Effects of slash piles on soil moisture, soil temperature, and light intensity in northwestern Pennsylvania forests

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Submitted in fulfillment of the senior thesis requirements of the
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and approved by the senior thesis committee.

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Pledge

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White-tail deer (*Odocoileus virginianus*) are one of the most influential mammal species in northeastern United States forests. Their browsing of tree saplings severely hinders the regeneration of forests, especially those after a harvest operation. However, there is hope in attempting to limit this effect as the value of slash, a timber byproduct of harvest operations commonly thought to be worthless, has been largely underestimated. Slash, when piled up, could act as a natural barrier that protects tree saplings from deer browse. Although, by covering an area in slash, tree growth parameters like water accessibility, soil temperature, and light availability could be altered. The primary purpose of this study was to determine if slash piles alter these environmental conditions. Its secondary purpose was to test whether these differences could be influenced by variations in canopy density. Three environmental parameters were considered: (1) soil moisture, (2) soil temperature, and (3) light intensity. Ten slash piles and ten adjacent areas without slash piles (i.e., control plots) were evaluated at four northwestern Pennsylvania sites. In recent years, these sites had been sustainably harvested by Firth Maple Products (FMP) in which they left slash piles behind. Soil moisture, soil temperature, and light intensity were not significantly different between slash piles and control plots. Canopy differences between slash piles influenced only light intensity ($P = 0.045$), in an inconclusive way as the pairwise comparison found no statistical difference between open and closed canopies, and soil temperatures ($P = 0.031$) in a manner that suggests piles under a closed canopy will have higher soil temperatures than those under a semi-closed canopy. Variation in canopy did not influence any of the other slash pile or adjacent area environmental conditions as no statistical differences were found. Additionally, variation in slash pile size did not alter the aforementioned environmental conditions. Based on these results, it is not likely that slash piles alone will hinder the growth of saplings by changing environmental conditions. Furthermore, slash piles should now be evaluated as a mitigation effort against white-tail deer browse.

Introduction

Forest Composition, Harvest, and Regeneration in Northwestern Pennsylvania

The main crown canopy of current Pennsylvanian second-growth forests consists of shade-intolerant species like black cherry, white ash, and yellow-poplar with shade-tolerant species like American beech and sugar maple kept in the lower canopy (Marquis, 1981; Redding, 1995). Shade-intolerant species make up the crown of the forest canopy because they germinate the fastest. These species had to outgrow shade-tolerant trees to persist in these successional environments and they thrived in the previously open agricultural areas of Northwestern Pennsylvania. An example of a shade-intolerant species is black cherry and it is a commercially valuable tree species with a great abundance in Pennsylvania making them an ideal target of harvest for logging companies (Hough & Forbes, 1943; Smith, Miles, Vissage, & Pugh, 2004).

Traditionally, silviculture is described as the art and practice of controlling forest growth, structure, and composition, but more recent silviculture also includes controlling the exploitation of forests (Baker, Wilson, & Gara, 1999). This description has led to the argument that only through the best biological health of an ecosystem will logging companies get the most economically favorable trees. This argument supports a shift in organizational approach towards sustainable forestry practices. If done without sustainability in mind, selective harvesting of species like black cherry will lead to less valuable, shade-tolerant species controlling the forest canopy with shade-intolerant species being unable to regenerate. Therefore, it is important for modern logging companies to account for this and establish a lumbering methodology that ensures long-term, sustainable, and profitable harvesting of these forests.

In northwestern Pennsylvania, the most commonly used harvest strategies are group selection and single-tree selection. These single-selection strategies, like diameter-limit cutting, can be harmful to forest ecosystems and hinder long-term economic yield (Kenefic, Sendak, & Brissette, 2005; Nyland, 2005). However, it can be done sustainably by taking out poorly-performing understory trees along with economically good ones (Buongiorno, Kolbe, & Vasievich, 2000). Therefore, by selectively and sustainably timbering individual trees and groups of trees, these strategies have fewer negative effects on forest biodiversity than other harvest practices, like clear-cutting (Reader & Bricker, 1992; Meier, Bratton, & Duffy, 1995; Falk, Burke, Elliott, & Holmes, 2008). These sustainable strategies promote more diverse, unevenly-aged forests by opening up the canopy, allowing for the regeneration of shade-intolerant species

(Falk et al., 2008). Ultimately, regeneration is key to sustainable forestry with many factors needing to be monitored by logging companies to ensure success. For example, soil compaction, caused by heavy machinery, can hinder forest regeneration by prohibiting water infiltration and tree root expansion (Wiersum, 1957; Aubertin & Kardos, 1965; Van-Camp et al., 2004; Alaoui & Helbling, 2006; Hartmann et al., 2014; Eisemann, unpublished data). Therefore, some companies have started using horses as an alternative to mitigate these effects (Eisemann, unpublished data). This change in approach is just one of many necessary to ensure optimal regeneration of a forest after a logging operation.

Deer Browsing Impacts Forest Regeneration

The white-tail deer (*Odocoileus virginianus*) population has reached new heights and herds live in higher densities than they ever have (Rooney, 2001). This is concerning as this species is influential to the vegetation composition of forest ecosystems (Augustine & McNaughton, 1998; Gill and Beardall 2001; Russell, Zippin, & Fowler, 2001). Their ecosystem-level impacts have been well documented and are generally attributable to their browsing feeding behavior (Nugent & Challies, 1988; Tilghman, 1989; Waller & Alverson, 1997; Rooney, 2001). White-tail deer do have browsing preferences, but they are known as indiscriminate browsers when sources are limited, which leads to the stunted growth of many plant species. In northwestern Pennsylvania forests and when given a choice, they tend to browse seedlings of all hardwood trees except for *Prunus serotine* (black cherry) and *Fagus grandifolia* (American beech) (Nugent & Challies, 1988; Tilghman, 1989; Waller & Alverson, 1997). However, at the high densities they are found in today, preference is hardly ever an option as they must compete with each other for resources. This, coupled with current harvesting practices, poses significant threats to forest regeneration and biodiversity (Tilghman, 1989; Sage, Porter, & Underwood, 2003). Attempts have been made, through the use of recreational hunting and the erection of exclusion fences, towards mitigating these browsing effects (Webb, King, & Patric, 1956; Tierson, Patric, & Behrend, 1966; Behrend et al., 1970; Harlow & Downing, 1970; Ross, Bray, & Marshall, 1970; Jacobson, 2001). However, these practices have their limitations and alone have not sufficiently achieved the desired goal (Brown et al., 2000; Jacobson, 2001; Riley et al., 2003). Therefore, an alternative control practice, one following the framework of sustainable forestry, is in high demand.

