Slash Presence in Harvested, Northeastern Hardwood Forests

Hunter J. Baker
Department of Environmental Science
Allegheny College
Meadville, Pennsylvania

4/16/2020

Submitted in fulfillment of the senior thesis requirements of the Department of Environmental Science at Allegheny College and approved by the senior thesis committee

Dr. Rich Bowden	Date	Dr. Cassey Bradshaw-Wilson	Date



Honor Pledge

Table Of Contents

I. Acknowledgments……2

II. Abstract....……3

III. Introduction…….....4

IV. Methods……8

V. Results……11

a. Dominate Species…….11

b. Seedling Density ..……..……..11

c. Seedling Height……12

d. Percent Browsed……..14

e. Slash Pile Size……..15

VI. Discussion……..17

VII. Appendix ……...21

VIII. References……..22

IX. Figures & Tables

1. Figure 1. Study sites located within Erie, Crawford, and Mercer County Pennsylvania……..10

2. Figure 2. Mean (±SE) Seedling Density per 100m2 at Each Study Region. nd = no difference, ins = insufficient amount of data to perform stats test, *:p=0.01, **:p=0.001, ***:p=<0.001…….12

3. Figure 3. Mean (±SE) Seedling Heights in cm at Each Study Region. nd = no difference, ins = insufficient amount of data to perform stats test, *:p=0.01, **:p=0.001, ***:p=<0.001…….13

4. Figure 4. Mean (±SE) Percent Seedlings Browsed at Each Study Region. nd = no difference, ins = insufficient amount of data to perform stats test, *:p=0.01, **:p=0.001, ***:p=<0.001…….....15

5. Figure 5. Slash pile size (m2) paired to mean (±SE) seedling density, mean (±SE) seedling heights in cm, and mean (±SE) percent seedlings browsed……16

6. Table 1. Description of the Dominate Species DBH, Basil Area, and Seedlings per 100m2 per Species Across All Four Sites……..21

Acknowledgments:

I would like to thank my advisor Dr. Rich Bowden for his persistence, his guidance, and his confidence in me, pushing me to greater heights. I would also like to thank Mitchell Carrigan and Kendra Dolan for suffering through the rain all those days, trekking through the woods from sunup to sundown to gather data. Finally, my friends and family for believing in me and always being there any time that I need them without hesitation.

Abstract:

Within the last fifty to eighty years, white-tailed deer have increased dramatically throughout the northeastern United States. One of the factors that is directly correlated with their population growth is the hindered regeneration of woody plants, this is especially true at logging sites after a thinning or clear-cut operation. White-tail deer will forage saplings that are regenerating within the forest after the operation to the point where their impact is irreversible. This study proves that if the treetops or, "slash piles," still grounded after a logging operation are present on the cleared forest floor, seedlings/saplings will regenerate within them and, their growth is exponentially larger than when the seedlings are unprotected. What sets this study apart from others though is that, the size of the slash covered plot has been identified and, a specific 25 square meter adjacent, uncovered plot was also created allowing for direct seedling density, seedling height, and percent seedlings browsed comparisons to be made between the two treatments. This study identified that the "size" of the top left grounded does not have a correlation with the success and density of seedlings and saplings growing within the pile. The density of saplings regenerating in the area is dependent upon the dominate species at the study site and, whether is protected or exposed. The Study took place in 4 different locations in Northwestern Pennsylvania. Each of the four sites are hardwood stands and, have all been harvested within the last four years.

Introduction:

White-tail deer, (*Odocoileus virginianus*), are overpopulating most of the northern United States including the native forests of northwestern Pennsylvania, having detrimental effects on the landscapes. The population density of this animal has increased almost tenfold across the United States during the 20th century, compared to the densities of the 18th and 19th centuries, (Seton, 1953, Severinghaus and Maguire, 1955, McCabe and McCabe, 1984, 1997, Horsley et. al., 2003). Their overpopulation leads to a wide array of environmental complications. These complications range from, "crop damage, to deer vehicle collisions, and nuisance deer in suburban areas", (Waller and Alverson, 2007). White-tail deer were on the verge of extinction but, Pennsylvania instilled hunting regulations and, areas that had been logged for timber were regenerating, causing an influx of deer offspring. The deer greatly benefited from the habitat fragmentation, elimination of natural predators from deforestation, and management practices created by state wildlife agencies, (Diefenbach et al., 1997). With this mass influx in deer populations, forest regeneration is severely hindered. Regeneration of seedlings >30 centimeters tall declined linearly and, as local browsing pressure increased, complete regeneration failure occurred where browsing pressure was greatest, (Rooney and Waller, 2003).

There are numerous studies detailing the diet of the white-tail deer, including hemlock dominated forests that consist of, hemlock, white cedar, white, red, and jack pines, and balsam fir stands, all forests had significant deer browse damage, (Anderson and Loucks, 1979). This damage caused by the white-tailed deer extends beyond just trees, in fact, Goetsch et al. (2011) found that, decades of over browsing caused the formation of a highly depauperate understory dominated by a single fern species. Browsing caused the site level extinction of shrubs and, drove forbs to extremely low abundance (<0.2 percent cover per meter squared). So, it is clear that not only do white-tails have the ability to reduce plant diversity but, they have the means to eradicate select species all together. The different tree species listed above play a key role in the diverse forest compositions of Pennsylvania. One technique that has been observed to help combat this issue of high deer abundance depleting forest species is, the presence of brush or, "slash" left behind after a harvesting operation. Varying in different heights and sizes, slash piles are left behind throughout the property when trees are cut down. These piles usually consist of

one to three treetops, the portion of the tree that has no economic value to the harvester. These piles allow species regeneration to progress and, they protect the seedlings from deer browse.

Many studies have determined that slash pile presence is directly correlated to the abundance of saplings being browsed in forested areas. For example, Hunn (2007) concluded that there was a higher browsing factor in open plots verses top-covered and fenced plots. Within this study, the size of the slash pile and, the abundance of saplings as a whole were never identified, only the plants that exemplified signs of browse pressure. While brush piles play a significant role in protection from deer browse, seasonality also plays a key role in sapling regeneration. The different seasons provide different environments and stages of growth of select plant species. White-tailed deer are usually restricted to eating twigs and leaves of woody plants in winter, when snow cover exceeds three inches, (Telfer, 1972). When the snow accumulates over a certain height in an area, the deer look for other means of nutrition to taller, more developed plant species. Common plants such as barberry, Grape, snowberry, and fragrant sumac have a relatively high palatability rating from the fall through winter months, October through March, (Sieg and Severson, 1996). Along with snow cover, cold temperatures accompany its arrival. These cold temperatures also influence the deer's browsing selection as they move to different habitats to stay warm. Ozoga and Gysel (1972) found that, the animals seek out, and congregate in sites that provide them optimal shelter, even though the food supply at these sites may be marginally or nutritionally inadequate. Fullbright and Ortega-Santos (2006) have described three main principals that are consistent across all white-tail deer habitat regions. The first, all white-tail deer habitats consist of a mosaic of vegetation dominated by woody plants with herbaceous plants intertwined within the landscape. Second, landscapes with diverse vegetation provide better habitat than homogenous landscapes. The third and final, along with the abundance of food sources, plant species that provide deer with thermal cover from the weather are also abundant. Each of these regional aspects are found in the forests of Pennsylvania and, in all the sites observed in this study. Slash piles as of late, are being left behind after a thinning operation whereas before, in the 2000's and previous, some private landowners would set them on fire, or transport them to landfills to remove them from their property and, in some cases, tree and woody plant species benefit from this. Seed and soil amendments containing viable AM (Arbuscular Mycorrhizas) propagules would increase the establishment of native plants in severely burned slash pile scars, (Korb et al., 2004). The scar is now a nitrogen rich garden with

