Deer as agents of seed dispersal in a mixed hardwood forests of differing deer population management.

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Abstract:

Overabundance of white-tailed deer (*Odocoileus virginianus* Zimmerman) is a growing problem throughout the eastern United States. This study investigates the role that deer play as seed dispersers focusing on two main questions. Are they now spreading invasive plant species? Which species are viable after passing through the deer? I compare seed dispersal by white-tailed deer at two contrasting sites: the Florence J. Reineman Wildlife Sanctuary in Landisburg, Pennsylvania, where heavy deer browsing has eliminated the understory allowing invasive species such as Asian stilt grass (*Microstegium vimineum* (Trin) A. Camus) to take over the forest floor, and a nearby stretch of heavily-hunted forest (State Gamelands170) with comparable canopy tree composition but with a dense understory. Twenty- four deer pellet samples containing between 10 and 30 pellets were collected from the two locations, 13 from Reineman and 11 from the state gamelands. Half of each sample was planted to investigate germination rates, and the other half was dried and sorted for seed counts and types. Thirty-three species of seeds were extracted and fourteen were identified. An additional nine species were identified from the germinated plants. In total, thirty-six plants germinated. The species distribution was significantly different between the two sites and had very little overlap in dominant species. The species found in the Reineman Wildlife Sanctuary samples tended to be field herbs which require full sun suggesting that the deer are foraging in fields in or near the sanctuary. The state gamelands samples contained more shade tolerant woods plants. Despite these differences between the sites, the seed and plant data suggest that the deer at both RWS and SGL disperse invasive and native species comparably. About 30 percent of the seeds in the pellet piles at both locations were non-native. This is important for the future management of the Reineman Wildlife Sanctuary and similar sanctuaries throughout Pennsylvania and the east coast.

TABLE OF CONTENTS:

LIST OF TABLES AND FIGURES:

INTRODUCTION:

In Pennsylvania, as throughout much of the eastern United States, white-tailed deer (*Odocoileus virginianus* Zimmerman) overabundance has become a serious concern. Because of their pervasiveness throughout the state, white tailed deer are very much a part of Pennsylvania history and culture. Deer are considered to be among the most important big game species in the United States and certainly within Pennsylvania. Pennsylvania is the second highest state in the nation for in-state hunting and deer are a popular game species (Rosenberry et al, 2009) However, their size, abundance, and appetites make deer capable of having a major impact on plant species, and white tailed deer need to be managed not only for recreational use but also for the protection of Pennsylvania forests. Deer browsing is well understood to impact plant growth in forests (DCNR, 2013). This study investigates another way in which they may have major impacts: seed dispersal of the plants they eat.

History

White tailed deer have existed in Pennsylvania since before European settlement. They are abundant across a wide range of habitats from arctic climates in Canada to tropical forests in South America as well as throughout areas of suburban development. They do particularly well in post agricultural habitats such as Pennsylvania's (DiTommaso et al, 2014). Historically, their populations were limited by predators such as wolves and mountain lions as well as through hunting by Native Americans (Rosenberry et al, 2009; DCNR, 2013). They quickly became part of the early European culture in America and were used as a supplemental food source for thousands of households in addition to providing recreational benefits. Deer were nearly hunted to extinction in Pennsylvania and throughout the east coast. In 1907, a law was passed prohibiting the hunting of antlerless deer because it would hinder the herd's ability to recover

(Rosenberry et al, 2009). At the same time, heavy logging increased the amount of early successional habitat, ideal for white-tailed deer. In addition, suburban development and agricultural expansion in Pennsylvania created a mosaic of forest patches and open fields ideal for deer (Williams et al, 2007). Finally, their natural predators became locally extirpated (Horsely et al, 2008). The combination of these circumstances facilitated the recovery of white-tailed deer. From 1905 to 1928, Pennsylvania's deer population increased from approximately 1,000 deer to 1,000,000 deer. Since their recovery in the 1920s, deer populations have been high enough to cause significant impacts across the state (DCNR, 2013).

Impacts

Large grazing mammals are known to be keystone species in forests because they can restructure entire ecological communities. They act both as important agents of seed dispersal and vertical forest structure manipulation (Rooney & Waller, 2003; Myers et al, 2004; Pedersen & Wallis, 2004). The white-tailed deer is one such species known to have significant impacts in both of these roles (Baiser et al, 2008). In fact, deer are considered one of the two greatest threats to natural preserves (Williams et al, 2007). Deer preferentially browse nearly 100 endangered or threatened plant species (Williams et al, 2007). Overbrowsing by deer can cause local extirpations of native plants (Augustine and Frelich, 1998). One example of extreme local extirpation by deer is Woods Metro Park in Ohio. Over 150 species of vascular plants have been locally extirpated by the deer population which at times throughout history reached densities of 110 animals per square kilometer in that area (Rooney & Wallis, 2002). They are also important seed dispersers for the many plants that they browse. A study of seed dispersal in southern New Englad found that out of 82 taxa dispersed by white tailed deer, 72 successfully germinated (Williams et al, 2007).

Seed dispersal

Large herbivores like deer are important for seed dispersal because they can transport seeds over large distances. Seeds are transported on the coats of deer or through ingestion and subsequent defecation of the seeds (Baiser et al, 2008). This allows the seeds to germinate further away from the parent plant thus to and spread the population. Viable seeds are often found in the feces of wild ungulates like deer. Passing through the gut of a deer can be extremely beneficial for certain plants. Ingested seeds need less time to germinate, germinate in greater numbers, and produce more robust plants (Traveset & Verdu, 2002). Due to the enzymes and acidity within the gut, seeds coats break down in the digestive tract allowing the seed to more easily germinate after passing through a deer. The subsequent seedlings are more robust because these seeds are given a competitive advantage by the surrounding nutrient rich feces (Traveset & Verdu, 2002). In particular, small and hard-coated seeds persist through the gut and are viable (Myers et al, 2004). Studies show that 95 percent of the seeds successfully dispersed by deer are carried over 100 meters and 30 percent are carried over a kilometer (Myers et al, 2004). Deer are known to be seed dispersers for both alien and native species. Deer have been found to disperse between 30 and 70 alien species depending on their availability in the area (Myers et al, 2004; Williams et al, 2007). This capacity to introduce and spread invasive species gives deer the ability to potentially change forest ecosystems, in regards to species composition.

Forest Regeneration and Canopy Gap Replacement

White-tailed eer browsing affects tree growth and survival as well as species composition and abundance. Deer browsing also affects tree height development (Horsely et al, 2003; Pedersen & Wallis, 2004). Deer directly affect forest succession by inhibiting tree establishment and canopy gap replacement which they do by consuming all young trees (Pedersen & Wallis, 2004; Horsely et al, 2003). In a healthy ecosystem, an overstory tree will die and leave an opening in the canopy. New trees will establish near the dead tree and begin to fill in the gap. As time passes, these trees compete for resources, such as light, in that gap until one or two trees are left to fill the space (Pedersen & Wallis, 2004). Through preferential browsing deer can influence which trees ultimately fill the gap. In a balanced ecosystem, deer can benefit certain woody species because they browse competing vegetation or increase growth rates by biting off the tips of plants (Pedersen & Wallis, 2004). However, in ecosystems where the deer population densities are too high, studies show that deer can inhibit canopy gap replacement. In these cases, the gaps are closing very slowly or not at all due to the low density of small trees capable of joining the overstory (Pedersen & Wallis, 2004). Studies show that only 43 percent of Pennsylvania's forests are adequately stocked with regeneration trees (DCNR, 2013). Thus, as these forests age, less than half will have sufficient ability to perpetuate themselves through regeneration.