Slash Piles Could Aid Sustainable Forestry

Post-harvest treetops could serve as natural barriers that prevent deer browse. The decision of what to do with the tops of logged trees, an economically worthless byproduct of harvest operations often referred to as "slash", has most commonly been to leave it to decompose. However, in some cases, it is collected as a source of firewood or burned by landowners for aesthetic reasons (Korb et al., 2004). The controlled burnings result in burnt areas called slash pile scars that have been found to assist in the establishment and spread of non-native plant species into the forest interior (Dickinson & Kirkpatrick, 1987). Furthermore, these burnings have adverse effects on the chemical composition and biotic properties of the soil within the slash pile scars (Vihnanek & Ballard, 1988; Certini, 2005). By piling slash and leaving it alone, these effects would be avoided and they may end up mitigating effects of white-tail deer browse because the deer will avoid the saplings growing in these inaccessible areas. Slash is believed to have the potential to do this and promote a biologically healthy and diverse forest ecosystem (Grisez, 1960), but is yet to be tested in published work. Additionally, it is possible that when covering an area of the forest floor with slash, certain environmental conditions could be altered influencing tree sapling composition, growth rate, and health. This is why it is necessary to evaluate slash piles' effects on growing conditions before investigating their role in deer browse prevention.

Slash Piles Could Alter Environmental Conditions

Examining environmental conditions within slash piles is important. When an area of land becomes covered by a treetop, the ground surface becomes more shaded. As an area increasingly becomes more shaded, and consistently stays shaded, the plant composition within that area begins to change (Dodd et al., 2005). Additionally, when monitoring the soil nitrogen content within increasingly shaded areas, nitrogen cycling within the soil becomes reduced under the shaded conditions because cooler conditions cause reduced plant decomposition leading to a smaller pool of mineralizable organic nitrogen (Dodd et al., 2005). This is a hindrance as plants take up a large supply of available soil nitrogen during the early stages of growth and nitrogen availability is influenced by the effects of moisture and temperature on decomposition and mineralization (Allison, 1957; Meentemeyer, 1978; Wilson, 1996). If nitrogen is insufficient at any point in the development of a new sapling, growth may be severely slowed or halted (Allison, 1957). Furthermore, sapling growth can be hindered under increased shade exposure

because the plant has to allocate more energy on increasing leaf size to absorb more light (Stoneman & Dell, 1993). The impacts of shade on tree growth suggest a shift in species composition towards those that are more tolerant to the effects of having increased amounts of shade. This is why logging companies have begun to perform more group selection harvests to open the forest canopy for better regeneration of shade-intolerant species.

Soil temperature is another environmental condition that impacts plant growth. When plants become shaded, the temperature of the soil decreases and this can lead to hindered growth (Stoneman & Dell, 1993). Soil temperature changes are one of the most influential factors of plant root growth (McMichael & Burke, 1998). The ability of a plant's root system to grow and function can be drastically reduced when temperatures exceed or fail to reach a plant species' optimum temperature range (McMichael & Burke, 1998). With this understanding, if slash piles are found to alter soil temperatures - it could mean two things: either the slash provides an insulating effect on days of cold weather, allowing for better sapling growth, or, the logging debris increases the area's shade resulting in lower temperature, worse sapling growth, and a species compositional shift toward more shade-tolerant species.

Soil moisture content is another influential environmental condition. The moisture content in both the lower leaf litter and upper soil layers is greatly influenced by the amount of throughfall precipitation that can occur based on the density of canopy cover (Anderson, Loucks, & Swain, 1969). Even though light availability for forest understories, influenced by canopy density, is considered the greatest limiting factor of growth and survival of tree saplings (Canham, 1988; Pacala et al., 1994; Kobe et al., 1995; Walters & Reich, 1996), the amount and degree of soil moisture in the surface layers of the soil can also be limiting (Anderson et al., 1969; Grubb, 1994; Walters & Reich, 1997). Under deeply shaded conditions, soil water availability has been observed to increase which improved the rate of growth for *Acer saccharum* (sugar maple) saplings, a shade-tolerant species (Walters & Reich, 1997). These environmental conditions: soil moisture (soil water content), soil temperature, and light intensity (shade) affect the development and regeneration of tree saplings and other plants. If conditions are slightly altered in areas covered in logging debris compared to areas not covered, then a shift in species composition could be explained and the method of using slash piles to promote forest regeneration would be counterproductive.

The goal of this study was to determine if slash-covered forest floor environmental conditions differed from their adjacent uncovered areas and if variation in canopy density had any influence on these measurements. The information found in this study could later be used as justification for whether slash piles should be tested as a mitigation tool against white-tail deer browse. The investigated hypotheses were that slash pile environmental condition measurements would differ from the measurements of their adjacent areas and that varying canopy densities would be influential. The predictions were as follows: (1) slash pile soil moisture would be higher than the adjacent area; (2) slash pile soil temperature and light intensity would be lower than the adjacent area; (3) slash pile and adjacent area soil moisture would be higher under semi-closed/closed canopies than under open/semi-open canopies; (4) slash pile and adjacent area soil temperature and light intensity would be higher under open/semi-open canopies than under semi-closed/closed canopies; (5) within each canopy classification, soil moisture would be higher within slash piles than adjacent areas; (6) within each canopy classification, soil temperature and light intensity would be lower within slash piles than adjacent areas; (7) slash pile soil moisture would increase as slash pile size increased; (8) slash pile soil temperature and light intensity would decrease as slash pile size increased.

Methods and Materials

Site Determination, Description, and History

Four sites logged by Firth Maple Products (FMP) were picked for data collection (Table 1). Ewing Family Woods was the furthest property from Allegheny College (62.8km) and was located in Corry, PA (Fig.1). The sites were harvested during three different years, but still represent a uniform slash pile age across the sites (Table 1). Each of the studied sites are cumulatively a part of Northwestern Pennsylvania's hardwood forests. Historically, these lands were deforested by European settlers to establish farm and industrial lands that later were mostly abandoned (Redding, 1995; Whitney & DeCant, 2003). This abandonment has led to the current composition and land coverage of Pennsylvanian forests. While today's northwestern, successional, mixed hardwood forests are under numerous management regimes, three of this study's sites are controlled by the Foundation for Sustainable Forestry (FSF) and one (Robertson) is owned by Allegheny College.