ample sunlight. The propagules, which are simplistically, the material a plant produces to move itself into the next portion of its life cycle, are propelling the species into its adult stage (Lamberton et. al., 2010). In cases of tree species such as Black Cherry or, Tulip Poplar which are both intolerant species, these characteristics of burn scars or, complete plant absence from slash removal with ample sunlight, become a breeding ground for these species.

Browsing pressures are not the only influencing factor in sapling growth. Nutrient needs and light abundance can also be limiting factors to a sapling/seedling's growth. Most studies only observe that the slash pile that has saplings within in it and, their density and, whether or not they have shown any signs of browse. Grisez (1960) found that pitch pine reproduction in the slash of a cutover area in southern New Jersey suffered less damage from deer browsing than reproduction in "slash-free" locations. Light level also plays a significant role and strongly influences regeneration performance in hardwood stands, (Beaudet et. al., 2002). Light traveling through the canopy is important because, the light found at the microsite level, is a major determinate in growth and survival of species, (Bazzaz, 1979, Bjorkman, 1981, Pacala et al., 1994, Kobe et. al., 1995, Beaudet and Messier, 1998). Species succession at the community level is also strongly linked to light conditions, (Forcier, 1975, Canham and Marks, 1985, Beaudet et. al., 1999). If the slash pile is over a certain size, light will not be able to penetrate the pile into the regenerating saplings/seedlings below, causing their growth if any at all, to be stunted. At the other end of the spectrum, if a slash pile or treetop is too small, a white-tail deer will have no problem foraging on the young saplings within.

This study will take place in Northwestern Pennsylvania, in an area of the United States that is primarily comprised of high value timber stands. Deer densities in this part of the world including the Allegheny hardwood forests have been high and, have been severely impacting seedling regeneration by selective browsing for over 70 years, (Redding, 1995). Four sites will be studied in this thesis, Robertson Sports Complex at Allegheny College that was harvested in 2015, Jane Ewing's family property located in Corey just off of Cater Hill road harvested in 2016, Diane Esser's family property located in Blooming Valley just off of Price road harvested in 2017, and Moxie Woods in Greenville PA, which was also harvested in 2017. All of these sites include a vast array of slash piles scattered throughout the property. The intent of this thesis is to further define deer browsing pressure and, to determine the contribution that size, in area, of

the slash piles adds to the species growth, if any at all. Grisez (1960) and, many others following have established that slash provides protection to seedlings, allowing them to grow within however, none of the studies specifically recount the absolute density comparisons between the covered plots and the open, nor the species heights. It would be highly preferable if the land is excluded from hunting to avoid biased data but, hunting is a very efficient way of controlling deer populations especially in Pennsylvania, (Frye, 2006). This region of northwestern Pennsylvania, specifically Crawford County, is comprised of a mixture of conifer, and hardwood stands. There are several different elements to these forests including the hemlock-white pine northern hardwood forest type, the beech and sugar maple forest type, and the oak and chestnut forest type, (Whitney and DeCant, 2003). All of which are desirable browse species for the white-tail deer.

Methods:

Each location of the four sites in this study are shown in (Figure 1.). The environments within this study include all or, a large majority of shrubs, trees, and grasses that white-tail deer consume on a daily basis in northeastern forests in the spring, summer, and fall months. The hemlock-white pine forest type that encompasses a mixture of intolerant hardwoods and, tolerant hardwoods including Black Cherry and Sugar Maple is one example of the sites within this study, (Crawford, 1982). This study is comprised of four selected properties all leased or, owned and operated by the Foundation for Sustainable Forestry, or FSF. Each site satisfies the qualifications above and, have a timber harvest history of no older than five years and, are not younger than two. Each of the four sites are densely populated with hardwoods species types including red maple, sugar maple, red oak, American beech, tulip poplar, black cherry, and white ash. Overall, each location has its own dominate species but, sugar maple was one of the most populated species throughout the entirety of the study.

At each of these four study site locations, a series of ten slash piles, piles of logging debris, brush, or single treetops were identified. Sigma Plot 12.5 was used for the statistical analysis of the data collected in the field. Slash pile size was determined using the formula for the area of a circle. At each pile, a total of three diameter measurements were taken across a center stake measured in meters. The center stake is based on a rough estimate of the tops approximated center. These three diameter measurements were then used to find the average diameter of the slash pile. Once the area mentioned above was constructed, an adjacent area directly beside the slash pile was constructed in an area excluding slash or, “open”. The adjacent area was a five-by-five-meter plot used to determine the density of saplings exposed to browse.

In both plot types, the individual sapling/seedlings were identified. Height measurements were taken with a two-meter-tall meter stick. Only seedlings/saplings that were less than or equal to 200 centimeters were counted. Anything taller would be out of reach for even the tallest white-tails. Browse presence was also documented. Minor soil traits may have been documented at each site such as, “very wet”. Each study plot within each of the sites were also documented as a latitude and longitude to be later represented on a map using ArcGIS software to describe forest composition at each site.

A much larger plot was also constructed at each site, separate from the slash piles and open plots. This plot is a 30-meter-by-30-meter study plot and, defines the dominant species at the site. At each site, the plot was constructed in a portion of the property that had been the least or, not at all effected by the timber harvest. Within this plot, all of the trees that have a diameter at breast height greater than 5 centimeters were recorded along with the species name.

All of the data was input and manipulated in Microsoft Excel 2016 to create the figures and tables in this paper. Sigma Plot 12.5 was used for all of the statistical analysis. T-tests, Mann-Whitney U test, and Two-way and Three-way ANOVA tests were run using the program for seedling height among the treatments at each site, seedling density among treatments at each site and for each species, the seedlings percent browsed per treatment at each site and by species. The two and three-way ANOVA analysis failed a majority of the time because the data was not normally distributed.

