Effectiveness of Treatments to Reduce *Rhododendron maximum* and Promote Tree Seedling Regeneration in the Southern Appalachians

by

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ABSTRACT

Rosebay rhododendron (*Rhododendron maximum* L.) is an evergreen ericaceous shrub that plays a dynamic role in the southern Appalachian forests. Commonly located on mesic sites, this understory shrub forms dense thickets that greatly reduce the amount of light available to herbaceous and woody plants found on the forest floor. Past research has shown that silvicultural methods can be used to eradicate *R. maximum*, however it is unclear which of these methods is most efficient and what effects other than stem mortality may occur. In this study, treatments involving prescribed fire, mechanical cutting, and herbicide applications were applied to *R. maximum* dominated forests in southwestern Virginia to determine what effect seven different silvicultural treatments had on 1) controlling of *R. maximum* as a forest weed 2) fuel loading inside of a *R. maximum* thicket, and 3) canopy tree seedling regeneration. Mechanical cutting treatments were successful in reducing *R. maximum* basal area per acre; however stump sprouting and increased fuel loading occurred. Herbicide applications were successful in controlling only the smallest diameter class of *R. maximum* stems. Prescribed fire reduced litter layers and caused delayed mortality on *R. maximum* stems three years following treatment. Hemispherical photographs taken within each plot showed that silvicultural treatments that successfully increased the amount of light entering each plot were influential in seedling establishment three years following treatments. Results from this study can be used to further perfect silvicultural applications that alleviate *R. maximum* cover on the forest landscape.

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Table of Contents

List of Tables

List of Figures

I) *Introduction*

The southern Appalachian Mountain region is greatly influenced by oak-hickory forests that contain variety of timber species, many of which are of commercial value. These forests, which are overwhelmingly dominated by broadleaved trees, also contain an important evergreen component that is influencing the natural dynamics of the southern Appalachian forest (Monk and Day 1985). The ericaceous subcanopy evergreen species rosebay rhododendron (*Rhododendron maximum* L.) occupies approximately 70 million acres of the southern Appalachian Mountains and forms extensive thickets near streams and on north slopes (Nilsen 1999). *Rhododendron maximum* is most abundant on sites with the highest potential for forest productivity (north facing slopes and cove positions), which increases the influence this species can have on the future composition of southern Appalachian forests following disturbance.

Due to the dense crown of *R. maximum*, limited light penetration seems to be the greatest detriment to canopy tree seedling establishment and survivorship in the understory (Phillips and Murdy 1985, Clinton and Vose 1996, Nilsen et al. 2001, Beier et al. 2005, Lei et al. 2006). However, other hypotheses for the inhibition of seedling establishment under *R. maximum* thickets have been proposed such as litter depth and quality, competition for water and nutrients, and allelopathy (Clinton and Vose 1996, Nilsen et al. 1999, Lei et al. 2002, Baker and Van Lear 1998). Silvicultural treatments can be applied in order to reduce the *R. maximum* canopy to allow greater light levels to reach the forest floor (Hooper 1969, Romancier 1979). Early silvicultural trials to reduce *R. maximum* in the southern Appalachians used the herbicide 2,4,5-Trichlorophenoxyacetic acid which was phased out of production in the late 1970's due to concerns about its toxicity. Therefore, it is unknown which treatments, or combination of treatments, provides the most effective means for eliminating *R. maximum* stems initially and the subsequent re-growth of new *R. maximum* stems. In addition, it is unknown what long term effects these treatments will have on fuel loading on the forest floor.

The overall objective of this project is determine which treatment, or combination of treatments, is most efficient in opening up the *R. maximum* canopy and what effect these treatments have on fuel loading and hardwood seedling regeneration on the forest floor. Research plots and methods will be established so that applied silvicultural treatments and hardwood regeneration can be monitored over time. Our underlying hypothesis is that accurate measurements of *R. maximum* stem mortality resulting from a combination of applied silvicultural treatments will improve the knowledge of how to treat understory *R. maximum* thickets that are inhibiting the regeneration of hardwood species.

II) *Project History*

Chuck Harrell began work on this research project in 2005 as a graduate student with the Department of Forestry at Virginia Polytechnic Institute. Under the supervision of Dr. Shepard Zedaker, Harrell's main objectives were to administer seven different silvicultural treatments on *R. maximum* plants throughout sites in western Virginia and test the applicability of each. Herbicide, mechanical cutting, and prescribed burning were used as treatments onto themselves and well as in combination with one another. The purpose of his study was to determine the effects of each treatment on both the fuel loading within an *R. maximum* thicket and the control of *R. maximum* as a forest weed. The final objective of his project was to determine the cost effectiveness of each implemented treatment. Under Harrell, replications 1, 2, and 3 were established and analyzed for pre- and post-treatment data.