Invasive and Alien Species

In addition to directly modifying vertical forest structure and composition through preferential and over browsing, white-tailed deer also indirectly engineer forests by facilitating the growth of invasive plants. In this case, significant browsing by deer creates ideal habitat for invasive species thus allowing these species to take over (Rooney & Waller, 2002). Native species are plants that are indigenous to a particular region or country. Invasive species are alien species that when introduced to a region become aggressive once they establish. They have negative impacts on the communities in which they establish (Sarver et al, 2008).

In the northeastern United States the native hayscented fern *(Dennstaedtia punctilobula (*Michx.) T Moore), native New York fern (*Thelypteris noveboracensis* (L.) Nieuwl), and the invasive Asian stilt grass (*Microstegium vimineum* (Trin.) A.Camus) tend to do well in areas heavily browsed by deer (Horsely et al, 2003; Baiser et al, 2008; DCNR, 2013). These species have the ability to rapidly form dense stands, which exclude other plants (Pedersen & Wallis, 2004).

The Asian stilt grass is one invasive species which studies have shown benefits greatly from deer browsing. In less than 100 years, this shade tolerant C4 grass has invaded the entire east coast from Florida to Maine (Baiser et al, 2008). Deer homeranges average about 233 hectares for a male and 221 hectares for a female in Pennsylvania. This range allows the deer to move through areas of fragmented forest and pass between areas of stilt grass and non-stilt grass making them effective seed dispersers for this plant (Baiser et al, 2008).

Asian stilt grass is an annual grass that grows between 30 to 100 centimeters tall, produces copious amounts of seeds, and can tolerate closed canopy systems making it the perfect invasive species (Gibson et al, 2002). It does well in edge habitat and disturbed habitat, and stilt grass is not a species preferred by deer (Baiser et al, 2008; Gibson et al, 2002; DCNR, 2013). In this way, the deer maintain the stilt grass dominance as they do not eat it but will eat anything that manages to establish and poke through the grass (Baiser et al, 2008).

Even once the deer population is under control, the legacy of their presence remains. The ferns and stilt grasses are still present and may continue to maintain the altered forest composition despite the reduction in the deer population (Pedersen & Wallis, 2004; DCNR, 2013). For this reason, deer overabundance is of great concern.

Collective Impacts on the Forest

The effects of white-tailed deer accumulate over time (Horsely et al, 2003). They inhibit canopy gap replacement through overbrowsing of small trees and dispersal of invasive species which outcompete native ones. They also affect the reproductive viability of trees by defoliating and consuming the fruit from reproductive plants (Augustine & Frelich, 1998; Williams et al, 2007). Significant defoliation in one season can lead to lower reproductive success in subsequent seasons and thus the size and species distribution of the forest begins to change (Augustine & Frelich, 1998).

Deer-induced changes in the spcecies composistion of the forest has implications throughout the food web (Rooney & Waller, 2002; Baiser et al, 2008). Browse tolerant species and browse sensitive species are generally structurally different. Browse tolerant species have a higher lignin content making them harder to break down (Rooney & Waller, 2002). An increase in the relative abundance of browse-tolerant species can cause a buildup of leaf litter on the forest floor thus changing the microclimate, the soil chemistry, and site fertility (Rooney & Waller, 2002; Baiser et al, 2008). The change in microclimate affects soil-based ecosystem services whose effects can be seen throughout the trophic levels (Baiser et al, 2008). For example, the changes in the insect community in the soil, in conjunction with a loss of understory habitat can alter bird communities (Basier et al, 2008; Rooney & Waller, 2002; DCNR, 2013). Some ecosystem services such as water retention abilities may be lost as well (Basier et al, 2008). Once all of these changes have combined, the deer have engineered a new forest with different plants, animals, and insect communities.

Human Impacts

White-tailed deer are costly to residents in areas with high densities. There are over 40,000 deer –vehicle collisions a year in Pennsylvania. In addition to costing millions of dollars in repairs, these collisions can be fatal (Suburban Whitetail Management of Northern Virginia, 2014). Last year, New Jersey reported over $10 million dollars in damage and over 100 deaths

(Suburban Whitetail Management of Northern Virginia, 2014). The agriculture and timber industries also experience millions of dollars in losses due to deer browsing.

Deer impact Pennsylvania's crops by consuming corn, small grains, orchards, nurseries, and vegetables. The estimated costs in lost crop damages are between $16 and $30 million dollars annually (Rosenberry et al, 2009; Horsely et al, 2003; Basier et al, 2008). In addition to crop loss, deer are vectors for disease. They are carriers for bovine brucellosis and tuberculosis which affect livestock. They are also vectors of human diseases such as Lyme's disease and ehrlichioses (Rosenberry et al, 2009; USDA, 2003).

No only do the deer affect the agricultural industry but also the timber industry. The deer impact on the timber industry is a result of their ability to slow down forest regeneration capacity. This impediment of forest regeneration impacts how long loggers need to wait in order to be able to re-cut an area. This setback is estimated to cost as much as $367 million annually (Rosenberry et al, 2009). In areas with high deer densities, loggers have begun to install fences after cutting to increase the chance of successful regeneration. Ten percent of timber revenue is now put aside for activities associated with regeneration projects such as fencing, mowing, and herbicides (DCNR, 2013). The Bureau of Forestry maintains approximately 40,000 acres of this fencing which cost about $16 million in installation fees alone (DCNR, 2013).

Management Strategies

The Pennsylvania Game Commission is responsible for managing the white-tailed deer population. Its goals are to manage the population for a sustainable deer herd, for a safe and acceptable level of deer-human conflict, for a healthy forest habitat, and for recreational opportunities (Rosenberry et al, 2009). There are two types of management options, lethal control and non-lethal control (Rosenberry et al, 2009). Lethal control options such as hunting are considered the most effective with species, like deer, that have a low reproductive rate and high survival rate (Rosenberry et al, 2009). They are also easier and cheaper.

Non-lethal options, which are generally more accepted by animal activists, include fertility control and fencing. Both of these options are temporary. The fencing option involves installing high fences around tracts of land from which deer need to be excluded. The fencing remains in place until trees are established above the browse line (Rosenberry et al, 2009). Fertility control is a more controversial alternative to hunting. Fertility control involves the use of immunocontraceptive vaccines which interfere with proteins and hormones essential to reproduction. There are two types although they are not both EPA approved yet. Poorcine Zona Pellucida is the first type. A single shot effectively reduces fertility in females for at least five years (Rosenberry et al, 2009). It is still considered experimental. The second type, Gonadotropin Releasing Hormone is a registered EPA pesticide. It is effective for one to two years. Both vaccines need to be applied via injection (Rosenberry et al, 2009). The process of controlling deer becomes much more time and money intensive when remote delivery is not an option.