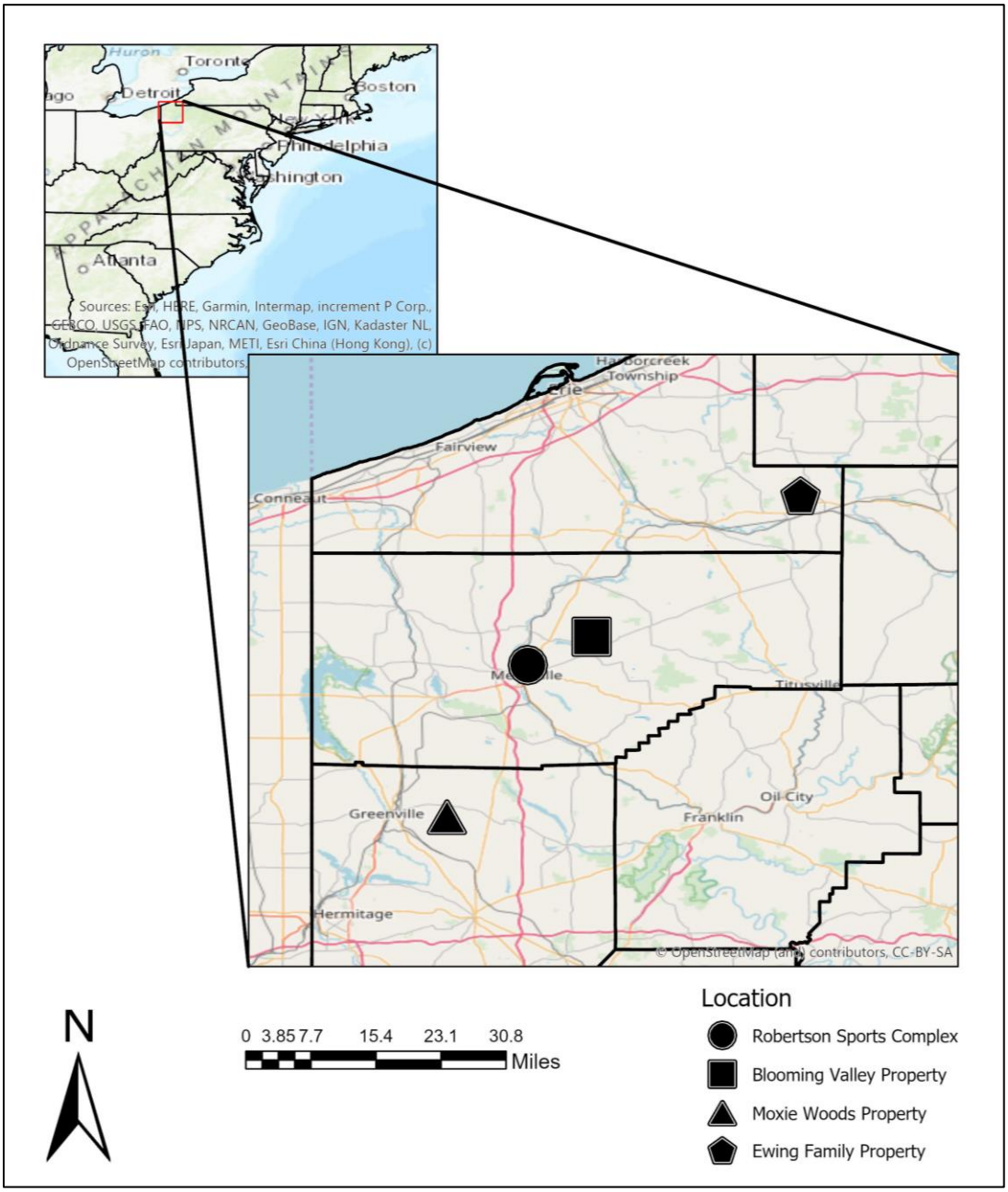

Figure 1. Locations of FSF sites spanning Erie County, Crawford County, and Mercer County Pennsylvania.

Table 1. Northwestern, PA sites logged by Firth Maple Products (FMP) with their location, elevation, the years they were harvested, the dominant tree species, and the dates that data was collected.

Property Name:	Location:	Elevation (feet):	Year of Last Harvest:	Dominant Tree Species:	Dates of Data Collection:
Robertson Forest	Park Ave, Meadville, PA	1,400	2015	Sugar Maple, White Ash, Black Cherry	September 13th-14th
Blooming Valley	Price Rd, Saegertown, PA	1,285	2017	Tulip Poplar, Northern Red Oak	September 28th-October 1st
Ewing Family Woods	Carter Hill Rd, Corry, PA	1,430	2016	Northern Red Oak, Black Cherry	October 4th-5th
Moxie Woods	Linn Tyro Rd, Greenville, PA	945	2017	Sugar Maple, White Ash, Northern Red Oak	October 19th-20th

These 4 locations were past agricultural land as none of them had pit-to-mound topography or rocky terrain with boulders protruding the ground. However, the age mosaic of the forests differed among the sites. Blooming Valley and Ewing Family Woods had understory vegetation while Robertson Forest and Moxie Woods consisted mostly of mature vegetation with some low-to-ground sapling growth. Additionally, the canopies of Blooming Valley and Ewing Family Woods were much more open than the other locations.

Tree composition was evaluated by making a 50x50 meter plot. These plots were constructed randomly at each site and did not contain all (if any) tested slash piles. Each site's composition varied slightly (Table 2). Robertson Forest and Moxie Woods were dominated by sugar maple and white ash whereas Blooming Valley was dominated by tulip poplar and Ewing Family Woods was dominated by northern red oak (Table 2). Although Robertson Forest and Moxie Woods were both dominated by sugar maple and white ash, their secondary composition differed (Table 2). Robertson Forest had a large presence of black cherry and a few pin cherry whereas Moxie Woods lacked a presence in both but had a few American basswood (Table 2). Blooming Valley was the only location to have adult cucumber magnolia and white birch trees within the test plot (Table 2). The table below (Table 2) consists of descriptive site data collected as part of a larger project - these data are important for understanding site characteristics but are not crucial to the purpose of this study.