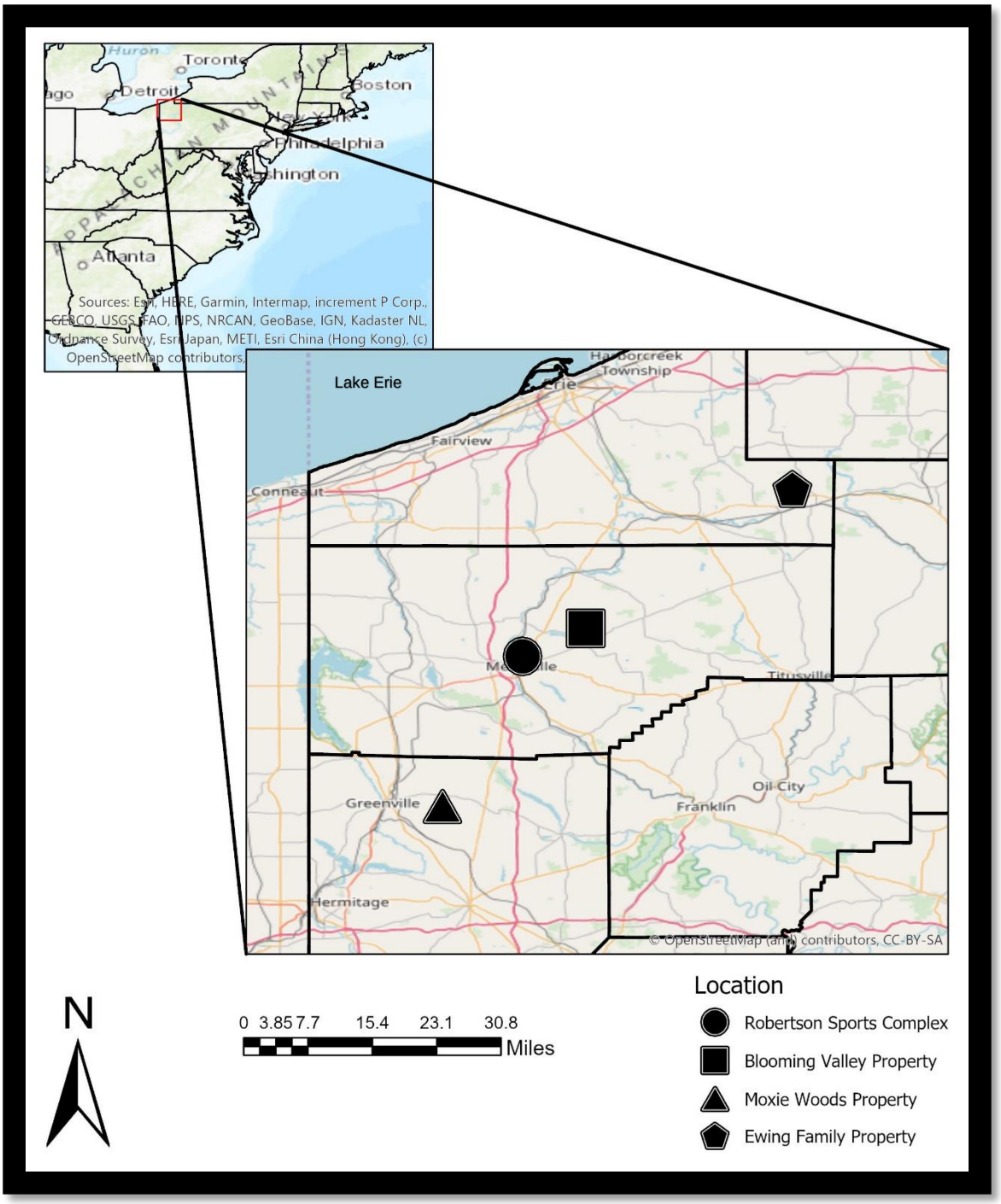


Figure 1. Study sites located within Erie, Crawford, and Mercer county Pennsylvania

Results:

A total of 24 different species were observed across all four of the study sites, (Table 1.). Of these 24 species, only seven species were sufficiently abundant at all four sites to report any comparable observations across all four sites. The seven different species that recorded the most data are American beech (*Fagus grandifolia*), sugar maple (*Acer saccharum*), red maple (*Acer rubrum*), black cherry (*Prunus serotina*), northern red oak (*Quercus rubra*), tulip poplar (*Liriodendron tulipifera*), and white ash (*Fraxinus americana*).

Dominant Species:

Each of the four sites recorded a dominant species. Robertson Sports Complex recorded 16 diameters at breast height (DBH) measurements for sugar maple. Sugar maple was the dominate species at this site with an average DBH of 34.7 centimeters and, a basal area of 19.9 meters squared per hectare(m2-1). Blooming Valley property's dominate species is tulip poplar. Tulip poplar recorded 12 DBH measurements with an average of 29.4 cm. The basal area of tulip poplar at this site is 11.8 meters squared per hectare which, far outcompetes the second most abundant species within this site, white birch. The Ewing Family property's dominate species is northern red oak recording 14 measurements with an average DBH of 42.6 cm. The basal area of the northern red oak species at this site is 26.4 meters squared per hectare. Sugar Maple is the dominate species in Moxie Woods. Sugar Maple recorded 35 total DBH measurements with an average DBH of 24.7 cm, not the largest but, most abundant. The basal area calculated for sugar maple at Moxie woods is 24.5, almost 5 times larger than the second largest basal area of 5.1 from white ash, (Table 1.).

Seedling Density:

Seedling density was compared using the two different treatments per species, slash vs. open, and across all study sites. Overall, of the ten pairs, slash and open, across the four sites, Robertson, Blooming Valley, Ewing, and Moxie, only three of the 40 tests showed any significant difference between the seedling density in the open plots verses the density in the slash covered plots. American beech at the Blooming Valley site demonstrated a P-value of 0.016, portraying a significant difference in density in the open plots vs. the slash covered plots. The open plots were slightly more than twice as dense (±5.6 seedlings/100m^2) as the slash covered (±2.7). American beech was also shown to have a higher density in the open plots at the

Ewing family property with a P-value of 0.03. The mean value for American beech in the open was slightly less than half that of the slash cover plots, (±22.4 seedlings/100m^2 vs. ±12.2 seedlings/100m^2). The final significant statistical change that occurred was also at the Ewing family property where, northern red oak was more dense in the open plots than in the slash covered plots, (P = 0.022). the average density in the open plots is ±40 seedlings per 100m^2 while, in the slash covered plots the average seedlings per 100m^2 is ±22.7, (Figure 2.).