Objectives

The objectives of this study are to further investigate the role of deer at a local wildlife sanctuary which has been heavily impacted by overbrowsing. This study seeks to answer two questions: Are deer spreading invasive plant species like the Asian stilt grass? Which species are viable after passing through the deer? The managers of the wildlife sanctuary do not currently actively manage the deer population. This study hopes to inform the management of this sanctuary and other like sanctuaries by looking at deer impacts through seed dispersal and by making deductions about deer movements based on the plant species they consume. Specifically, this study compares the diet of white-tailed deer in this heavily impacted wildlife sanctuary to a tract of state gamelands with similar canopy vegetation composition to see how the role of deer as seed dispersers is different between the two locations. The overbrowsed wildlife sanctuary has no understory and dense stands of the invasive Asian stilt grass while the state gamelands has a well-developed and diverse understory (Pedersen & Wallis, 2004). Since Asian stilt grass is so pervasive at the wildlife sanctuary, this study hypothesizes that the deer must in fact eat the grass and further exacerbate the forest degeneration. Since invasive species are opportunistic, this study hypothesizes that they will benefit from being ingested by the deer and have mechanisms to allow them to have higher germination rates than the native species.

METHODS:

The methodology for this study was largely based off a study done by Myers et al (2004) in which they collected fecal pellet samples and extracted the seeds. The Myers et al (2004) study investigated how the role of deer as seed dispersers changed seasonally. This study advances the Myers et al (2004) study by investigating how deer act as seed dispersers at one point in time and comparing this across two forests with differing management strategies.

Study Site

Two sites were chosen based on having differing deer management strategies. The first site chosen was the Florence J. Reineman Wildlife Sanctuary (RWS) in Landisburg, Pennsylvania (Fig 1).

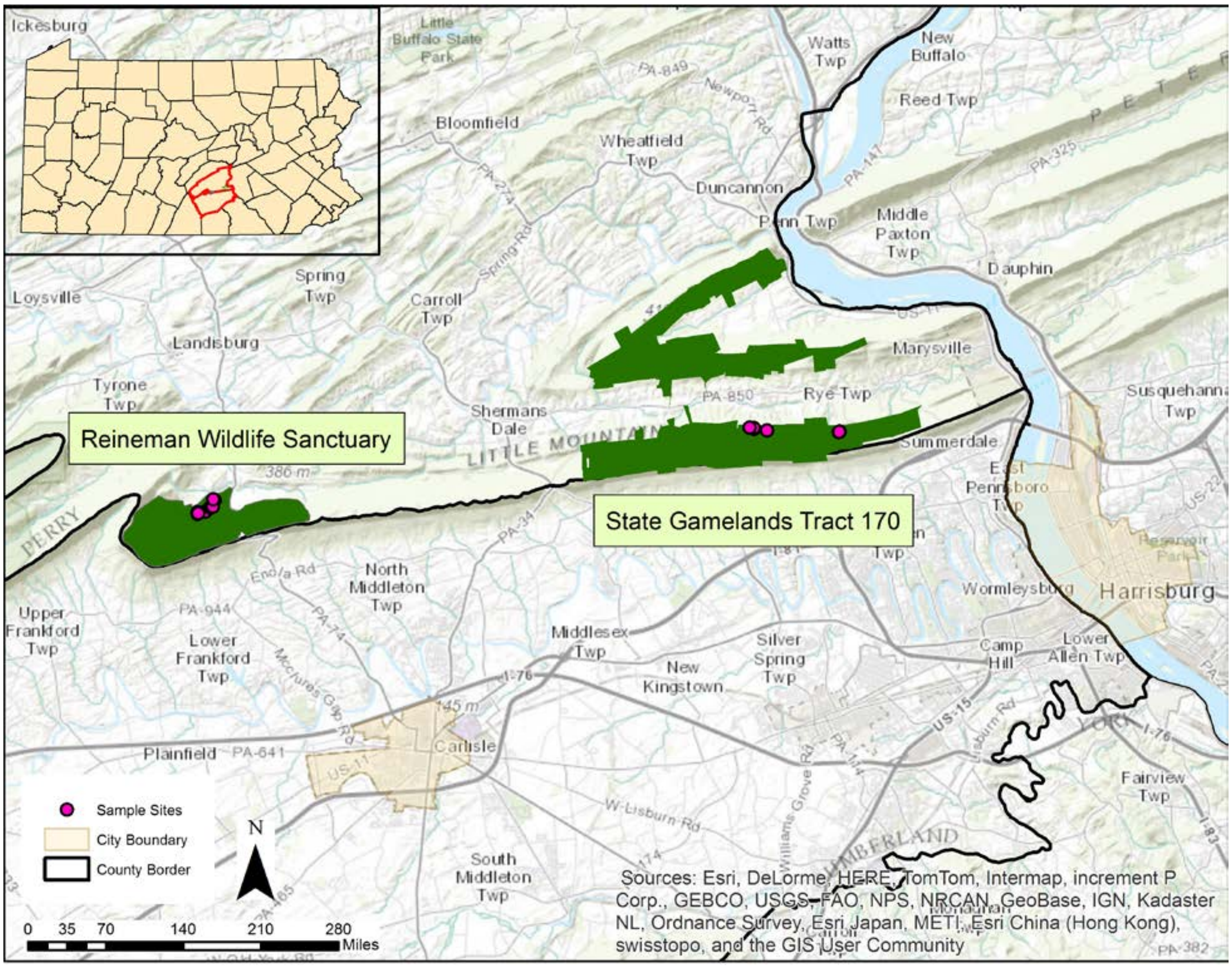

Figure 1. Location of sample sites in RWS and SGL 170.

RWS is a 3,100 acre tract of land which has been protected against deer hunting since 1965 (National Park Service, 2013). Since its protection in the 1960s, the deer population has grown tremendously. In this time, RWS has experienced a drastic change in the vertical forest structure. A very clear browse line has developed. There are little to no new saplings sprouting up throughout the forest. In fact, there is hardly anything between the canopy and the ground vegetation. In addition to the development of a browse line the invasive species, Asian stilt grass, has completely covered the forest floor (Fig 2) (Pedersen & Wallis, 2004).

Figure 2. Example of the vertical forest structure of RWS with a blanket of Asian stilt grass and ferns on the forest floor and then nothing until the canopy.

Given that Asian stilt grass is the dominant species of the RWS understory and one facilitated by deer browsing, samples were collected in September when the grass was seeding to check for its presences in the deer diet.

The faculty of Dickinson College have studied Reineman Wildlife Sanctuary extensively. Studies include deer counts, exclosure studies, and canopy gap replacement studies. These studies suggest that the deer population is impacting the sanctuary severely. The complete lack of understory creates grounds for concern. Without an understory of young trees, there will be no way for RWS to undergo successful forest regeneration. The trees that currently constitute the canopy were largely established before the deer overabundance became a problem (Pedersen & Wallis, 2004). These trees are getting older now, and studies show that the gaps are not closing very quickly or in some cases at all because of the loss of understory (Pedersen & Wallis, 2004).

State Gamelands 170 (SGL) was chosen as a contrasting study site. It has a more manageable deer population because it allows hunting (Pedersen & Wallis, 2004). Consequently it also has a more developed understory. SGL has a very similar canopy vegetation composition to RWS but a drastically different understory. The understory in the SGL is well developed and diverse (Pedersen & Wallis, 2004). SGL is located in a geographically similar location to RWS with similar soils and geology (Fig 1). Both the SGL site and the RWS site are located on the north slope of the Kittatinny Mountain Ridge (Pedersen & Wallis, 2004). The one big difference is that the deer population is much more manageable most likely due to hunting permitted on the land.