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

NUMBER OF STEMS

Site		Total	American Beech	Sugar Maple	Red Maple	Black Cherry	Northern Red Oak	Tulip Poplar	White Ash	American Basswood	American Elm	American Hornbeam	Bitternut Hickory	Common Hoptree	Common Sassafras	Cucumber Magnolia	Manchurian Crab Apple	Northern Prickly Ash	Oregon Ash	Paper Birch	Pin Cherry	Shagbark Hickory	Trembling Aspen	Gray Birch	White Oak	Witch Hazel
Robertson Forest	Density (stems/100 m2)	1004.7	75.9	146.2	38.3	11.5	13.7	103.4	467.5	N/A	9.8	N/A	9.0	4.0	53.7	42.9	N/A	5.5	15.5	N/A	4.9	N/A	2.8	N/A	N/A	N/A
Blooming Valley		1139.0	83.1	114.6	3.1	N/A	224.1	281.7	336.5	4.0	N/A	N/A	4.0	51.4	N/A	N/A	33.5	3.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Ewing Family Woods		1569.7	346.1	75.9	N/A	N/A	626.8	N/A	314.9	N/A	N/A	N/A	N/A	12.0	N/A	N/A	25.5	N/A	N/A	N/A	N/A	N/A	N/A	130.4	N/A	38.1
Moxie Woods		1369.1	113.3	116.6	55.7	N/A	229.9	113.3	490.7	N/A	N/A	70.9	N/A	N/A	N/A	N/A	15.7	N/A	N/A	N/A	N/A	48.5	N/A	N/A	72.7	41.9

BASAL AREA

Site		Total	American Beech	Sugar Maple	Red Maple	Black Cherry	Northern Red Oak	Tulip Poplar	White Ash	American Basswood	American Elm	American Hornbeam	Bitternut Hickory	Common Hoptree	Common Sassafras	Cucumber Magnolia	Manchurian Crab Apple	Northern Prickly Ash	Oregon Ash	Paper Birch	Pin Cherry	Shagbark Hickory	Trembling Aspen	Gray Birch	White Oak	Witch Hazel
Robertson Forest	(m2/ha)	39.3	N/A	44.4	0.1	18.0	10.3	N/A	26.9	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.3	N/A	N/A	N/A	N/A	N/A	N/A
Blooming Valley		22.4	3.4	8.0	7.6	N/A	18.7	52.6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.3	N/A	N/A	N/A	4.2	N/A	N/A	N/A	5.1	N/A	N/A
Ewing Family Woods		33.4	N/A	6.6	0.1	14.4	78.8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Moxie Woods		34.4	N/A	70.2	1.0	N/A	10.9	N/A	14.9	3.06	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Site		Total	% Total
Robertson Forest			
Blooming Valley			
Ewing Family Woods			
Moxie Woods			

DBH (cm)

Site	x	SE
Robertson Forest	N/A	N/A
	34.7	3.9
	31.9	4.8
	41.7	13.1
	68.0	N/A
	N/A	N/A
	6.0	N/A
	N/A	N/A
	N/A	N/A
	N/A

Setup and construction materials

At each site, ten slash piles were evaluated along with ten control plots. Slash piles were picked at random at various accessibilities and sizes to later compare the potential effects of pile size on environmental conditions. The control plots were not covered with slash - leaves and some stray sticks were acceptable. For each slash pile, 3 flag stakes were placed horizontally along both edges of the treetop, and diameters were then measured between opposing flags, intersecting at a center stake. Later, these three diameters were averaged to calculate area for each slash pile. A 5x5 meter plot was constructed in each adjacent area, an area of forest floor within a 5-meter distance from the slash pile, intended to utilize enough uncovered ground to get a proper representation for each parameter measured.

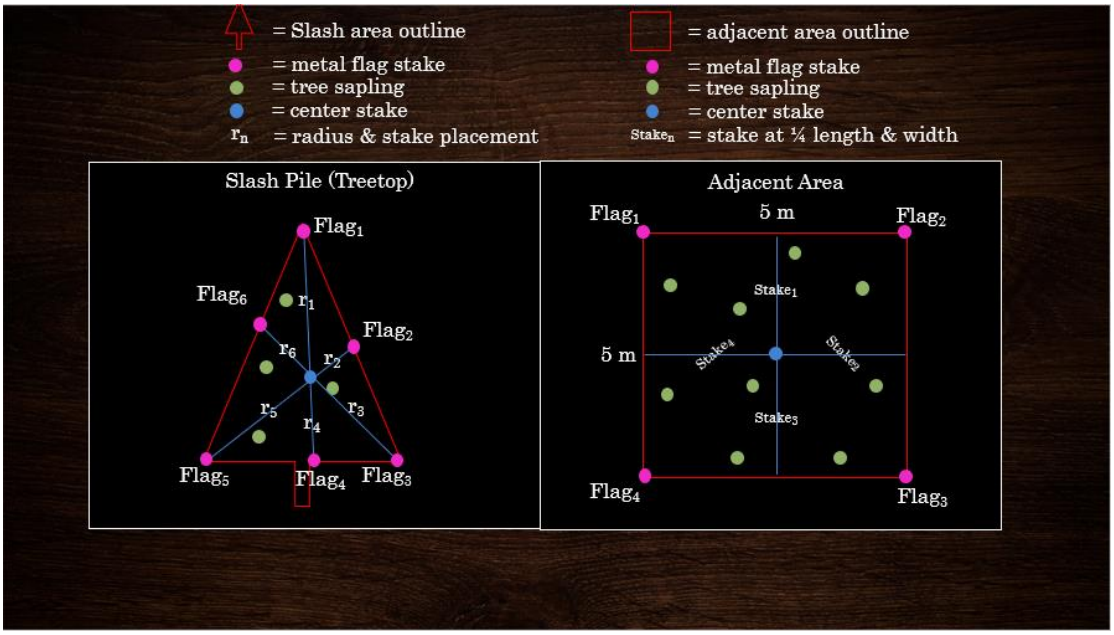

Figure 2. Slash pile and adjacent area data collection structures.

Treatments and measurements

The environmental condition parameters evaluated were: (1) soil temperature; (2) soil moisture; and (3) light intensity. For soil temperature measurements, seven were taken at each treetop site (10cm depth) using a digital soil thermometer: one at the base of the center stake and one at the base of each of the six stakes placed half the distance of each radius. Additionally, five measurements were taken at each control plot (10cm depth) using a digital soil thermometer: one at the base of the center stake and one at the base of each of the four additional stakes. Soil moisture was measured for both areas by taking a soil core sample at a depth of 10cm with an

Oakfield corer using the same sampling pattern used for temperature. These soil cores were then placed in plastic Ziploc bags. Light intensity measurements (Lux) were taken using a Plexon LX1010B digital light meter at each of the same locations that soil temperature measurements were taken, at both slash piles (7) and control plots (5). However, light measurements were recorded 25cm above the ground.

