versus quadrants outside (*n*=120). An α-level of 0.05 was used. Any p-values below this were deemed statistically significant, indicating an effect of the deer exclosure on plant presence. As seen in Table 2, the p-value for *B. thunbergii* and *R. phoenicolasius* are both less than 0.0001. Upon further examination, it is revealed that the average *B. thunbergii* individuals per outside quadrant is 10.0250, versus an average individuals per inside quadrant of

1.2593. In the case of *R. phoenicolasius*, there was an average of 0.2778 individuals per inside quadrant, but an average of 5.51667 individuals in each outside quadrant.

Table 2. Anovas: Exclosure (Inside vs. Outside).

Plant	Degrees of Freedom	F-ratio	P-value
R. multiflora	1	1.7100	0.1832
L. japonica	1	0.1872	0.8294
B. thunbergii	1	15.7022	<0.0001
R. phoenicolasius	1	11.1937	<0.0001

Table 3 shows the effects of ground shape. Only *B. thunbergii* showed a significant difference (a p-value below the α-level of 0.05). Furthur examination shows a higher average (u=7.76) of individuals per concave quadrant (*n*=117), and a lower average of individuals per quadrant in convex (*n*=93) quadrants (u=3.22).

Table 3. Anovas: Exclosure (Concave vs. Convex).

Plant	Degrees of Freedom	F-ratio	P-value
R. multiflora	1	2.0187	0.1569
L. japonica	1	0.0131	0.9090
B. thunbergii	1	7.2252	0.0078
R. phoenicolasius	1	1.9104	0.1684

The ANOVA comparing quadrants of different slopes only showed a significant difference in the case of *R. multiflora*, with a p-value of 0.0381 (Please see Table 4). The highest mean was seen in the 'Level' group (*n*=33), with an average of u=1.93548. The other group averages were much lower in the 'Slight' group (*n*=102, u=0.57426), the 'Sloped' group (*n*=87, u=0.58621), and the 'Steep' group (*n*=5, u=0.2000).

Table 4. Anova: Slope (Level vs. Slight vs. Sloped vs. Steep).

Plant	Degrees of Freedom	F-ratio	P-value
R. multiflora	3	2.4007	0.0381

L. japonica	3	1.5750	0.1682
B. thunbergii	3	0.7577	0.5812
R. phoenicolasius	3	0.3865	0.8578

Table 5 indicates that only *R. multiflora* was affected by the stream presence. In the absence of the stream (*n*=191), the average *R. multiflora* individuals per quadrant was 0.55450. However, in the presence of the stream, *R. multiflora* averaged much higher (u=1.97059) per quadrant.

Table 5. ANOVA: Stream (Presence vs. Absence)

Plant	Degrees of Freedom	F-ratio	P-value
R. multiflora	1	14.0094	0.0002
L. japonica	1	0.7900	0.3751
B. thunbergii	1	3.4124	0.0660
R. phoenicolasius	1	0.8706	0.3518

The Mantel tests revealed r correlation coefficients. All tests were run with 9999 permutations, and *B. thunbergii* and *L. japonica* were each run a second time with 99999 permutations in an effort to lower the p-value.   However, this lengthy computational effort was largely unsuccessful, as the p-values only dropped by several hundreths. The r correlation coefficient is on a scale of -1.00 to +1.00. Hence, the greatest absolute value of an r coefficient indicates a larger degree of positive or negative correlation. In this case, the *R. phoenicolasius* had the largest r coefficient, with the lowest p-value (indicating the strength of the r coefficient given the number of iterations performed). The higher r coefficient of *R. phoenicolasius* indicates better spatial correlation. However, it is still quite low. It appears all four species have a small degree of positive spatial correlation.

Table 6. Mantel Tests (Spatial Analysis).

Plant	*R. multiflora*	*B. thunbergii*	*L. japonica*	*R. phoenicolasius*

| *r Coefficient* | 0.01872239 | 0.1026360 | 0.02070744 | 0.1556907 |
| *Simulated P-value* | 0.2682 | 0.0012 | 0.2458 | 1e-04 |

Discussion

B. thunbergii and *R. phoenicolasius* both showed a significant difference in abundance inside the deer exclosure versus outside of it. There were higher concentrations of both plants on the outside of the exclosure. The concentrations of *R. multiflora* and *L. japonica* were the same on either side of the exclosure fence. These results suggest that there is a difference for how the two groups of plants grow or are dispersed.