Field Data Collection

Fresh deer pellet piles were collected from the two sample sites from September 14th to September 29th in an attempt to capture the seeding time of Asian stilt grass. Measures were taken to ensure that seeding species composition did not change drastically between collection dates. Every time pellet piles were collected from one of the study sites, the other one was sampled within two days. Samples were only collected if they were within a few days old. The freshness requirement was met if the samples were soft, moist, and dark. The piles were collected in Ziploc bags and stored in the refrigerator until they could be further processed.

In order to ensure that the seeds present in the pellet samples had been consumed by deer and were not from neighboring plants, the pellet piles were checked for a seed dusting on the outside. In all cases, the seeds were pervasive throughout the sample thus reducing that confounding factor. Gloves and hunting vests were worn as necessary to ensure the safety of the field researcher when out in the field.

Lab Data Collection

Each sample was split in half by weight. The seeds were manually extracted out of one half of the sample. The other half of each sample was split among ten cups filled with Agway brand potting mix and placed in a walk-in refrigerator at 4°C for six weeks to simulate cold wet stratification. Some seeds require this cold wet stratification in order to break dormancy (Baskin et al, 2002). The need for cold wet stratification is species dependent and some species require cold stratification while others require warm and still others require both (Baskin et al, 2002). Given the time constraints for this experiment, cold wet stratification was the only type used because it simulates conditions most similar to central Pennsylvania winters.

During this time, the potted seeds were watered once a week and the light regime in the refrigerator was set to mimic winter light conditions. After six weeks, the potted plants were placed in a greenhouse and watered on a regular basis to investigate germination rates of the species. Once the seeds had sprouted and grown large enough for identification, the Rhoads and Block (2007) and Holgren (1998) guides were used to identify them.

The second half of each sample was manually sorted for seeds. In order to get to the seeds, the sample was broken up and dissolved in water to free the seeds from other matter in the pellets. The slurry was then poured over a 0.5 mm sieve as suggested by Myers et al (2004). The water that passed through the sieve from the first two samples from each site location was checked to ensure that seeds were not small enough to pass through it. Larger samples were pre-sorted using floatation methods to cut down on processing time. These samples were broken up and then poured into a large basin of water. A modified 0.5 mm sieve was again used to this time to skim the seeds off the top. Similarly to the first sieving method, the material that sank was checked for the first two samples to ensure species were not missing because they sunk.

Once the seeds had been isolated on the sieve either through the slurry method or floatation, they were pulled out, counted, and identified using Montgomery (1977). This identification was used to give insight into the species composition of the deer diet. More specifically I wanted to see what the deer at RWS might be eating given they have more limited options than the SGL deer.

Data Analysis

The data were then analyzed using the inverse Simpson's index for biodiversity (Chiarucci et al, 2011). Both the seeds and the germinated plants were analyzed for biodiversity. The inverse Simpson's Index is a measure of evenness and the number of seed types. Evenness refers to how close the count is for each species. In order to have an even distribution, all of the species would need to have a similar count. As the number of species types increases and the evenness increases, the inverse Simpson's Index also increases.

Prism software was used to run statistical analysis of the data for Reineman Wildlife Sanctuary compared to the state gamelands. A chi-squared test of independence was used to compare the species distributions at the two sites. A two-tailed t-test to test was used to compare the mean number of species and number of seeds found in the samples from the two sites. Prism, Excel, and ArcGIS were used to create the figures. ArcGIS was also used to determine the areas of human use that would have the potential to be impacted by RWS deer.

RESULTS:

Twenty-four deer pellet piles containing 10 to 30 pellets were collected from RWS and SGL 170. The average weight of the dry fecal matter was 3.006 grams per sample. In total, 33 species were identified from the seeds (Table 1).

Table 1: Descriptive data collected from the seed counts of the half pellet piles. The average weight of the dry fecal material was determined by weighing all of the dry material from each site at once to get an average per pellet pile.

	RWS	SGL	Total
Number of samples	13	11	24
Number of seeds	879	434	1,313
Average number of seeds per sample	68	39	56
Average weight of dry fecal material	3.090g	2.921g	3.006g
Seeds per gram of fecal material	22 seeds/gram	13.6eeds/gram	17.8eeds/gram

Seed Analysis

On average, the pellet samples from RWS contained more seeds than those from SGL although the difference was not significant (Fig 3) (t=0.9969. df=22, p=0.3297).

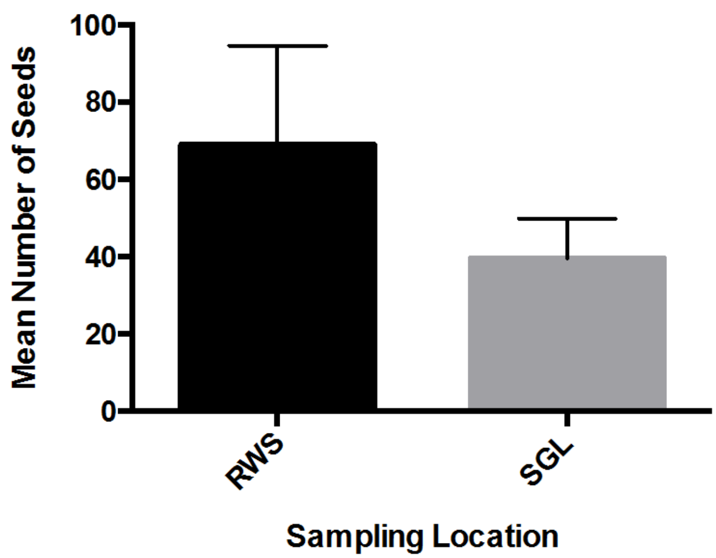

Figure 3. The mean number of seeds per half pellet pile found in each site. The error bars represent a 95 percent confidence interval.

In total, 1,313 seeds were extracted from the 24 samples. However, only half of each sample was processed for seed counts. This number can therefore be doubled to reflect approximately the full pellet sample. This suggests that these 24 samples contained close to 2,600 seeds or 56 seeds per sample. The number of seeds found per sample ranged from one seed found in Sample 4 to almost 330 seeds found in Sample 7. For the purpose of analysis, seed species contributing less than one percent of the total relative abundance were not used.

The 1,300 seeds represented 33 plant species. Of those 33 species, 14 species contributed more than one percent to the relative abundance of seeds and were thus considered for the results (Table 2).

Table 2. Species identified from samples through both seed counts and germinating plants. The non-numbered plants are those identified only from germinated plants (Rhoads & Block, 2007).