Controlling for light intensity measurements

To control for potential influencing factors, light intensity at 0% canopy coverage was recorded before walking into each of the 4 sites and then recorded at the same location again after completion of data gathering. An estimated percentage of cloud coverage was also recorded before and after taking data at each site. This estimation was taken at the same location as the 0% canopy light intensity measurement by looking at the total expanse of the sky and estimating cloud coverage. Finally, an estimated percentage was determined on how open, semi-open, semi-closed, or closed the canopy was above each area's central stake by estimating a range of canopy coverage (0-25% = open, 25-50% = semi-open, 50-75% = semi-closed, and 75-100% = closed).

Soil Moisture Data Analysis

Soil samples were stored in a refrigerator (1.6°C) until they could be dried at 105°C for 48 hours, weighed, and passed through a 2 mm sieve to correct for non-soil material. Non-soil material was weighed and subtracted from the dried soil mass. From these collected and corrected masses, soil moisture percentages were calculated (% Soil Moisture = $(\frac{wet-dry}{dry})$*100).

Soil Temperature and Light Intensity Data analysis

The seven soil temperature and light intensity measurements of each individual slash pile were averaged separately to obtain a single value for each pile. The same was done for the five soil temperature and light intensity measurements taken at each control plot.

Statistical Analysis

SigmaPlot statistical software was used for statistical analyses. To evaluate the effects of slash on each environmental condition, paired t-tests were used when data were distributed normally. If data were not distributed normally, and could not be transformed into a normal distribution, then a Wilcoxon test on ranks was performed.

To determine the effect of canopy coverage on the measured slash pile and adjacent area environmental parameters, 1-way ANOVAs and t-tests were used when data were normally

distributed. A few sets of data were not normally distributed requiring the use of a non-parametric alternative (Kruskal-Wallis - ANOVA, Mann-Whitney - t-test). Where significant differences occurred among the ANOVA tests, pairwise comparison tests were used to determine where differences occurred (Holm-Sidak - ANOVA, Dunn's Method - Kruskal-Wallis). Linear regressions were the last tests used in the SigmaPlot software to determine if slash pile size had any effect on the three measured environmental parameters.

Results

Effects of Slash on Environmental Conditions

With all sites combined, there was no difference in soil moisture, soil temperature, or light intensity between all slash piles and open areas. Robertson, Blooming Valley, and Moxie showed no significant difference in soil moisture between slash piles and open areas, whereas at Ewing, moisture was 12.1% higher in the open than in slash piles ($P = 0.0481$) (Fig. 3). Blooming Valley and Ewing showed no significant difference in soil temperature between slash piles and open areas, whereas temperature at Robertson was 0.3°C warmer in the open than in slash piles ($P = 0.000143$) and temperature at Moxie was 0.4°C warmer in slash piles than in the open ($P = 0.0151$) (Fig. 3). Robertson, Blooming Valley, and Moxie showed no significant difference in light intensity between slash piles and open areas, whereas the not-normally-distributed Ewing data showed slash piles to be statistically significantly lower than open areas by 1876 Lux (difference between medians) ($P = 0.037$) (Fig. 3).

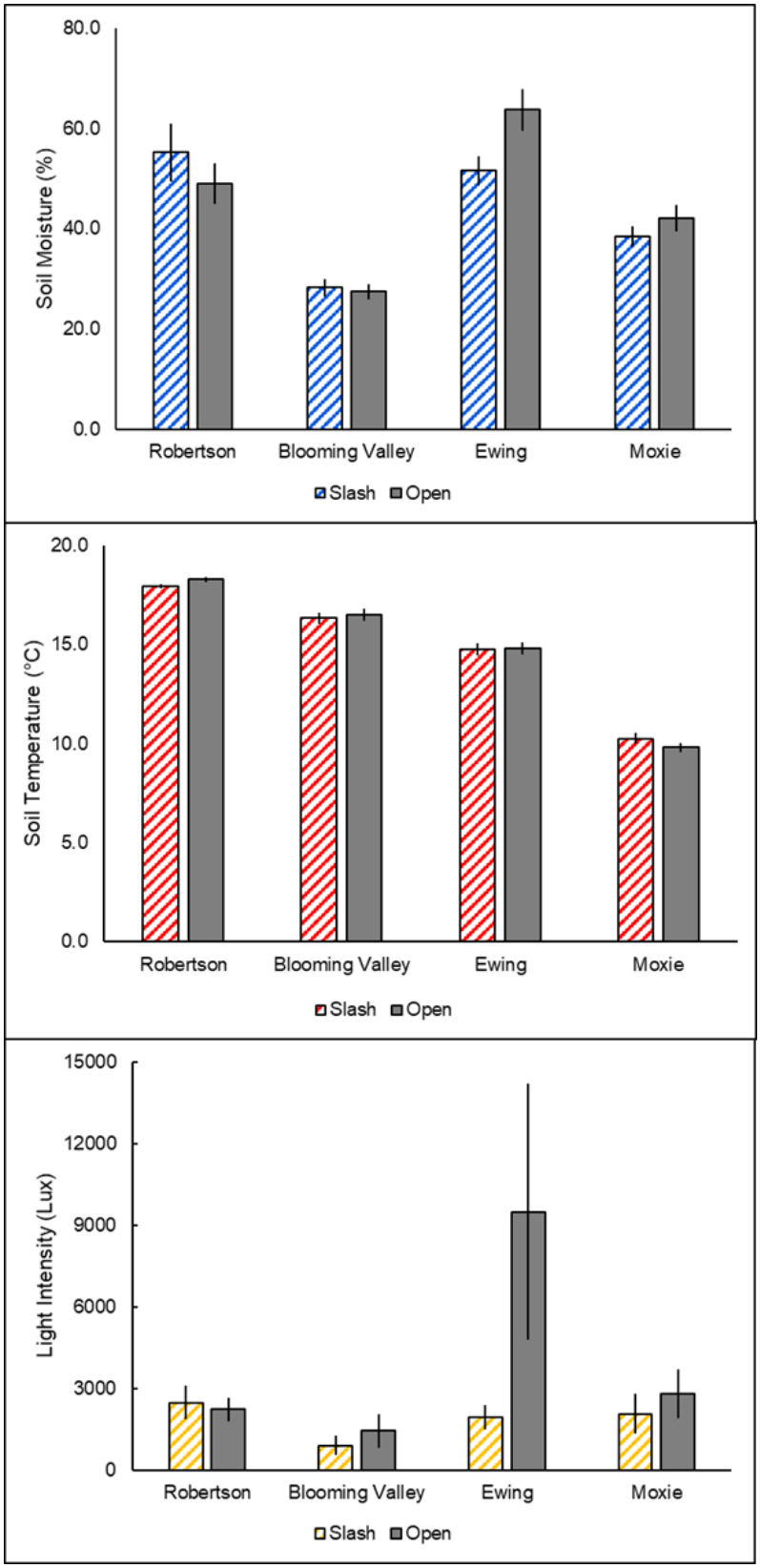

Figure 3. Soil moisture, soil temperature, and light intensity (mean, SE – error bars) in slash piles and adjacent areas in northwestern PA.