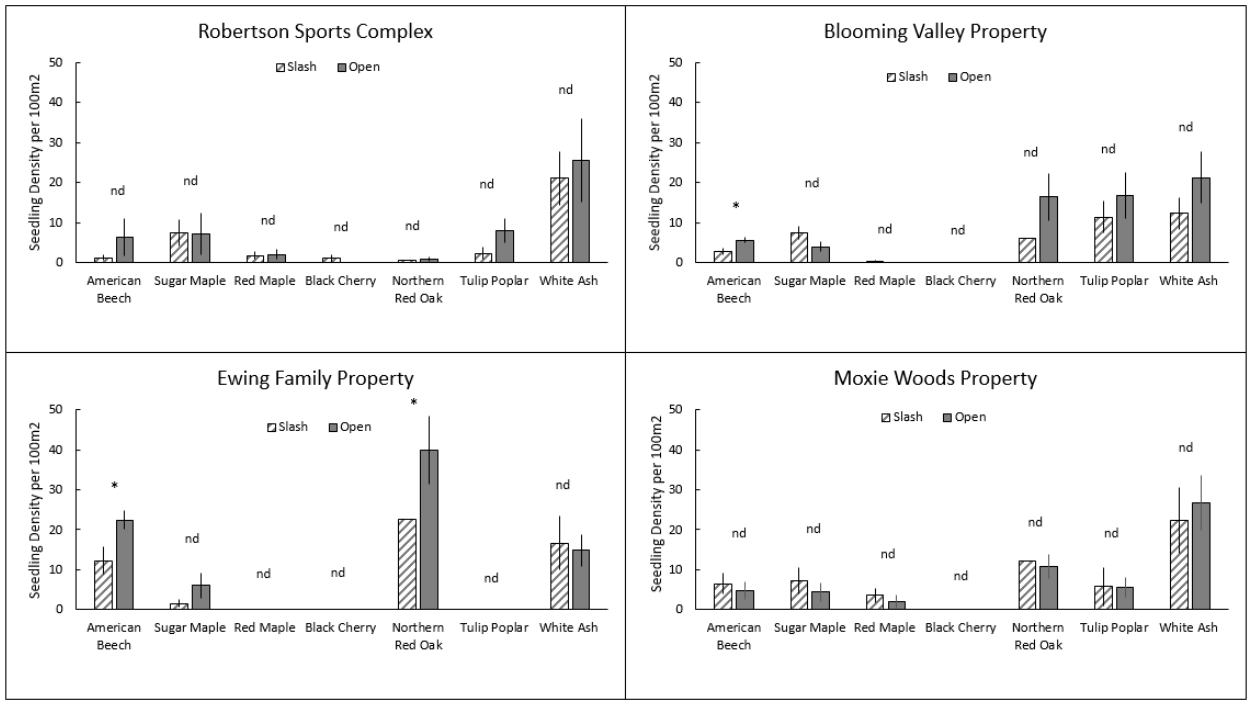


Figure 2. Mean (±SE) seedling density per 100m^2 at each study site. (nd = no difference, ins = insufficient amount of data to perform stats test, *:p≤0.01, **:p≤0.001, ***:p≤0.001)

Seedling Heights:

Robertson Sports Complex revealed 3 major statistical differences, sugar maple seedling heights in centimeters were found to be taller in the slash covered plots than in the open plots, (P=0.001). Red Maple was found to be statistically taller in the slash covered plot than in the open plot. White ash showed the highest statistical difference in heights between the two treatments with a P-value of less than 0.001, (Figure 3). Figure 3 also shows Blooming Valley property having three species whose heights were statistically different among the two treatments. Northern red oak was found to be twice as tall in the slash covered treatments (±42.8 cm) than in the open,

(±20.3 cm) (P = 0.006). Tulip poplar is the second species at Blooming Valley that had a significant difference in heights between the treatments with a P-value less than 0.001. The final species at the Blooming Valley property that represented a statistically significant difference in height between the slash covered plot and the open plot is white ash. Ewing Family Property has two species that were shown to be significantly different between the two treatments. Northern red oak resulted in a P-value of less than 0.001. White ash is the second of the two species at this site that showed a significant height difference between the slash covered plot and the open plot. The statistical test for white ash produced a P-value of 0.005, (Figure 3).The seven species at Moxie Woods Property did not show any significant difference in the open versus the slash covered plots. The mean heights between the two treatments at all ten pairs were too similar to support a statistically significant difference.

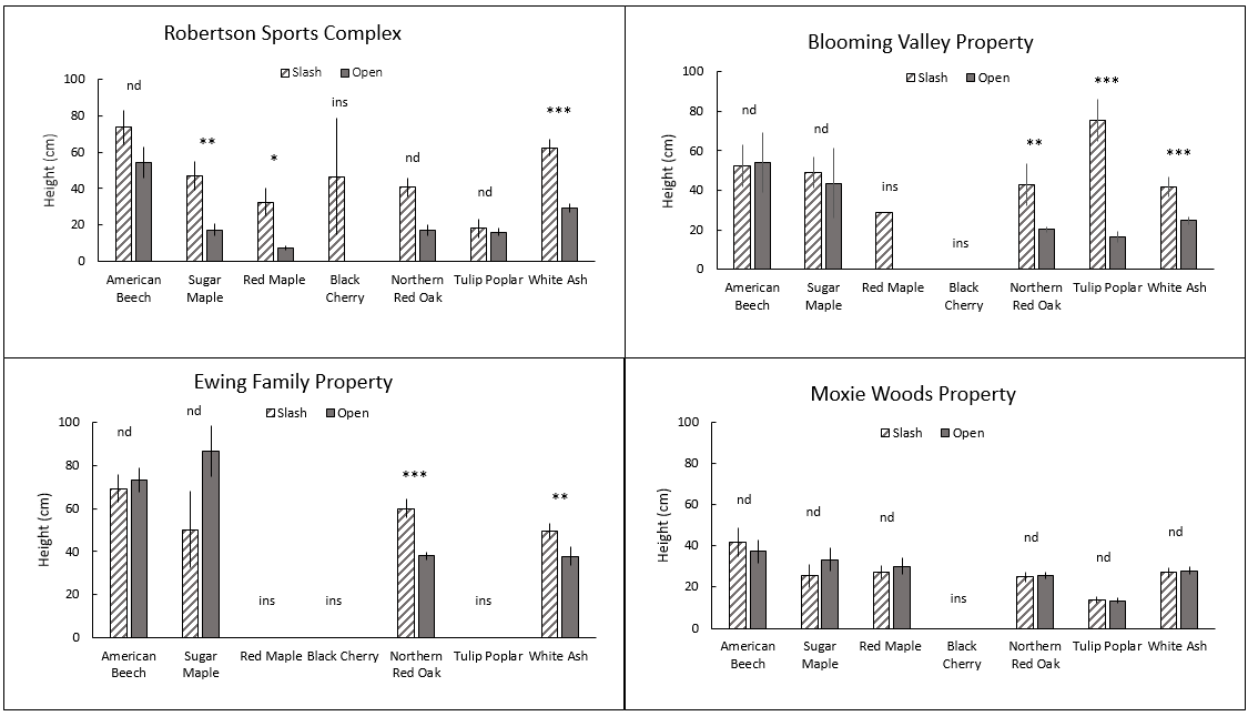


Figure 3. Mean (±SE) seedling heights in cm at each study site. (nd = no difference, ins = insufficient amount of data to perform stats test, *:p≤0.01, **:p≤0.001, ***:p≤0.001)

Percent Browsed:

At Blooming Valley, the seedlings in the open plot have a higher browse rate than that of those in the slash covered plot, (P = 0.005). The Ewing Family property produced a similar result. The P-value from this test is less than 0.001 supporting the evidence that the percent of seedlings browsed in the open plot is significantly higher than the percent of seedlings browsed in the slash covered plot. Moxie Woods produced a P-value of 0.002. Similar to the previous two sites, the test shows that there is a statistically significant difference in the percent browsed seedlings in the open plot versus the slash covered plot. The final site, Robertson Sports Complex, reveled a P-value of 0.006 supporting the data showing the percent browse in the open plot is higher than the percent browsed seedlings in the slash covered plots.