Seed #	Scientific Name	Common Name	Dominant Site	Grand Total	Invasive/Native	Light Preference
1	*Persicaria sagittata* (L). H.Gross	Tearthumb	SGL	208	Invasive	Shaded/ wooded
2	*Persicaria maculosa* S.F. Gray	Lady's thumb	SGL	59	Invasive	Partial or full sun/ canopy gaps and fields
3	*Cratagegus pruinosa* (H.L.Wendl.) K.Koch sensu lato	Frosted hawthorn	SGL	17	Native	Shaded/ wooded
4	*Viola canadersis* L	Canadian white violet	SGL/RWS	122	Native	Sunlight to light shade/ wooded
5	*Betual alleghaniensis* Britton	Yellow birch	SGL	10	Native	Shaded/ wooded
8	*Euphrasia stricta* J.P.Wolff ex J.F.Lehm	Eyebright	RWS	463	Invasive	Sunlight/ field
9	*Sorghum halepense*	Johnson's grass	RWS	79	Invasive	Full Sun/ field
13	*Rubus idaeus* L or *occidentalis*	Raspberry	SGL	124	Native	Shaded/ wooded
16	*Cyclachaena xanthifolia* (Nutt.) Fresenius	Marsh-elder	RWS	11	Native	Full Sun/ field
17	*Solanum nigrim* L.	Black nightshade	RWS	86	Native	Light-Moderate Shade/ canopy gaps and wooded
27	*Digitaria sanguinalis* (L.) Scop.	Large (Northern) crabgrass	SGL	16	Native	Full Sun/ field
30	*Saxifraga virginiensis* Michx	Early saxifrage	RWS	10	Native	Light shade to partial sun/ edge habitat and open wood
31	*Rumex acetosella* L.	Sheep sorrel	RWS	15	Invasive	Full sun/ field
32	*Amaranthus blitum*	Purple amaranth	RWS	42	Invasive	Full sun/ field
-	*Chenopodium album* L.	Lamb's-quarters	SGL	1	Native	Full to partial sunlight/ field and edge habitat
-	*Oxalis dillenii* Jacq.	Southern (Common) yellow wood-sorrel	SGL	2	Native	Light shade to full sun/ field
-	*Amaranthus retroflexus* L.	Green amaranth	RWS	2	Invasive	Full sun/ field
-	*Ageratina altissima* (L.) R.M.King & H.Robinson	White snakeroot	RWS	1	Native	Partial sun/ field
-	*Trifolium pratense* L.	Red clover	RWS	2	Invasive	Full sun/ field
-	*Draba retans (Lam.) Fernald*	Whitlow-grass	RWS	1	Invasive	Full sun/ field
-	*Phytolacca americana* L.	Pokeweed	RWS	1	Invasive	Full sun to partial shade/ field
-	*Trifolim repens* L.	White clover	SGL	1	Native	Full to partial sun/ filed
-	*Unknown*	Unidentified	RWS/SGL	9	-	-

Eight of the fourteen species identified from seed counts were native to Pennsylvania. An additional eight plant species were identified from the germinated plants. Of these species, four of them were also native to Pennsylvania. Of the species identified from the RWS samples, all of them are species with a preference for full or partial sun. There was greater variety of light condition preferences in the SGL species.

The species with the highest relative abundance are eyebright (*Euphrasia stricta),* tearthumb (*Persicaria sagittata)*, raspberry (*Rubus idaeous or occidentalis)*, Canadian white violet (*Viola canadersis*), and black nightshade (*Solanum nigrim*). Both eyebright and tearthumb are classified as invasive. Although eyebright distribution is marginal in the SGL samples, it is the most abundant species in the overall relative abundance because of its high abundance in the RWS samples. RWS samples did have considerably more seeds and this is reflected in the overall relative abundance values. In general, the species distribution and abundance varied greatly between RWS and SGL (Fig 4).

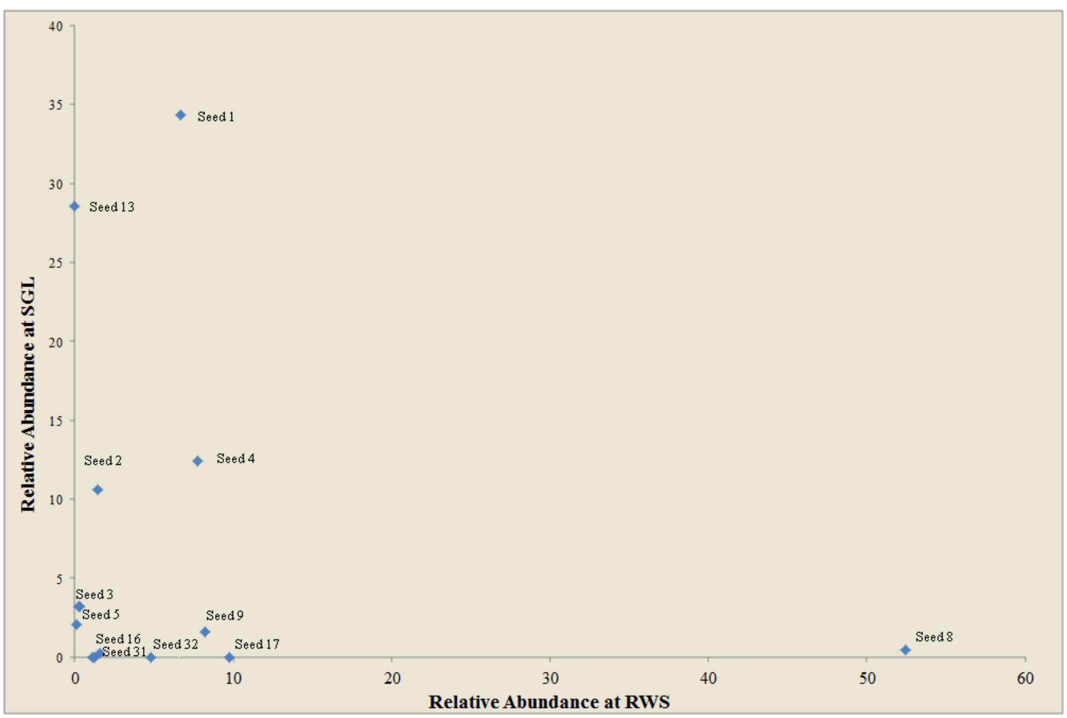

Figure 4. The relative abundance of the species at RWS and the SGL. See Table 1 for identification of seed.

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Eyebright, raspberry, and tearthumb have very high abundances at one site with very low abundances at the other. With the exception of the Canadian white violet, most species were more strongly represented at one site over the other. The difference in the species distribution between SGL and Reineman was statistically significant (χ^2=825, df=13; p value <0.0001). The deer eat very different diets between the two locations. Not only was the species distribution different between the two sites but the deer are also browsing on a greater number of species at RWS compared to the SGL. The samples from RWS contained 29 plant species and the samples from SGL contained only 19 plant species. The inverse Simpson's Diversity Index showed significantly greater species diversity in the pellet piles taken from RWS than those taken from SGL(t=2.309, df=22, p=0.0307) (Fig 5).