Effects of Canopy Coverage on Environmental Conditions

Across each canopy density, there was no difference in soil moisture for slash piles and open areas. There was a difference in slash pile soil temperature under different canopy densities ($P = 0.031$), where temperatures under closed canopies were warmer than those under semi-closed canopies by 2.9°C ($P = 0.034$) (Fig. 4). No difference was found in soil temperature for open areas. Another difference occurred in slash pile light intensity under the different canopy densities ($P = 0.045$), however, no difference was found between open and closed canopy slash pile light intensities, halting the pairwise comparison test (Fig. 4). No difference was found between the open area soil temperatures under the different canopy densities.

No differences in soil moisture, soil temperature, and light intensity were found between slash piles and open areas within each canopy class (Fig. 4). Three tests could not be run as sample size for open areas that were under an open canopy was too small ($N = 2$).

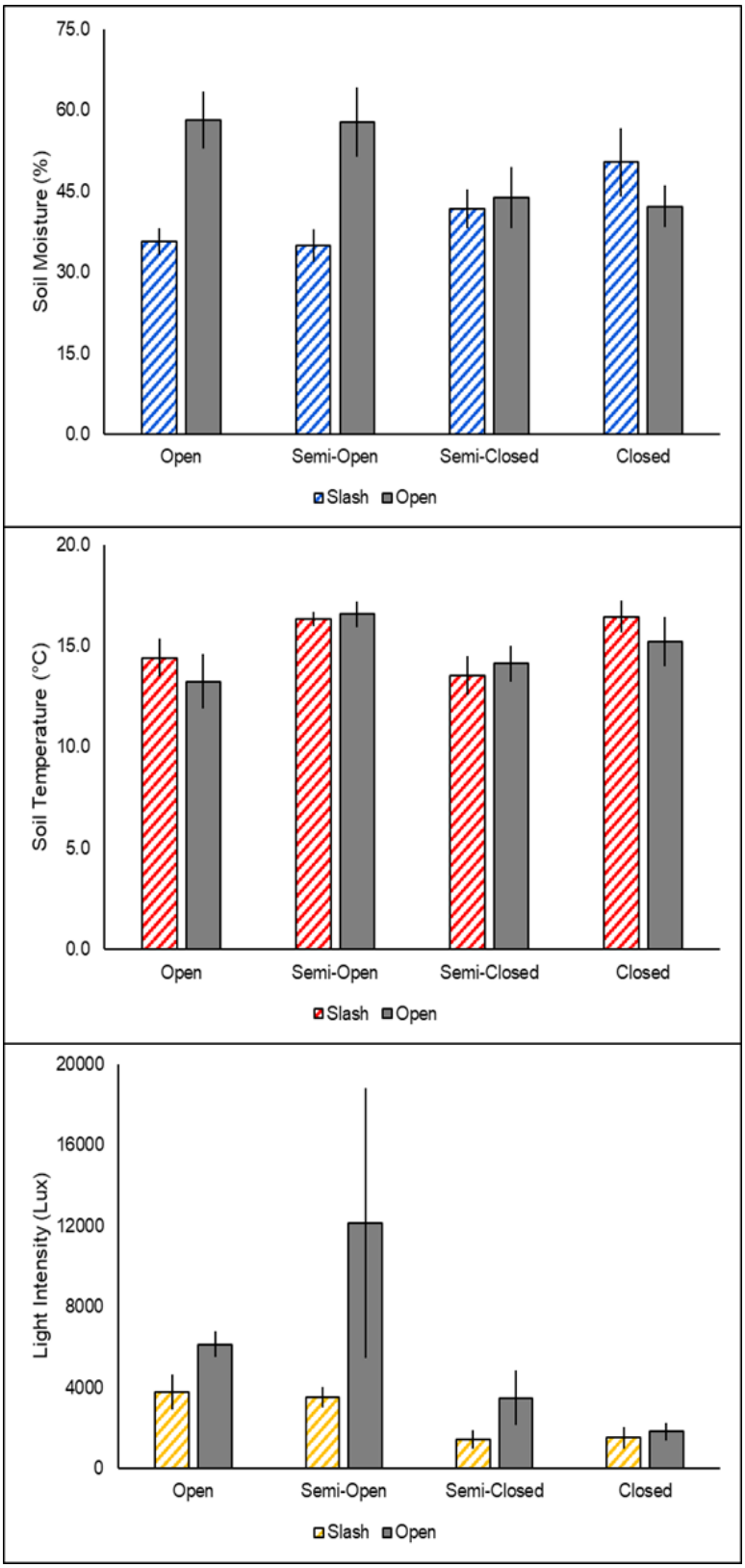

Figure 4. Soil moisture, soil temperature, and light intensity (mean, SE – error bars) in slash piles and adjacent areas of four different canopy densities in northwestern PA forests.

Effects of Slash Pile Size on Environmental Conditions

Linear regression tests showed that slash pile size (calculated area estimate) has no effect on the environmental conditions within that area. Soil moisture ($R^2 = 0.187$), soil temperature ($R^2 = 0.137$), and light intensity ($R^2 = 0.0907$) varied randomly throughout pile size such that no direct correlation exists between these environmental parameters and slash pile size.