The individual, 7 most dominant species within the 4 sites were also tested. At Robertson, only one of the seven species, white ash, showed a statistically significant difference between the open plot (±64.1%) and the slash covered plot (±9.2%). The test created a P-value of 0.008. Blooming Valley conveyed two of the seven species having statistically significant differences between the percent seedling browsed in the open versus the slash covered plots. Sugar maple seedlings produced a P-value of 0.017. Slash covered plots had a mean value of ±23.9% whereas the open percent seedlings browsed mean value is ±83.3%. The second species at Blooming Valley found to be statistically significant is white ash with a P-value of 0.002. The mean value of the percent seedlings browsed in the open (±75.6%) is 4 times larger than that of the slash covered plots (±17.7%) in Blooming Valley. The Ewing Family property houses three of the seven species that show significant statistical differences in percent browsed seedlings in the open plots than in the slash covered plots. American beech has a mean percent seedling browsed of ±93.4% in the open plots and, a mean value of ±11.5% in the slash covered plots. Northern red oak revealed a P-value of less than 0.001. The mean percent browsed seedlings in the open is ±89.2% while the slash covered mean is ±11.8%. The final seedling species at this site that showed significant difference in the open plots versus the slash covered plots is white ash, with a P-value of 0.004. The mean percent seedlings browsed in the open is ±70.2% while ±26.7% is the mean percent seedlings browsed in the slash covered plot. Finally, Moxie Woods has two species that are significantly different among the two different treatments. Northern red oak was the first of the two species, unveiling a P-value of 0.011. The mean percent seedlings browsed in

the open plot (±85.7%) is higher than the mean percent seedlings browsed in the slash covered plot (±10.0%). White ash is the second of the two, with a P-value of less than 0.001 supporting the mean percent seedlings browsed in the open plots (±81.6%) is much higher than the mean percent seedlings browsed in the slash (±11.6%), (Figure4).

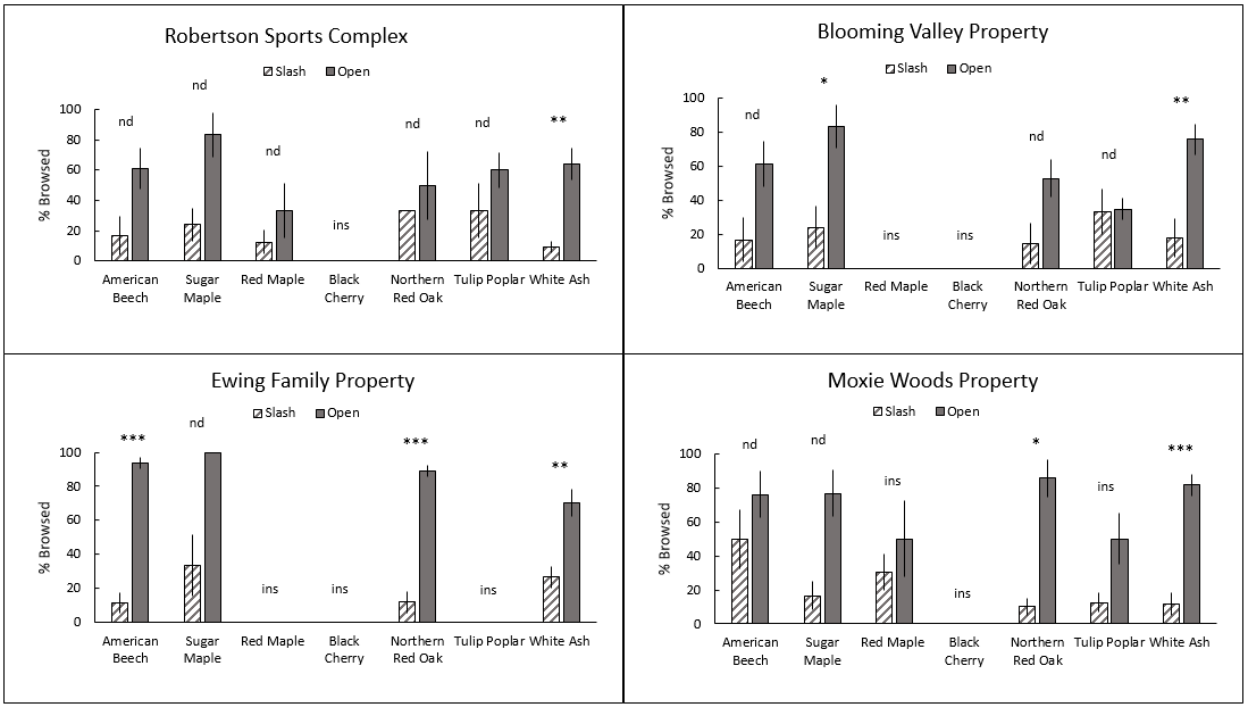


Figure 4. Mean (±SE) percent seedlings browsed at each study site. (nd = no difference, ins = insufficient amount of data to perform stats test, *:p=0.01, **:p=0.001, ***:p=<0.001)

Slash Pile Size:

The size of the piles were proven to protect the seedlings growing within. Seedling density when correlated to slash pile size, (Figure 5.) does not provide any significant differences when the pile areas change. The overall heights of the seedlings were taller in the slash covered plots than in the open plots but, the heights of the seedlings within the slash covered plots did not change when the size of the slash covered plot did change, (Figure 5.). Figure 5 also recounts the percentage of seedlings browsed within a slash pile does not change when the slash pile area increased or decreases.