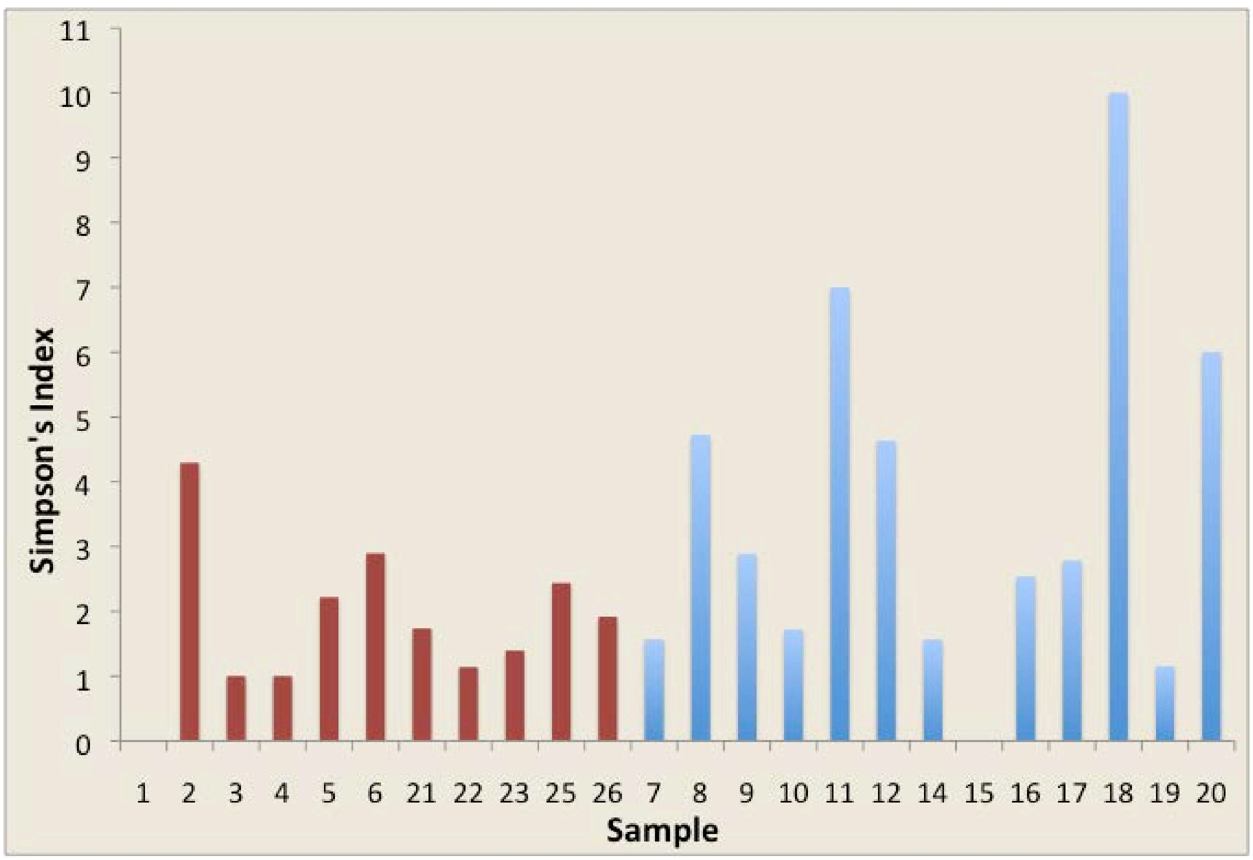


Figure5. The Simpson's Diversity for each sample. The red samples are from SGL and the blue samples are from RWS.

On average the Simpson's diversity index for RWS is 3.58. In comparison the average Simpson's Diversity index at the SGL is 1.91. This is reflected in the germinated plant species diversity as well, although the sample size was much smaller and therefore the difference between the sites was not significant.

Germination Analysis

Out of the 24 samples, 36 plants germinated. In the 13 samples from RWS, 23 plants sprouted. In the 11 samples from SGL, 13 plants sprouted. Overall 23 species were identified between the plants germinated and the seeds counted. Of these 23 species, 12 are classified as native to Pennsylvania (Fig 6A).

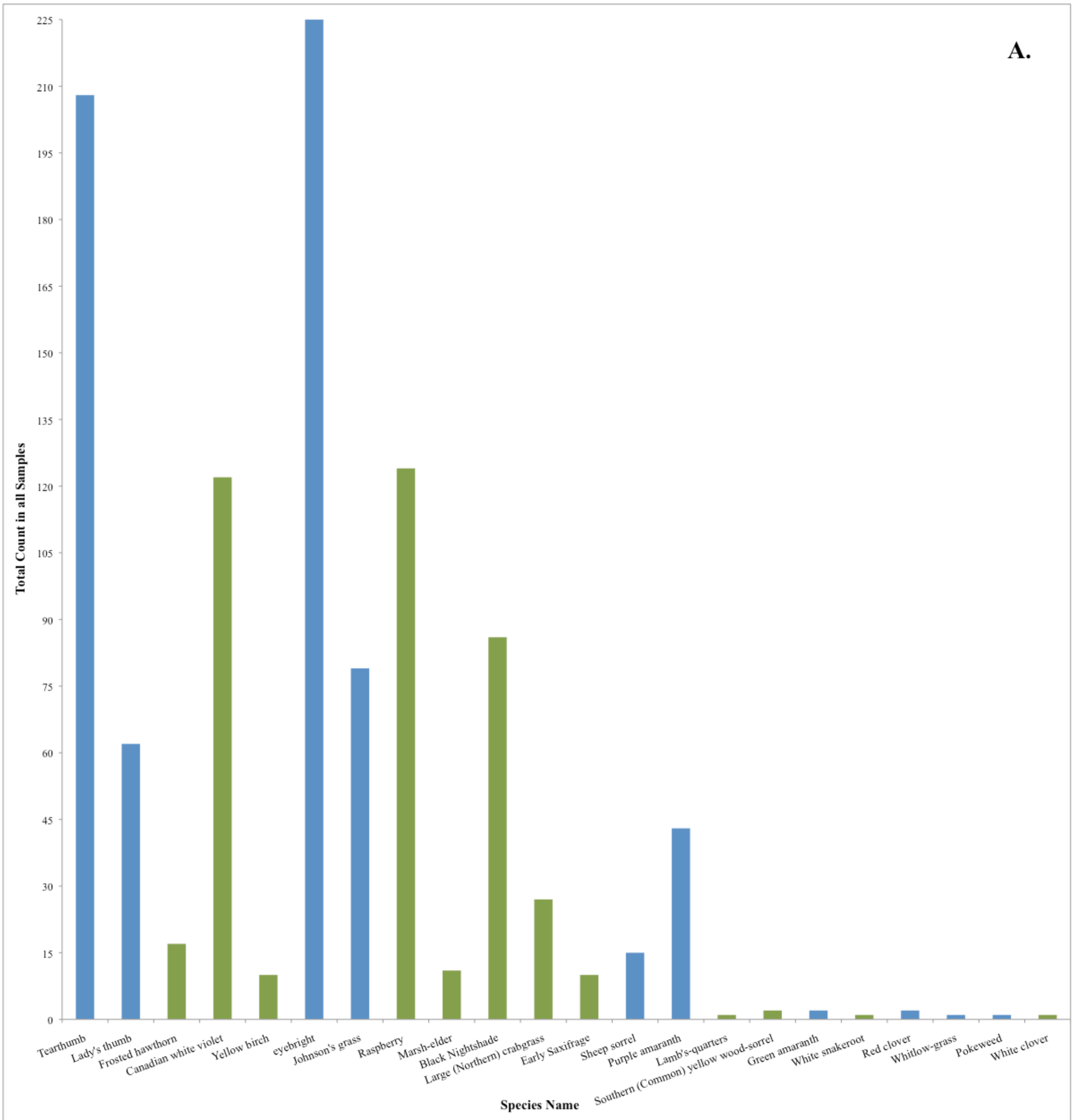
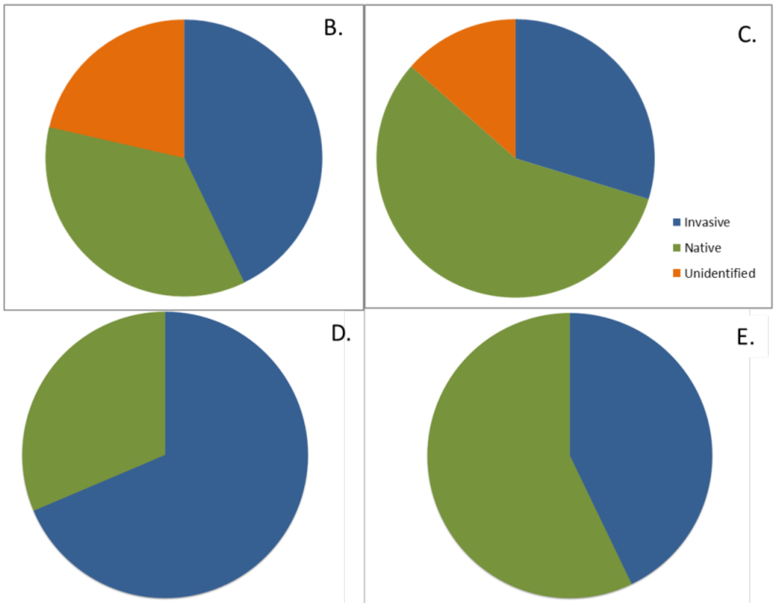