Christopher Pearce started the continuation of this project in the spring of 2007 as a graduate student with the Virginia Tech Department of Forestry. Under the supervision of Dr. Shepard Zedaker, replications 1, 2, and 3 (established by Harrell) were measured for year 2 and year 3 data. An additional fourth replication was installed to increase the strength of pre- and post-treatment data. Measurements of fuel loading and *R. maximum* stem mortality were continued objectives but the cost effectiveness analysis was not. A new objective was established under this portion of the research project to determine what effects each of the treatments had on the regeneration of canopy tree seedlings.

III) *Literature Review*

3.1 *Establishment of R. maximum in the southern Appalachians*

Rhododendron is a widely distributed genus that occurs throughout much of the northern hemisphere with more than 1000 species worldwide (Chamberlin 1996). The term rhododendron means “rose tree”, which is fitting due to many species (such as azaleas) having showy flowers. *Rhododendron* is in the *Ericaceae* (heath) family, which thrives in acidic soils, and includes notable species in the genus *Vaccinium* (blueberry) and *Kalmia* (mountain laurel). The species *Rhododendron maximum* (Great or Rosebay Rhododendron) is a perennial evergreen shrub that is native to eastern North America and is most concentrated in the southern Appalachians (Cox 1979).

Rhododendron maximum forms extensive thickets composed of mature even-aged plants that reach a height of 9 to 18 ft. near streams and on north slopes (McGee and Smith 1967, Hooper 1969). Once established, *R. maximum* can aggressively expand into adjacent forest through root sprouting and branch layering forming a persistent thicket (Lei et al. 2002). These thickets which reach extreme densities can endure for many decades, reproducing by seed, layering and sprouting (Romancier 1971).

The productivity of *R. maximum* varies significantly with topographic location (Monk et al. 1985). In a study of the ecological importance of *R. maximum* in the southern Appalachians, Monk (1985) found that *R. maximum* basal area and density was influenced by aspect and elevation. Furthermore*, R. maximum* located in mesic sites were found to produce greater twig elongation with significantly more leaves that had greater weight and surface area than those found in xeric areas.

There is evidence that this subcanopy evergreen shrub is increasing in area and occupying high quality forestry sites (Dobbs, 1995). This is mainly due to the extensive history of anthropogenic and natural disturbances that have occurred in the southern Appalachian forests since European settlement. Major disturbances such as grazing, agriculuture, chestnut blight (*Cryphonectria parasitica),* Dutch elm disease (*Ophiostoma ulmi*), and gypsy moth (*Lymantria dispar*) resulted in canopy openings that permitted *R. maximum* thicket establishment (Clinton et al., 1994; Woods and Shanks, 1959). Subsequent fire exclusion, logging, and reversion of agricultural land to forest have further altered forests in this region allowing *R. maximum* to dominate in the understory (Elliot et al. 2004).

Three periods of fire activity have occurred in the southern Appalachians (Brose et al. 2001). Native Americans frequently burned low-intensity surface fires for agriculture and hunting until the mid 1800’s (Day 1953, Pyne 1983). Beginning in the mid-1800’s European settlers used high intensity fires in combination with land clearing until nearly the entire southern Appalachian region was cleared or logged during the early 1900’s (Elliot et al. 2004). After 1920 an era of fire suppression began in which intense fires became less frequent. Fire and grazing that were common in the southern Appalachians before the 1920’s probably prevented *R. maximum* from becoming an important competitor. McGee and Smith (1967) conducted a study on the origin of *R. maximum* thickets on the Bent Creek Experimental Forest near Asheville, North Carolina. Through age determination they found that a majority of the *R. maximum* studied were established between 1897 and 1917, which parallels the beginning of fire protection and grazing control in the area.

In addition to the suppression of fire activity, *R. maximum* grew more vigorously in disturbed sites created by the death of American chestnut in the canopy. Chestnut blight (*Cryphonectria parasitica*) decimated American chestnut (*Castanea dentata*) populations, a dominant component of the overstory canopy in southern Appalachian forests. Woods and Shanks (1959) study of American chestnut replacement in the Great Smokey Mountains found that American chestnut formerly occupied about 35% of the basal area of the oak–hickory (*Carya spp*.) forest type. This study was comprised of qualitative data taken on shrub layers as well as tree seedlings that were located in areas where the chestnut blight created gaps in the upper canopy. They found that *R. maximum* formed a "very important stratum" and was present in 60% of all stands ranging from hemlock-chestnut mesic habitats at one extreme to pine-chestnut xeric sites at the other.