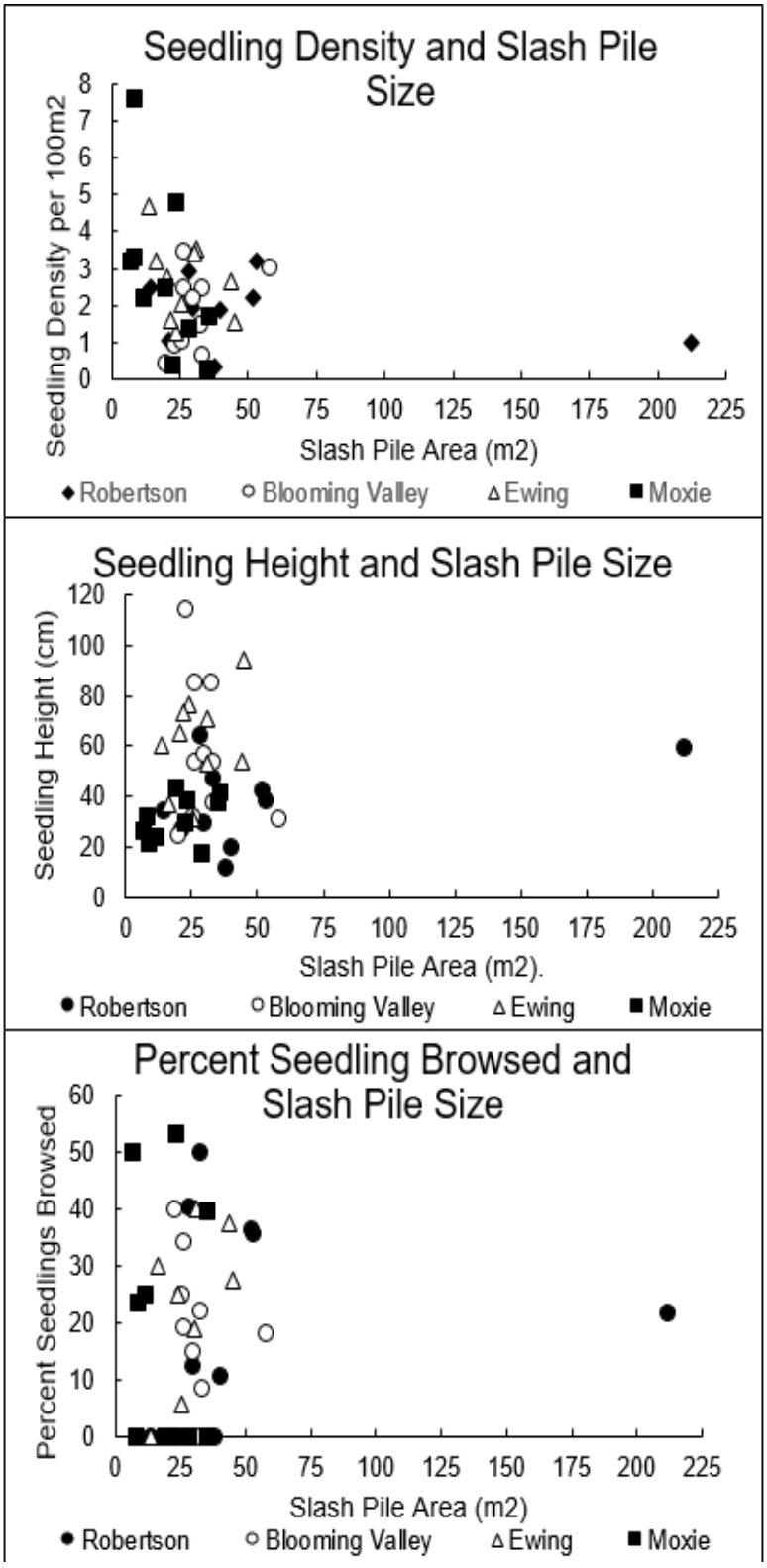


Figure 5. Slash pile size (m^2) paired to mean (±SE) seedling density, mean (±SE) seedling heights in cm, and mean (±SE) percent seedlings browsed.

Discussion:

The dominant species in each site were used to determine the species that would most likely regenerate the fastest or, create the most offspring. Knowing the dominate species in each of the four sites also allows forest harvest operators to create quotes for the land-owners, helping them understand what they have, what they can make, and what has the greatest potential for success in the future. The composition and structure of second growth forests, such as those in this study, reflect the spatial patterns of regeneration and the competitive interactions among the already established plants, (Hughes and Fahey, 1988). Success, however, is also dependent on the greatest limiting factors of seedling regeneration which, in this case, is the white-tailed deer's browse.

Robertson Sports Complex, harvested in 2015, contains a dominant species of sugar maple. Sugar maple across all sites is among the top three of the seven most dense species encountered in this study. It's also one of the species that has the highest seedlings browsed percentage in the open verses the slash covered plots. Similar studies, (Jenkins, 1997) believes that across large portions of the northeastern United States sugar maple reproduction are in decline and, the largest influential factor is herbivory by white-tailed deer. Because this species is the dominate species in the study site, (Robertson), it would be expected that this species also has the highest combined density in the open and slash covered plots which, it does. The open plot has the higher percent seedlings browsed and, this high browse rate produces a very short mean seedling height in the open plot, as opposed to the slash covered plot with a lower mean percent seedling browsed and a high mean seedling height. The sugar maple seedlings in this study site are being browsed heavily by white-tailed deer in the open plots making them overall shorter in the open plots. The slash covered plots support the sugar maple seedlings growth, protecting them from the white-tailed deer's browse allowing them to be taller in the slash covered plots. Overall, the average height across all species in this study site are taller than that of the other four sites, perhaps due to the harvest time frame being much earlier than the other sites, the seedlings have had more time to grow in comparison to the other sites.

Jane Ewing's Family Property was harvested in 2016 supports a dominate species of northern red oak which is one of the most profitable hardwoods species in this region. Northern red oak was extremely prolific at this site especially in the slash coved plot with heights of up to 199cm tall.

The opposite is true of the open plots. The northern red oak species struggled to average a mean height of over 40cm. This is consistent with Ward, Gent, and Stephens (2000), who created two different plantations, one with seedling protection devices and one without. 92% of the plantation of northern red oaks that were unprotected had been browsed at least once while only 32% of the protected seedlings reported any signs of browse. The interesting fact about this species at this site however is that despite the abundant pressure from deer, northern red oak still created the largest basal area of all four study sites and, all species found in the study.

Blooming Valley was harvested in 2017 and, displays a dominant species of tulip poplar. This species at Blooming Valley was incredibly dense. It was immediately evident that there was more tulip poplar at this study location than any other species at any other site. Tulip poplar had the tallest mean height in the slash covered plots and the lowest mean height in the open plots. In terms of percent seedlings browsed, tulip poplar didn't show any differences in the open versus the slash covered plots. However, a statistical test was run to determine if there was a significant difference among all species across the site and, there is. Overall, the test provided that species in the open plots had a significantly higher percentage of browsed seedlings than those in the slash covered plots which, aligns with the theory that deer will not attempt to browse on saplings within the slash piles (Grisez, 1960), especially if other means of nutrition are readily available elsewhere.