Figure 6 A. The occurrence of each plant species in the germinated plants and seed counts. The green species are native plant species and the blue species are invasive. Eyebright had over 400 occurrences and is cut off.



B. Relative abundance of the native and invasive plant species found in the germinated plants. C. Count of native plants species types compared to invasive plants species types found in the germinated plants. D. Relative abundance of the native and invasive plant species found in the seeds. E. Count of native plants species types compared to invasive plants species types found in the seeds.

The abundance of invasive species was greater than the abundance of native species in both the germinated plants (Fig 6B) and the seed counts (Fig 6D). Despite this, there were more types of native species present in both the germinated plants (Fig 6C) and the germinated plants (Fig 6E). The orange unidentified section represents 5 plants of at least three distinct species which are still too small to identify as they have only just sprouted. The high seed count of the invasive species allowed them to have a high relative abundance despite less species variety (Fig 6D).

Despite having more plants germinate in the RWS samples, the germination success rates are not significantly different between SGL and RWS because SGL had two fewer samples (Fig 7).

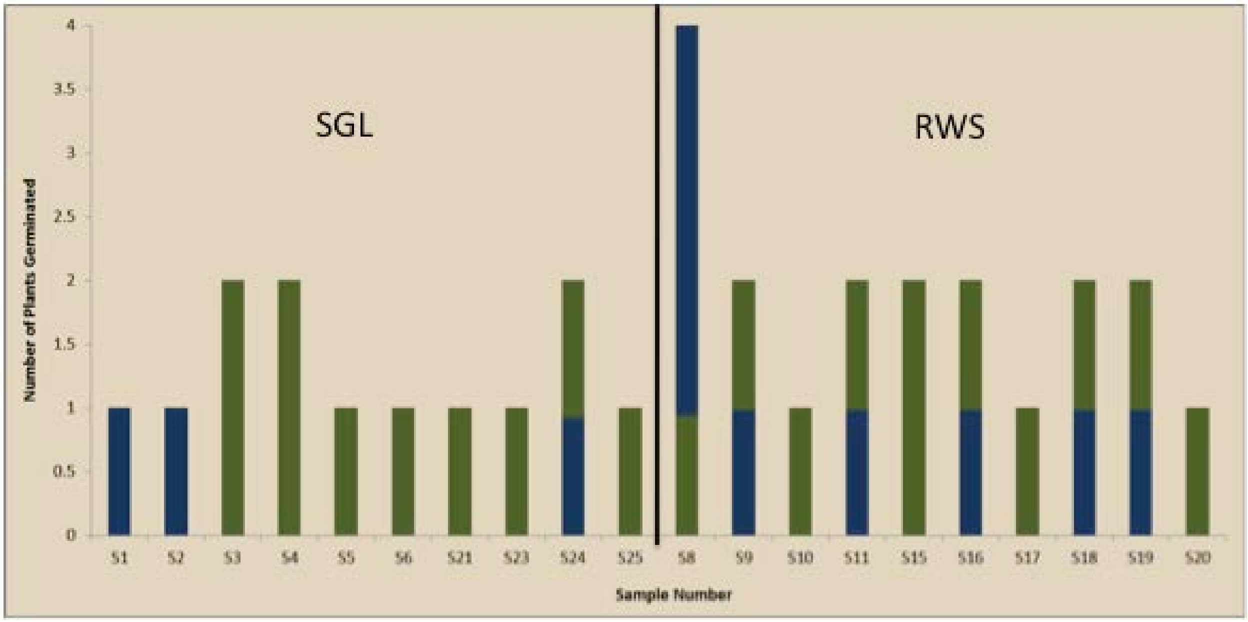


Figure 8. Germinated plants per sample. S1 through S25 are the plants that germinated from SGL. S8 through S20 are the plants that germinated from RWS. Green coloration represents native plant germination, blue coloration represents invasive plant germination and the mixed bars had both invasive and native plants germinate in accordance with the height of the coloration.

About 1.2 plants per sample germinated from the SGL sites and 1.8 plants per sample germinated from the RWS samples. Instances where multiple plants germinated from the same sample were common in the RWS samples. RWS had two more samples in which invasive plant species germinated. Proportionally invasive species constituted about 30 percent of germinated species at both sites.

DISCUSSION:

In general, the white-tailed deer have different diets between RWS and SGL. The RWS deer appear to be relying heavily on the field species. The higher species diversity at RWS reflects the variety of wildflowers present in the sanctuary fields. Only one of the species identified in either site location, the yellow birch, was actually a tree. All of the other species were wildflowers and grasses which is why RWS had a much higher species diversity. The sanctuary maintains fields to provide variety to their habitats and foster different communities of insects and small rodents. The RWS field species prefer the high sunlight conditions of an open meadow rather than the understory conditions of the forest floor. The SGL samples had a greater variety of shade and sun preferring species. This reflects the variety of light habitats available from canopy gaps, which do have a lot of light, to dense forest which have heavy shade.

Pennsylvania white-tailed deer have a small average home range that they maintain of about 2.3 square kilometers but they can extend that range when necessary to about 8 square kilometers. If the RWS deer have average ranges, then they would not impact significant numbers of people although they may heavily impact the people they do interact with (Fig 8).