The ecological consequences of an increasing abundance of *R. maximum* presents problems for timber management on millions of acres in the Southern Appalachians. The increasing abundance and dominance of *R. maximum* in riparian forests could alter historical patterns of succession resulting in significant changes in the structural, compositional, and functional diversity of these systems (Baker and Van Lear 1998). *Rhododendron maximum* is most abundant in sites with the highest potential for forest productivity (north-facing slopes and cove positions). Its dense thickets cast so much shade on the forest floor that tree species cannot reproduce, and eventually the site is lost as a timber-producing area (Romancier 1971). The result is a significant increase in acreage of dense stands of *R. maximum* which will continue to provide competition to reproduction and growth of both woody and herbaceous vegetation.

3.2 *Regeneration of seedlings under R. maximum*

The shrub-tree interaction between *R. maximum* and canopy tree seedlings has important consequences due to its suppression of productivity and development in high quality forests sites in the southern Appalachians. Several hypotheses have been researched to explain the basic mechanisms by which evergreen shrubs inhibit recruitment of seedlings. These mechanisms which include: reduced seed rain, litter depth and quality, low light levels, competition for water and nutrients, allelopathy, and inhibition of mycorrhizae (Beier et al. 2005, Phillips and Murdy 1985, Clinton and Vose 1996, Lei et al. 2006, Nilsen et al. 2001, Nilsen et al. 1999, Lei et al. 2002, Baker and Van Lear 1998, Walker et al. 1999).

Beneath dense understories of *R. maximum*, establishment of species are limited and inversely related to *R. maximum* abundance. Phillips and Murdy (1985), in a long-term ecological study at the Coweeta Hydrologic Laboratory in North Carolina, assessed the change in tree regeneration patterns over a 38 year period. Study plots which were established from 1934 and 1935 and re-inventoried in 1969 to 1972 were analyzed to assess the impact *R. maximum* has on the regeneration of dominate species in chestnut and mixed oak forest types. During this 38 year period, *R. maximum* increased in basal area an average of 123 ft^2/acre per 2 acre plot. The density of stems per acre of tree saplings dropped an average of 68% in areas of high *R. maximum* density (>15% basal area of plot) and was due to an increase in density and basal area of *R. maximum*. Chestnut oak (*Quercus prinus*) was found to show depressed reproduction in Mixed Oak forest types only while white oak (Quercus alba) and scarlet oak (Quercus coccinea) exhibited depressed reproduction in both forest types. Hemlock (*Tsuga Canadensis*) was the only species to show an increase in sapling density from 1934 to 1972. Red maple (*Acer rubrum*) was found to have a density-diameter distribution that did not change with time showing that it was capable of survival and reproduction under site conditions that exist under *R. maximum* thickets.

R. maximum establishment in canopy gaps caused by various disturbances have significant effects on seedling regeneration. Rivers et al. (2000) conducted a study that determined the effects of *R. maximum* on community composition and species richness in different sized canopy gaps in cove forests of the Blue Ridge Mountain province of the southern Appalachians. Sites were selected by the presence of wind throw trees that created canopy openings. Criteria for choosing canopy gap sites included: 1) gap-making trees must have been upper canopy tree 2) gaps must be naturally occurring 3) gaps must be less that 7 years old 4) gaps occur on mesic areas 5) gaps were located no greater than 115 ft. from a stream. Densities of *R. maximum* were classified into separate categories (high, medium, low, scarce) to determine the effect of different densities of *R. maximum* on species richness in the regeneration layer. Vegetation was sampled along two different transects coinciding at the center of the canopy gap. The study found that total species richness in the regeneration layer was inversely related ($R^2 = 0.92$) to percent *R. maximum* cover. An average of 6-7 plant species were found on sites with high densities of *R. maximum* in comparison to 26-29 species found where *R. maximum* was scarce or absent.