Moxie Woods Property harvested in 2017, has a dominate species of sugar maple. However, when conducting the dominate species plot, another interesting species had been encountered. A pocket of mature white ash trees were encountered without any signs of infection or degradation from the Emerald Ash Borer which, has made its presence known in this area. The extent of the damage to ash trees in the area and the size of the infestation suggest EAB has been present in western Pennsylvania for several years, (Pennsylvania State University, 2009, Duan et. at., 2009). It was evident that sugar maple was the dominate species but, this species density also played a large rule in this determination. With their high percentage of seedlings browsed, they still sported one of the highest seedling densities and tallest heights and, there are no statistically significant differences in height between the two treatments, aligning with Bergquist and Orlander (1998). This study portrayed a similar timeline in terms of harvest history but is contrary to Sullivan (2015) who's study plots had a harvest recorded to take place in 2013 and,

conducted her study in 2014. She determined that there was a significant height difference between the two treatments even after only one year of growth. This could mean that within the Moxie woods site, deer populations are much lower than the other sites in this study and, more likely align to deer densities found in Bergquist and Orlander (1998) study sites. Unlike the other sites within this study, Moxie is the "youngest" in terms of when the harvest operation took place. This leads me to believe that, for a significant height difference to be observable between the two treatments here, more than three years has to pass allowing those protected to continue their growth while the unprotected continue to be exposed.

White Ash made its presence known in more than just Moxie's dominant species plot. Overall, across all species and all sites, White Ash had the highest seedling density, it was present in the slash and shown to have signs of browse in the open and, it was one of the top three species that had the tallest seedlings in both the open and in the slash covered plots. Moxie woods however is the only plot that had any adult white ash species. It seems evident that white ash has the ability to be the dominate species in this region of Pennsylvanian however, due to the heavy influence from deer browse and, the Emerald Ash Borer, the white ash can't surpass the seedling stage. Further research must be done to support this hypothesis.

White-tailed deer are the largest influential factor when it comes to seedling density and growth. Carrigan (2020, unpublished) found that environmental factors including soil temperature, soil moisture, and light intensity inside and outside of the slash piles did not show great enough influence to effect seedling abundance. Similar studies such as Ward, Gent, and Stephens (2000) further reinforces the determination that the ungulates cause more change than the environmental conditions within the minute study plot selections. This study further concludes that the overall, environmental conditions at the site itself are still not as constricting to seedling growth as deer browse will be.

This study also answered the question as to whether the size of the slash pile directly impacted the seedling characteristics within the pile. It again like many others has proven that slash protects seedlings growing in a forest after a harvest operation has occurred. It further shows that seedling density does not change even when the slash pile area increases or decreases. The size of the area within the pile also has no correlation with seedling heights growing within. the seedling heights do not increase or decrease as the area increases or decreases. Finally, the

percent seedling browsed within the piles were also shown to be unaffected by the area of the pile as it changes. Although the study did not show any correlation between the area of the slash pile and the density of seedlings within, seedling heights, or percent seedlings browsed, it has proven that the slash piles do in fact substantially protect seedlings within from deer browse. Further studies similar to this or, using the methods enclosed in this study should also document the height of the slash pile and, if possible, decipher the species composition that the slash cover plot consists of. This information may help to conclude why certain species are found in one pile versus another and, their specific characteristics in comparison to other species.

Forest harvest operations take place all throughout Pennsylvania and the United States, it's a staple of property management in the U.S. and, has the potential to be economically reliable for private and public landowners for generations when managed correctly. Knowledge of slash in a harvested forest allows landowners and foresters to create a mosaic of vegetation and control the growth of select species where they want them to grow. This knowledge allows the managers or owners to further improve upon what they already have. Many landowners across the U.S. are consistently taken advantage of by private foresters looking to make a quick profit. With the ever-growing deer population continuing to flourish and, hunter populations declining, knowing how to protect a future yield is of upmost importance. Managing land in a sustainable way should be everyone's first priority, not only with their own land but with all land. As the world is ever changing, creating a sustainable ecosystem is our duty as we share the land with others, future generations, and mother nature herself.

Appendix:

| Sapling, Basal Area, DBH table | | |

Table 1. Description of the dominant species DBH, basal area, and seedlings per $100m^2$ per species, across all four sites.

References:

Anderson, R. C., Loucks, O. L. (1979). White-tail deer "(Odocoileus virginianus)" influence on structure and composition of "tsuga canadensis" forests. *The Journal of Applied Ecology, 16*(3), 855.

Bazzaz, F. A. (1979). The Physiological Ecology of Plant Succession. *Annual Review of Ecology and Systematics, 10*(1), 351-371.

Beaudet, M., & Messier, C. (1998). Growth and Morphological Responses of Yellow Birch, Sugar Maple, and Beech Seedlings Growing Under a Natural Light Gradient. *Canadian Journal of Forest Research, 28*(7), 1007-1015.

Beaudet, M., Messier, Christian., Canham, C. (2002). Predictions of Understory Light Conditions in Northern Hardwood Forests Parameterization, Sensitivity, Analysis, and Tests of the SORTIE Light Model. *Forest Ecology and Management, 165*(1-3) 235-248.

Beaudet, M., Messier, C., Paré, D., Brisson, J., & Bergeron, Y. (1999). Possible Mechanisms of Sugar Maple Regeneration Failure and Replacement by Beech in the Boisé-des-Muir Old-Growth Forest, Québec. *Ecoscience, 6*(2), 264-271.

Berdanier, Aaron., Julia A. Klein. (2011). Growing season length and soil moisture interactively constrain high elevation aboveground net primary production. *Ecosystems, 14*(6), 963-974.

Bergquist, J., Örlander, G. (1998). Browsing Damage by Roe Deer on Norway Spruce Seedlings Planted on Clearcuts of Different Ages: 1. Effect of Slash Removal, Vegetation Development, and Roe Deer Density. *Forest Ecology and management, 105*(1-3), 283-293.

Beier, Paul. (1987). Sex differences in quality of white-tailed deer diets. *Journal of Mammalogy, 68*(2), 323-329.

Björkman, O. (1981). Responses to Different Quantum Flux Densities. *Physiological Plant Ecology I* (pp. 57-107). Springer, Berlin, Heidelberg.

Canham, C. D. (1985). The Response of Woody Plants to Disturbance: Patterns of Establishment and Growth. *Natural Disturbance and Patch Dynamics*, 197-216.

Carrigan, M. (2020). Evaluating Slash Pile Environmental Conditions in the Context of Sustainable Forestry. Unpublished Manuscript, Allegheny College, Meadville, Pennsylvania.

Crawford, Hewlette. (1982). Seasonal Food Selection and Digestibility by Tame White-Tailed Deer in Central Maine. *The Journal of Wildlife Management, 46(4),* 974-982.

Diefenbach, Duane., William L. Palmer., William K. Shope. (1997). Attitudes of Pennsylvania Sportsmen Towards Managing White-tailed Deer to Protect the Ecological Integrity of Forests. *Wildlife Society Bulletin (1973-2006), 25*(2), 244-251.

Didier, K. A., & Porter, W. F. (2003). Relating Spatial Patterns of Sugar Maple Reproductive Success and Relative Deer Density in Northern New York State. *Forest Ecology and Management*, *181*(1-2), 253-266.

Duan, J., Fuester, R., Wildonger, J., Taylor, P., Barth, S., Spichiger, S. (2009). Parasitoids Attacking the Emerald Ash Borer (Coleoptera: Buprestidae) in Western Pennsylvania. *Florida Entomologist*, *92*(4), 588-592.