Discussion

This study indicates that piling slash on an area of forest floor does not alter environmental conditions within that area. Virtually no differences between slash piles and control plots were found, however, a few statistical differences occurred, needing further evaluation. It is difficult to explain why the Robertson Forest slash piles had statistically significantly lower soil temperatures than the adjacent areas ($P = 0.000143$) whereas Moxie Woods soil temperatures were significantly higher in slash piles ($P = 0.0151$). However, these differences were only 0.3°C (Robertson) and 0.4°C (Moxie). These significant differences are small enough where temperatures will not fall outside of any tree sapling's optimum temperature range. Furthermore, the effects were opposite for each site, suggesting soil temperature can change on a site-to-site basis but these changes will not hinder plant and root growth as they will not exit optimal temperature ranges (McMichael & Burke, 1998).

Soil moisture, by 12.1% ($P = 0.0481$), and light intensity, by 1876 Lux ($P = 0.037$), were found to be greater in the adjacent areas of Ewing Family Woods. These differences could be attributed to this site visually having the most open canopy areas out of all of the sites and may be more representative of the effect that canopy coverage can have on these environmental parameters rather than the presence or lack of slash. This is supported by there not being a difference in these parameters at any other sites. Also, other findings have suggested that canopy density is the most influential factor in soil moisture (Anderson et al., 1969). It is difficult to gauge the implications of this moisture difference as some research has found no evidence that variation in water availability has an effect on sapling growth (Pacala et al., 1994), whereas others have found it to be influential (Walters & Reich, 1997). The light intensity difference may be important as light needs vary by species and shade-intolerant species often have insufficient exposure to light (Anderson et al., 1969; Drever & Lertzman, 2003; Barbier et al., 2008; Cogliastro & Paquette, 2012). Moreover, light intensity and availability in forest understories is largely influenced by canopy density (Canham, 1988; Pacala et al., 1994; Kobe et al., 1995;

Walters & Reich, 1996). This study, however, did not find a difference in soil moisture, soil temperature, and light intensity between slash piles and adjacent areas within each canopy density. This makes it difficult to attribute Ewing Family Woods' differences to changes in canopy. Perhaps slash pile and adjacent area light intensity were influenced by other aspects. Variations in cloud coverage throughout the day and changes in sunlight according to the angle of the sun throughout the day could have impacted these results. This study's results do not contradict previous findings, they instead suggest that changes in forest floor environmental conditions can occur from a variety of influential forest ecosystem aspects. To say these changes occurred purely from their being a presence or lack of slash is unlikely.

Slash pile soil temperature under closed canopies were found to be warmer than those under semi-closed canopies by 2.9°C ($P = 0.034$). However, none of the other canopy densities produced differences in slash pile soil temperature. Furthermore, these two canopy classes are fairly similar in density. This makes it difficult to attribute this difference to just the slight change in canopy. However, any daily, weekly, or seasonal variation in temperature that might have occurred while collecting data across separate weekends was accounted for by using paired t-tests. There is plenty of research describing the effects of canopy density on the environmental factors of soil moisture and light intensity (Anderson et al., 1969; Clinton, 2003; Bartemucci, Messier, & Canham, 2006; Barbier, Gosselin, & Balandier, 2008), but information about the effect it has on soil temperature is severely lacking in literature. That being said, there is some evidence that changes in canopy do not have an effect on soil temperature (Clinton, 2003). Therefore, with this difference, and not much other evidence of canopy having an effect on soil temperature, logging companies should be aware that canopy differences may influence soil temperature within slash piles. However, this study's results do not suggest that the change in soil temperature will be drastic enough to hinder plant or root growth.

Slash pile light intensity across the different canopy densities was also found to have a difference. However, the two canopy densities where a difference occurred could not be determined; the pairwise comparison test was inconclusive. The fact that a difference occurred is not surprising as canopy density is known to influence the amount of light reaching the understory (Anderson et al., 1969; Clinton, 2003; Bartemucci, Messier, & Canham, 2006; Barbier, Gosselin, & Balandier, 2008). Like soil temperature, logging companies must be aware that canopy can impact slash pile light intensity and is an influential aspect of forest ecosystems.

No statistical differences were found in soil moisture for slash piles and adjacent areas across each canopy class. Additionally, no statistical differences in soil temperature and light intensity occurred within adjacent areas across the canopy classes. These results suggest changes in canopy will not affect the growth of most saplings within slash piles. However, shade-intolerant tree saplings that grow within slash piles will require close monitoring of the canopy so they receive enough light to germinate. Overall, canopy density should be considered and controlled on a site-by-site basis to guide forest regeneration and create opportunity for shade-intolerant tree species to flourish.

Slash pile size was found to have no correlation with slight locational shifts in environmental conditions. This information can be used as a simple construction guideline for logging companies that attempt to use slash piles as a mitigation tool against white-tail deer browse. Prior to testing, the seventh and eighth predictions were made based on the assumption that an increase in pile size would increase the amount of shade. However, the manner that pile size was evaluated in this study did not account for some interrelatable factors. Piles of much larger size than those evaluated in this study could be created by logging companies. These larger sizes could impact environmental conditions differently than what was observed in this study. So, until larger slash piles are evaluated, logging companies should construct piles within the range of sizes evaluated in this study. Furthermore, other pile structure components such as height and density could have acute effects on environmental conditions. For example, saplings under taller, more dense slash piles could become limited in light availability. Future research must be done to evaluate the effects of slash pile height and density in relation to individual tree species' moisture, soil temperature, and light requirements before recommendations on maximum slash pile density can be made. Additionally, slash pile settling rate should be quantified alongside height and density as these factors are interrelated. The amount and duration of browse protection a slash pile provides is dependent on these factors until tree saplings grow to unreachable heights.

Some recent research has shown that slash piles indeed protect seedlings from deer browse (Hunn, unpublished data; Baker, unpublished data). Sapling height was found to be greater within slash pile areas and there was less visible evidence of browsed saplings within the slash piles (Baker, unpublished data). However, if deer populations continue to rise, intra-species competition could reach the point where white-tail deer attempt to access tree saplings within

these slash pile areas, regardless of accessibility. Just like the older deer browse mitigation techniques of hunting and putting up exclusion fences (Brown et al., 2000; Jacobson, 2001; De La Cretaz & Kelty, 2002; Riley et al., 2003), this mitigation technique could eventually falter. Therefore, the most logical approach to mitigating deer browse would be utilizing a combination approach of these three strategies. Logging companies who utilize and promote a combination of these three strategies will see the best results in forest regeneration.