3.3 *Above and belowground influence of R. maximum on canopy tree seedlings*

Tree replacement after small scale disturbances in the southern Appalachians depends on successful seed germination and seedling establishment. Pre-emergent factors that could lead to the suppression of canopy tree seedlings under *R. maximum* include reduced seed input and seed viability in the seed bank in soils (Nilsen and Horton 2002). In a study looking at the effects of *R. maximum* on the regeneration of canopy tree seedlings, Lei et al. (2002) evaluated possible mechanisms by which *R. maximum* interferes with different life history stages of common southern Appalachian forest trees. The study, conducted at the Coweeta Hydrologic Laboratory in North Carolina, randomly placed circular mesh seed traps underneath *R. maximum* thickets as well as adjacent forest areas outside of *R. maximum* thickets. Total seed count was collected monthly from May 1996 through December 1997 and again in April 2007. Lei et al. (2002) found that seed trap data that was collected over the two growing seasons were not significantly different in forest areas with or without *R. maximum*. The study concluded that seed fall within *R. maximum* is sustained by neighboring trees outside of thickets, which is plausible due to the steep terrain common in southern Appalachian forested areas.

Also investigated in this study was whether seed banks were different for various tree species (*A. rubrum, L. tulipifera, B. lenta, and Q. rubrum*) under *R. maximum* thickets in comparison with areas free from *R. maximum*. Substrates (including litter organic and top mineral layer) were collected from under *R. maximum* thickets as well as forest areas free of *R. maximum* presence and incubated in a green house for six months to allow for full germination before a total seedling count by species was made. While it has been hypothesized that physical and/or chemical traits associated with *R. maximum* thickets could affect germination of seedlings, Lei (2002) found that *R. maximum* thickets did not significantly alter the seed bank for the four overstory trees that were observed. Furthermore, it was found that seeds dispersed into *R. maximum* thickets are just as capable of germinating on the forest floor as those found outside the thickets. The results from this study indicate that the mechanisms by which *R. maximum* inhibits seedling recruitment is more likely related to the effects that this shrub has on post-emergent conditions following dispersal and germination.

Due to the dense canopy of *R. maximum*, light penetration seems to be the main limiting resource responsible for poor seedling performance underneath thickets. Light levels in southern Appalachian forest are very low during the growing season (~ 15% that of full sun) for sites without *R. maximum* presence (Clinton et al., 1994). Light is further intercepted in the forest understory by *R. maximum*, which reduces light levels an additional 14-34% compared to a forest understory without shrubs (Clinton 1995).

Clinton and Vose (1996) designed a study that examined the differences in the light environment as well as seedling densities of *Acer rubrum* beneath open and closed understories of *R. maximum*. The study, conducted at Coweeta Hydrologic Laboratory, involved planting seeds from mature *A. rubrum* trees in plots containing three different treatments that manipulated light levels. The three treatments that were used included: dense *R. maximum* cover, open understory, and open understory with shadecloth. The shadecloth treatment duplicated light conditions (photosynthetically active radiation; 400-700 nm) found beneath *R. maximum* thickets. Seedlings in each plot were inventoried at 2 to 5 day intervals from early June through late August.

Results showed that initial seedling germination and establishment was significantly lower under the *R. maximum* treatment in comparison to the open and shadecloth treatments. The number of seedlings increased over time in the open and shadecloth treatment, while seedling mortality under *R. maximum* began approximately 1 week after germination. Seedling mortality under the shade cloth treatment began approximately 3 weeks after *A. rubrum* germination, indicating that the accelerated mortality was due to the effects of low light. Light levels were found to be ten times less under a *R. maximum* canopy in comparison to the open understory and photosynthetically active radiation (PAR) was significantly lower under the *R. maximum* treatments than in the open understory treatment. What is interesting to note in the study was that seedling mortality under the shadecloth treatment began to occur two weeks later than seedling mortality under the *R. maximum* treatment. This could suggest that other factors besides light could play a role in seedling mortality under *R. maximum* thickets.

Light availability is likely the major factor that subcanopy, evergreen thickets have on reducing resource availability for canopy tree seedlings. Sun flecks, which are high intensity beams of radiation that penetrate through holes in the canopy, are an important resource for maintaining positive carbon balance for seedlings (Nilsen and Horton 2002). Lei et al. (2006) conducted a study that investigated the impact that the light environment under a *R. maximum* thicket has on the photosynthetic responses of regenerating canopy tree seedlings. In order to determine the effect that *R. maximum* has on the light environment at the forest floor, PPFD (photosynthetically active photon flux density) was assessed using quatum sensors and canopy photographs in a total of 90 plots with *R. maximum* presence and where *R. maximum* was absent. In this study "sunflecks" were defined as pulses of light above 108 μmol ft^{-2} s^{-1} PPFD. Quantum sensors placed 8 in. above the ground recorded PAR at one minute intervals Hemispherical canopy photographs were also used to evaluate the spatial and temporal variation in the light environment.