Preferential browsing may explain the distribution differences. If deer preferentially browse on *R. phoenicolasius* and *B. thunbergii*, their exclusion could benefit or hinder their survival. Deer exclusion would hinder *R. phoenicolasius* and *B. thunbergii* survival if deer provide a vehicle of dispersal for both invasive species. In contrast, deer exclusion would benefit *R. phoenicolasius* and *B. thunbergii* if deer browsing significantly damaged their growth. The higher concentration of these invasives on the outside of the exclosure suggests that deer dispersion is important for their seed distribution.

Deer browsing may also explain the lack of concentration variance for *R. multiflora* and *L. japonica*. If deer do not feed on *R. multiflora* and *L. japonica*, then deer exemption may not affect their growth or concentration. Not only would these plants not be affected by vascular damage generated by deer browsing, they would also not rely upon deer for seed dispersal. Another explanation could be the balancing of beneficial and detrimental effects of deer browsing. A study by Fargione et al. (1991), which ordered a list of sixty plants based on how

likely they are to be browsed by white-tailed deer, found *R. multiflora* and a relative of *L. japonica*, *Lonerica heckrotti* are "occasionally severely damaged" by deer.   This was the second highest ranking for deer browsing. This finding suggests that damage of deer browsing for *R. multiflora* and *L. japonica* is counteracted by a benefit of browsing such as seed dispersal. One could distinguish between the two effects by observing the characteristics of invasives on the inside and outside of the exclosure such as vascular damage and biomass. Also, assaying neighboring deer for the viable seeds within their excrement could help determine if local *R. multiflora* and *L. japonica* rely upon deer for seed dispersal.

The distribution of the invasive species we studied may be explained by other environmental factors than deer browsing. In previous studies, a richer soil or lower C:N ratio was the single most important predictor for finding both *B. thunbergii* and *R. multiflora* (McDonald 2008). Deer feces could supply a large amount of nitrogen necessary for invasive growth.   However, this nitrogen availability would not explain how *B. thunbergii* and *R. multiflora* were differently affected by deer exclusion. Exposure to sunlight affects plant growth and reproduction. High exposure to sunlight produced invasive individuals more than six times the typical size in the case of Garlic Mustard in Central Illinois (Anderson 1996). While non-invasive growth was not directly measured, observations in the field suggested that non-invasives grew better within the deer exclosure. Thus, invasives within the exclosure may have less sunlight and nutrient available due to the success of non-invasives.   Difference in concentrations could be a result of higher tolerance for deer browsing, low nitrogen levels, and decreased direct sunlight.

The composition of native plants, which seem to benefit from deer exclusion, could be a factor in the success of invasive establishment and growth. On a study of annual plants in Northern California, community-composition data was a better predictor than biome characterization for the reproductive output of sown individuals and abundance of existing populations (Elmendorf & Moore 2008). A survey of native plant diversity and abundance at the study site may elucidate conditions that favor certain invasive species. From there, one could assess the effect of deer browsing on the native plants and determine if deer contributions to invasive abundance are primarily through native plant eradication.

Finally, other local animal species may override the effects of white-tailed deer. Invasive species rely upon other species for seed dispersal such as birds. Birds can disperse seeds as far as 450 meters away from the source (McAlpine & Jesson, 2008). For *R. multiflora* and *L. japonica*, birds may serve as the primary source of seed dispersion. If so, their concentrations would not be affected by deer exclusion.

The survey results proved our predictions accurate in the case of *Berberis thunbergii*. At 1,395 individuals, it was the most prevalent species by almost twice as next most prevelant species. It was also significantly more abundant outside of the exclosure. These findings strongly support previous research suggesting birds do not often disperse the berries and that deer likely forage on them even if it is only after other food sources are depleted. The results did not show significantly more *Berberis thunbergii* in the presence of the stream as we might have expected, but there was uniformly strong growth throughout the plot on the exterior of the exclosure.

Our predictions for *Rubus phoenicolasius* were also supported by our data. Our results showed it growing significantly more outside of the exclosure (P <0.0001). The clear difference between

the inside and outside of the exclosure suggests that, even though birds disperse the berries, they do not play a large dispersal role at our study site. Though some of our predictions were supported by our hypotheses, further direct and more restrictive measurements will be needed.