Slash has the potential to be used as a tool in the sustainable management of forests. Changes in environmental conditions caused by piling slash onto an area of the forest floor are minimal. Similarly, changes in canopy have little to no effect on changing these conditions within slash piles. However, canopy changes are what logging companies need to pay greater attention to as it is an influential part of a forest ecosystem. Ultimately, the growth of saplings within slash piles is unlikely to be reduced by changes in environmental conditions. Slash piles should be evaluated as a mitigation tool against the effects of deer browse on forest regeneration. As some studies are beginning to find, slash piles protect saplings growing within their area. This provides ecological value to a previously worthless byproduct of harvest operations. The economic value of this byproduct may have been underestimated as it can now be used to protect the growth of young economically valuable trees. Logging companies should begin to use and construct slash piles in a manner that best protects understory growth from deer browse and improves the regeneration of their harvested forests.

Appendix 1. Raw Data

Table 3. Raw data for all soil moisture measurements taken between slash piles and adjacent areas.

Soil Moisture Data											
Robertson Forest		Blooming Valley		Ewing Family Woods		Moxie Woods	
Slash Pile Averages:	Soil Moisture (%)	Slash Pile Averages:	Soil Moisture (%)	Slash Pile Averages:	Soil Moisture (%)	Slash Pile Averages:	Soil Moisture (%)
1	90.6	1	28.5	1	40.9	1	46.9
2	32.0	2	32.4	2	38.5	2	44.3
3	77.8	3	26.4	3	36.6	3	46.0
4	46.7	4	31.3	4	58.1	4	35.5
5	58.1	5	22.2	5	54.9	5	35.7
6	43.4	6	39.6	6	56.0	6	33.5
7	55.3	7	21.3	7	55.9	7	38.3
8	64.5	8	29.0	8	60.7	8	35.2
9	42.2	9	27.2	9	53.8	9	42.6
10	41.6	10	24.7	10	60.7	10	26.6
x̄	55	x̄	28	x̄	52	x̄	38
SE	5.7	SE	1.7	SE	2.9	SE	2.0
Adj. Area Averages:	Soil Moisture (%)	Adj. Area Averages:	Soil Moisture (%)	Adj. Area Averages:	Soil Moisture (%)	Adj. Area Averages:	Soil Moisture (%)
1	74.0	1	28.6	1	70.1	1	52.8
2	24.0	2	32.2	2	88.9	2	44.4
3	50.5	3	25.1	3	44.7	3	58.2
4	50.8	4	35.3	4	64.3	4	36.4
5	57.9	5	26.5	5	46.1	5	36.5
6	48.3	6	30.7	6	54.3	6	35.7
7	49.9	7	19.1	7	62.1	7	35.0
8	48.9	8	23.0	8	67.2	8	39.8
9	37.9	9	28.9	9	69.7	9	36.4
10	48.3	10	25.0	10	69.8	10	46.2
x̄	49	x̄	27	x̄	64	x̄	42
SE	4.0	SE	1.5	SE	4.1	SE	2.6

Table 4. Raw data for all soil temperature measurements taken between slash piles and adjacent areas.

Temperature Data											
Robertson Forest			Blooming Valley			Ewing Family Woods			Moxie Woods		
Slash Pile Averages:	°C		Slash Pile Averages:	°C		Slash Pile Averages:	°C		Slash Pile Averages:	°C	
1	18.1		1	16.0		1	16.2		1	9.5	
2	18.3		2	15.9		2	16.0		2	9.4	
3	18.2		3	15.4		3	15.2		3	9.0	
4	17.8		4	16.1		4	15.2		4	9.5	
5	18.3		5	15.9		5	15.4		5	9.1	
6	17.8		6	16.1		6	14.0		6	11.4	
7	17.6		7	16.3		7	14.0		7	10.9	
8	17.7		8	16.1		8	13.7		8	11.0	
9	17.7		9	18.1		9	14.4		9	11.5	
10	17.8		10	17.6		10	13.5		10	10.9	
	x̄	17.9		x̄	16.4		x̄	14.8		x̄	10.2
	SE	0.1		SE	0.3		SE	0.3		SE	0.3
Adj. Area Averages:	°C		Adj. Area Averages:	°C		Adj. Area Averages:	°C		Adj. Area Averages:	°C	
1	18.7		1	15.7		1	16.3		1	8.9	
2	19.0		2	15.7		2	15.9		2	9.0	
3	18.6		3	15.7		3	15.7		3	9.2	
4	18.1		4	16.2		4	15.5		4	9.3	
5	18.5		5	16.2		5	15.1		5	9.4	
6	18.0		6	16.4		6	13.8		6	10.3	
7	17.8		7	16.3		7	14.1		7	10.4	
8	18.2		8	16.3		8	14.0		8	10.7	
9	18.0		9	18.5		9	13.9		9	10.6	
10	18.0		10	17.8		10	13.8		10	10.2	
	x̄	18.3		x̄	16.5		x̄	14.8		x̄	9.8
	SE	0.1		SE	0.3		SE	0.3		SE	0.2

Table 5. Raw data for all light intensity measurements taken between slash piles and adjacent areas.

Light Intensity Data												
Robertson Forest			**Blooming Valley**			**Ewing Family Woods**			**Moxie Woods**		
Slash Pile Averages:	Lux		Slash Pile Averages:	Lux		Slash Pile Averages:	Lux		Slash Pile Averages:	Lux	
1	4977		1	514		1	2384		1	97	
2	1423		2	154		2	3223		2	365	
3	1684		3	148		3	1702		3	426	
4	1911		4	990		4	676		4	2781	
5	5043		5	603		5	1018		5	527	
6	5564		6	2040		6	287		6	302	
7	1821		7	3636		7	358		7	1149	
8	841		8	658		8	1912		8	4027	
9	1060		9	184		9	4114		9	4010	
10	470		10	159		10	3872		10	6960	
	x	2480		x	909		x	1955		x	2064
	SE	610.7		SE	353.9		SE	447.7		SE	729.3
Adj. Area Averages:	Lux		Adj. Area Averages:	Lux		Adj. Area Averages:	Lux		Adj. Area Averages:	Lux	
1	2642		1	159		1	4732		1	235	
2	622		2	262		2	2245		2	482	
3	3826		3	276		3	3050		3	642	
4	2014		4	2407		4	1882		4	4380	
5	3440		5	823		5	477		5	1006	
6	2348		6	1150		6	4317		6	620	
7	4188		7	6150		7	13796		7	2735	
8	1714		8	2930		8	12032		8	2742	
9	900		9	148		9	49840		9	7752	
10	550		10	86		10	2584		10	7552	
	x	2224		x	1439		x	9495		x	2815
	SE	415.2		SE	611.8		SE	4694.3		SE	907.9

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