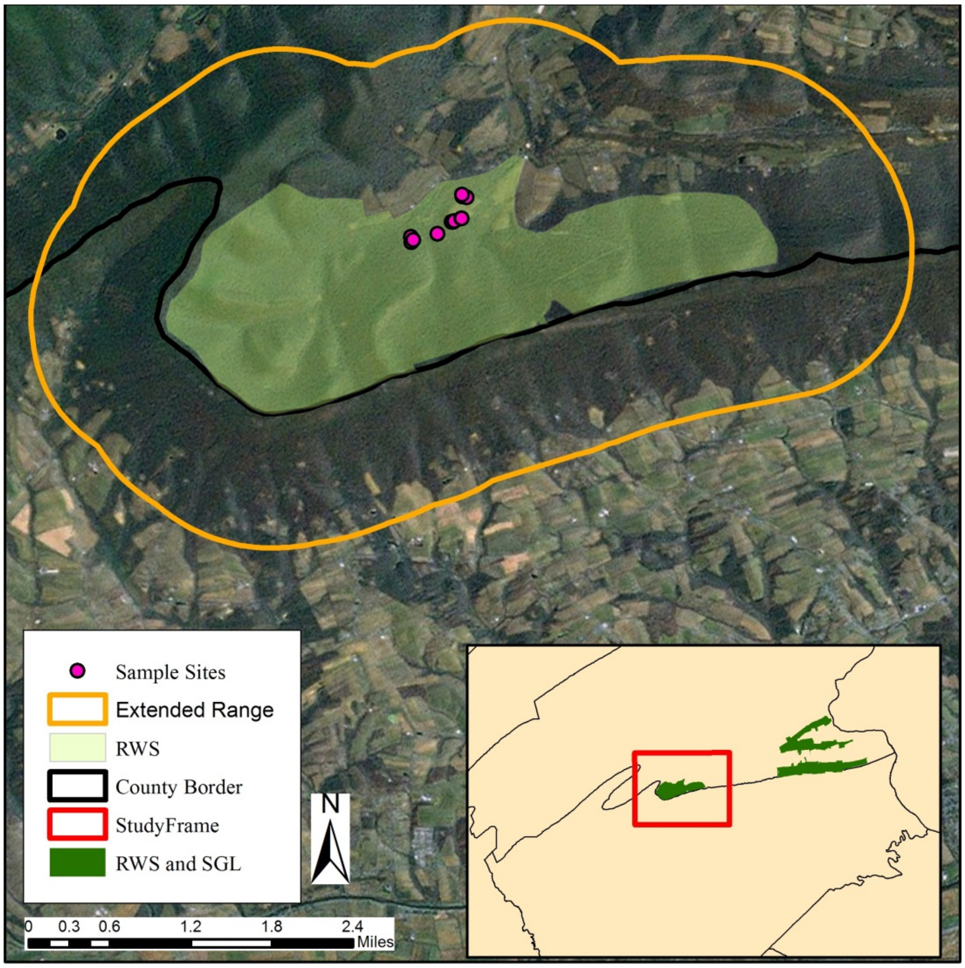


Figure 9. Map of RWS with the extended range of deer showing areas of potential deer- human conflict.

There are about 8.3 square kilometers of agricultural and suburban land that have the potential to experience conflict with RWS deer if they maintain their average homerange (Fig 8).

The plant species composition extracted from the pellet piles suggest that deer do spread invasive plants in addition to native ones. The invasive species were not only being transported but in the cases of species like eyebright and tearthumb, they also had high abundances. This was the case at both RWS and SGL and may reflect the tendency of invasive species to proliferate via very high seed counts as eyebright and tearthumb are known to do. In agreement with the previous literature, there was no Asian stilt grass in the samples (Baiser et al 2008; Gibson et al, 2002; DCNR, 2013).

Two of the top five most abundant species found in the samples are classified as invasive. Of the two, tearthumb is considered to be highly invasive in Pennsylvania. Tearthumb and Lady’s thumb, both present predominately in SGL samples, are in the smartweed family. Tearthumb has been given the name “mile-a-minute weed” due to its very rapid growth rates. Tearthumb is originally native to Japan, Korea, China, Taiwan, and India. It can grow up to six inches a day allowing it to form dense mats that choke out and smother the nursery seedlings of native plants (Abbey, 2000). Eyebright on the other hand, is not of significant concern as it is not a particularly aggressive invasive species.

Unlike the eyebright Johnson’s grass, like the smartweeds, is a major concern in Pennsylvania due to its highly invasive qualities. This agricultural weed is known to cause serious economic losses and is considered one of the most noxious weeds in the world. Not only does it have a rapid growth rate, but the seeds stay viable in the seed bank for up to 20 years making management very difficult (Natural Biodiversity, 2006). Like the Tearthumb, it can quickly form dense monocultural mats which prevent the growth of native species (Natural Biodiversity, 2006). This plant is so invasive that it is illegal to propagate, sell, or transport it in the commonwealth of Pennsylvania (Natural Biodiversity, 2006). Seeds and plants of both smartweed species were found at both RWS and SGL although they were much more prevalent at the SGL. On the other hand, the Johnson's grass was more prevalent at RWS. This suggests that deer are capable of acting as seed dispersers for invasive plants in both healthy and disturbed forests. In both cases, the dominate species present in samples for each site location was an invasive species.

RWS and SGL had similar germination rates. RWS had a rate of about 1.8 plants per sample and SGL had a rate of about 1.2 plants per sample. The spread of invasive to native species was about 30 percent at both sites. Nothing can really be said about whether or not the germination rates of plants were different between to two sites. In reality, the species that germinated represent the species that germinated first. Each time the plants are evaluated, new sprouts are coming up. This does not provide insight into overall germination rates but rather initial germination rates. It is possible that some of the species, especially the native species, are simply slower to emerge.

Many of the germinated plants did not match up with identified seeds. A number of seeds were not identified since their relative abundance was below one percent. It is possible that some of the germinated plants are represented by these seeds. Likewise, many seeds with high relative abundances like eyebright and raspberry did not germinate. These species have longer dormancy periods and needed a little bit more time to germinate (Baskin & Baskin, 1998). If the study had waited another three weeks, then these species would probably have appeared.

Most of the species, native and invasive, present in the RWS pellet samples were sun preferred species and species that do well in disturbed habitats. In regards to the first hypothesis of this study, it is clear that the RWS deer are not eating and dispersing the Asian stilt grass in September because it is not found in any of the samples. In regards to the second hypothesis, about 30 percent of the plants that germinated were invasive species. Both RWS and SGL had comparable invasive species compositions and germination rates. Therefore the deer at both sites have equal ability to spread invasive species.

The implications for human wildlife conflict are that the deer do spread invasive species. Fortunately for the locals, the RWS deer do not appear to be spread large quantities of the highly problematic Johnson's grass but they are spreading sheep sorrel. Sheep sorrel is an invasive species that prefers open and disturbed areas such as pastures and meadows. It can spread rapidly in acidic and nutrient deficient soils and it is known to be poisonous to livestock if consumed in high enough quantities (USDA, 2006). The potential to spread plants harmful to livestock may be a concern to farmers in the surrounding area. Fortunately for most farmers, Pennsylvania deer have a fairly small home range. Ultimately, deer have equal potential to spread invasive species at both sites.

CONCLUSIONS:

The deer at both sites are dispersing a wide variety of seed species with an equal proportion of invasive species to native species. The RWS deer had a high presence of meadow species in their pellet piles. This probably reflects a reliance, in September, on the fields maintained by the sanctuary. Since a vegetation analyses of the fields was not completed, it is impossible to say definitively whether or not the meadow species were from the maintained sanctuary fields or from surrounding agricultural fields and suburban lawns. It seems as though, by maintaining those fields the land manager is, in part, helping to maintain the deer population.

It is very possible that this reliance on meadow species changes seasonally. There was no evidence of Asian stilt grass in the samples, but had the sites been sampled in October this may have been different. Despite the lack of Asian stilt grass, the pellet samples were dominated by high abundances of invasive species at both the SGL site and the RWS.

Further research should allow for a longer growth and germination period and different stratification methods to encourage the growth of more plant species and see if the distribution of invasive and native species changes over time. In addition, vegetation analysis of the available vegetation could have provided great insight into availability versus preference in the deer diet as well as help to distinguish which seeds came from human developed areas and which occur naturally at the sites. Finally, a full analysis of the composition of the pellet samples would be a way to further investigate the difference in deer diet between the deer at these two locations. An analysis which considered percent woody matter and grassy matter in the samples could provide insight into eating habits that are not represented by the seeds.

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