The *Rosa multiflora* results confirm only one aspect of our hypotheses. We were correct in predicting that the exclosure would have little effect on its distribution. However, This result may not be related to our predicted causes. We predicted *Rosa multiflora* to show strong growth, but it proved to be the least abundant of the species measured. The low numbers on both sides of the exclosure fence may be a reason why there were not significantly more on either side. The role of bird dispersal over deer dispersal as predicted cannot be discounted either. The significant finding of more *Rosa multiflora* by the stream was an unexpected one (P = 0.0002), but it suggests species preference for wetter soils. The significance of the finding should be followed up with future studies.

One future study might include a similar study with the removal of all bird species. Nets or repellants could be used over portions of the site to examine the role of birds in seed dispersal. If the same results were discovered after such a study, the significant findings between the interior and exterior of the deer exclosure could be attributed to deer presence. Another study that could determine the validity of our hypotheses is a sun-exposure test. A greenhouse experiment with differing light treatments could be constructed for *Rubus phoenicolasius* to measure this (Snitzer et al. 2005). Similarly, if a sun-intensity measurement could be taken at the study site and compared with our results, we would be able to correlate our significant findings with our light measurements to understand the role of sun-exposure. Another greenhouse study should be

constructed to test the repeatability of our finding of significantly more *Rosa multiflora* in the presence of a stream.

There were no significant differences in plant concentration due to aspect, or slope suggesting that they do not influence invasive growth. However, this could be a result of inconsistent data collection. Different groups collected field data daily and, thus, personal differences in measurement techniques could have accounted for discrepancies in aspect and slope measurements.

Some limitations to the data collection procedure include the reliability of the deer exclosure fence. Many of the thunderstorms that occurred in Front Royal caused trees to fall and knock down sections of the fence. There were times when portions of the fence were down for days at a time before CRC staff was able to fix it. During these times, deer were observed within the exclosure. Thus, it is possible that the density of the invasive plants we found inside of the exclosure area was not accurate. Unfortunately, there was not much that could be done to prevent this except to continually reinforce the fence after each tree fall in a timely fashion. However, because of the overwhelming number of deer on the property as a whole, the damage done by the small number of deer that got into the exclosure area should be negligible.

Another confounding factor is that *L. japonica* grows very low to the ground. Unlike the other three species' that we counted, it was difficult to find underneath of the leaf litter and it is possible that *L. japonica* stems were left undocumented both inside and outside of the fence. Because there were so many different people collecting data throughout the week, we cannot be sure that everyone was equally careful in looking for it. In the future, it would be better if there

was a more standardized method of looking for and counting the invasive plants so that the data collected would be more consistent.

The mantel tests showed a small spatial correlation by the r coefficient. However, the absolute value of any of the four species' r coefficient never climbs above 0.15 (see Table 6). It is difficult to find a perfect r coefficient of -1.00 or +1.00, so 0.15 is still noteworthy. Nonetheless, it is a lower indicator than we would have predicted. One can glean from this test that invasive species are spatially correlated, but it is not responsible for the majority of their spread. Explanations for this finding might also include the already widespread nature of the invasive species across the plot. If, for example, the data collection happened several years ago, it might be more clear as to where on the plot the invasive species originated. Hence, spatial correlation would be easier to track as a function of time. In this case, the statistic seems to be diluted by such an overabundance of every species on each plot.

Another option for our statistics would have been a Partial Mantel Test. In this test, two distance matrices are compared and a third matrix – detailing a third variable – is used much like an ANOVA, to test for significance of the variable. This would have been useful in our experimental set-up for testing the effects of the deer exclosure while simultaneously testing for spatial correlation. However, Pierre Legendre and many other scholars have written extensively on how the Partial Mantel Test is a weak test, and nearly impossible to interpret accurately (Legendre, 1998). Though it might have been quite useful in regards to our data set, it was avoided due to its unfortunate inherent limitations.

This data elucidated the difference with which invasive species are affected by deer exclusion in a temperate deciduous forest. The next step is to decompose the environmental

factors that affect invasive concentration. These studies could be performed in greenhouses

where the diverse variables that are encountered in the field can be controlled and accounted for.

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