Forcier, L. K. (1975). Reproductive Strategies and the Co-occurrence of Climax Tree Species. *Science*, *189*(4205), 808-810.

Frye, Bob. (1967). Getting to the Point of Managing Deer Correctly. *Deer Wars: Science, Tradition, and the Battle Over Managing White-tails in Pennsylvania.* (201-226). The Pennsylvania State University.

Fulbright, T.E., and Ortega-Santos, J. (2006). Habitat requirements of the White-Tailed Deer. *White-Tailed Deer Habitat* (1-44). South Texas: Texas A&M University.

Fulbright, T.E., and Ortega-Santos, J. (2006). The Gun: Harvest and management Planning. *White-Tailed Deer Habitat* (1-44). South Texas: Texas A&M University.

Goetsch, Chandra., Jennifer Wigg., Alejandro A. Royo., Todd Ristau., Walter P. Carson. (2011). Chronic over browsing and biodiversity collapse in a forest understory in Pennsylvania: Results from a 60-year-old deer exclusion plot. *The Journal of the Torrey Botanical Society, 138*(2), 220-224.

Grisez, T.J., (1960). Slash Helps Protect Seedlings from Deer Browsing. *Journal of Forestry. 58(5): 385-387*

Horsley, Stephen., Susan L. Stout., David S. DeCalesta. (2003). White-tailed deer impact on the vegetation dynamics of a northern hardwood forest. *Ecological Applications*, *13*(1), 98-118.

Hughes, J. W., & Fahey, T. J. (1988). Seed Dispersal and Colonization in a Disturbed Northern Hardwood Forest. *Bulletin of the Torrey Botanical Club*, 89-99.

Hunn, Joshua. (2007). Retention of Logging Debris to Reduce Deer Browsing and Promote Forest Regeneration.

Jenkins, J. (1997). Hardwood Regeneration Failure in the Adirondacks. *Wildlife Conservation Society Working Paper*, (9).

Kain, M., Battaglia, L., Royo, A., Carson W. (2011). Over-browsing in Pennsylvania Creates a Depauperate Forest Dominated by An Understory Tree: Results From a 60-year-old Deer Exclosure. *The Journal of the Torrey Botanical Society, 138(3), 322-326*

Kobe, R., Pacala, S. W., Silander Jr, J. A., Canham, C. D. (1995). Juvenile Tree Survivorship as a Component of Shade Tolerance. *Ecological applications*, *5*(2), 517-532.

Korb, J.E., Johnson, N., Covington, W. (2004). Slash Pile Burning Effects on Soil Biotic and Chemical Properties and Plant Establishment: Recommendations for Amelioration. *Restoration Ecology: 12(1), 52-66.*

Lamberton, P. H., Norton, A., Webster, J. 2010. Propagule Behavior and Parasite Transmission. *Encyclopedia of Animal Behavior,* 656-652.

Marquis, David. United States Department of Agriculture Forest Service. (1981). *Effect of Deer Browsing on Timber Production in Allegheny Hardwood Forests of Northwestern Pennsylvania.* Northwestern Pennsylvania

McCabe, T. R. (1997). Recounting whitetails past. *The science of overabundance*, 11-26.

McCullough, Dale., David H. Hirth., Stephen J. Newhouse. (1989). Resource partitioning between sexes in white-tailed deer. *The Journal of Wildlife Management, 53*(2), 277-283.

Ozoga, John., Leslie W. Gysel. (1972). Response of white-tailed deer to winter weather. *The Journal of Wildlife Management, 36*(3), 892-896.

Pacala, S. W., Canham, C. D., Silander Jr, J. A., & Kobe, R. K. (1994). Sapling Growth as a Function of Resources in a North Temperate Forest. *Canadian Journal of Forest Research*, *24*(11), 2172-2183.

Picture This. Glority LLC, 2018. Vers. 1.22.2. *Apple App Store*, https://www.picturethisai.com

Puglisi, Michael., James S. Lindsey, & Edward D. Bellis. (1974). Factors associated with highway mortality of white-tailed deer. *The Journal of Wildlife Management, 38*(4), 799-807.

Redding, J. (1995). History of Deer Population Trends and Forest Cutting on the Allegheny National Forest. *In: Gottschalk, Kurt W.; Fosbroke, Sandra L. C., ed. Proceedings, 10th Central Hardwood Forest Conference; 1995 March 5-8; Morgantown, WV.: Gen. Tech. Rep. NE-197. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experimental Station,* 214-222

Rhodes, A. F. (2007). The Plants of Pennsylvania: An Illustrated Manual**.** Philadelphia, Pennsylvania: *University of Pennsylvania Press*.

Rooney, T. P., & Waller, D. M. (2003). Direct and indirect effects of white-tailed deer in forest ecosystems. *Forest Ecology and Management, 181*(1), 165-176.

Seton, E. (1953). Lives of Game Animals, Volume IV-Part I Rodents, etc. *Charles T. Branford Company. Boston, Massachusetts*, 275-298.

Severinghaus, C. W., & Maguire, H. F. (1955). Use of age composition data for determining sex ratios among adult deer. *New York Fish and Game Journal*, *2*(2), 242-246.

Sieg, C., Severson, K. United States department of Agriculture Forest Service. (1996). *Managing Habitats for White-Tailed Deer.* Fort Collins, Colorado

Sullivan, A. (2015). Logging debris protects sugar maple (Acer saccharum) seedlings from white-tailed deer (Odocoileus virginianus) herbivory in wolf-occupied forest.

Telfer, E. (1972). Browse selection by deer and hares. *The Journal of Wildlife Management, 36*(4), 1344-1349.

Tilghman, Nancy. (1989). Impacts of white-tailed deer on forest regeneration in northwestern Pennsylvania. *The Journal of Wildlife Management, 53*(3), 524-532.

U.S. Forest Service. (1992). Silviculture Approaches to Animal Damage Management in Pacific Northwest Forests. *General Technical Report PNG-GTR- 278.*

Warren, R., Krysl, L. (1983). White-tailed deer food habits and nutritional status as affected by grazing and deer-harvest management. *Journal of Range Management, 36*(1), 104-109.

Watts, M. T., (1963). Tree Finder: A Manual for the Identification of Trees by Their Leaves. *1991 Nature Study Guild*

Waller, Donald., William S. Alverson. (1997). The white-tailed deer: A keystone herbivore. *Wildlife Society Bulletin (1973-2006), 25*(2), 217-226.

Ward, J. S., Gent, M. P., & Stephens, G. R. (2000). Effects of Planting Stock Quality and Browse Protection-type on Height Growth of Northern Red Oak and Eastern White Pine. *Forest Ecology and Management, 127*(1-3), 205-216.

Whitney, G. G., & DeCant, J. P. (2003). Physical and historical determinants of the pre- and post-settlement forests of northwestern Pennsylvania. *Canadian Journal of Forest Research, 33*(9), 1683-1697.