Results from Lei et al. showed that sunflecks were more frequent and brighter in forest sites without a thicket of *R. maximum* compared to sites where *R. maximum* thickets were present. Quantum sensor data showed that in late April, before overstory canopy closure, light conditions under both canopy types were favorable for carbon assimilation by oak seedlings. However in late May, after overstory canopy closure had occurred, the duration of sunflecks under *R. maximum* was less than 50 minutes per day and sites without a *R. maximum* canopy received about 4 hours per day. Both quantum sensors and hemispherical photographs showed that light levels during mid-summer (July) in forest locations without *R. maximum* presence had a higher cumulative PPFD than in areas with *R. maximum*, however the difference between the two became significantly less under full overstory canopy closure. The study concluded that seedlings growing under *R. maximum* thickets regularly encountered light levels insufficient to maintain a net daily carbon gain, including the month before canopy closure which is important for seedling survival.

Nilsen and Horton (2002) describe how reduced carbon gain could create a resource limitation spiral that leads to seedling mortality under a *R. maximum* thicket. Reduced carbon gain from low light acquisition leads to lower leaf area, which in turn leads to a seedlings' inability to capture sufficient light and obtain positive carbon gain. Seedlings starved for carbon are unable to allocate sufficient carbon to below ground resources such as root and mycorrhizal growth. This in turn reduces a seedlings ability to acquire below-ground resources such as water and nutrients, which further lowers a seedlings photosynthetic capacity.

3.4 *Silvicultural methods to control R. maximum*

The inhibitory effect of *R. maximum* on forest sites has led this species to be considered more of a forest weed than an aesthetic species. Silvicultural treatments are commonly prescribed to reduce the influence of evergreen shrubs when timber production is a primary objective (Clinton et al. 1993, Vose and Swank 1993). The rough mountain terrain favored by the plant makes the costs of control efforts high due to reduced accessibility (Romancier 1971). Although the research is not extensive, studies involving the eradication and suppression of *R. maximum* on high quality hardwood production sites in the southern Appalachians have been conducted (Wahlenberg and Doolittle, 1950; Yawney, 1962; Hooper, 1969; Romanier, 1971). More recent research has involved the use of herbicide applications to eradicate *Rhododendron poniticum* L., a species of Rhododendron native to Europe and southwest Asia (Esen and Zedaker 2004, Dixon and Clay 2002, Lawrie and Clay 1992).

(3.4.1) Prescribed Fire

Hooper (1969) investigated the use of prescribed fire as a tool for the control of *R. maximum* in the southern Appalachian Mountains. Eight acres of a mixed oak and pine forest located on the Bent Creek Experimental Forest in North Carolina were chosen to burn. Before and after the burn, *R. maximum* stems were measured, numbered, and tagged to determine the effectiveness of the fire. Results from this study showed that smaller stems of *R. maximum* were more severely damaged by fire than larger stems.

Thirty percent of all *R. maximum* stems measured were completely top-killed 4 months after the burn. Eighteen months after the burn, only 16% of the *R. maximum* stems remained completely top-killed with many of the *R. maximum* plants recovering to some degree and putting forth a small amount of leaves.

Prescribed fire may also be a useful tool to restore mesic mixed-oak communities in the southern Appalachians. Effective fire exclusion over the past 80 years has contributed to current stand and site conditions that are not conducive to oak regeneration. Upland oak stands harvested after 1930 are now frequently dominated by other hardwood species and stands originating prior to 1930 are usually dominated by oaks (Wang 2005). Fire should favor oaks in comparison to other hardwoods, due to their thick bark, sprouting ability, resistance to rotting after scarring, and suitability of fire-created seedbeds for acorn germination (Abrams 1996).

Van Lear and Waldrop (1989) reported that oaks resprouted more frequently than most other hardwood species after burning and repeated burning may be necessary to promote successful oak regeneration. A study by Wang (2005) that investigated the effects of prescribed fires on white oak seedling survival and growth during the first growing season in the Upper Piedmont region showed that prescribed fire treatment affected density and biomass, but it did not affect the mortality and root to shoot ratio of new white oak seedlings.

Elliot et al. (2004) examined the effects of a single dormant-season prescribed fire on the vegetation dynamics (mortality, regeneration, and diversity) in a southern Appalachian mesic mixed-oak ecosystem. Percent mortality of understory stems showed that a higher percentage of *A. rubrum* stems did not resprout after burning in comparison with any other species. There was a significant recruitment of *Quercus spp*. (*Q. alba, Q. prinus, Q. rubra,* and *Q. velutina*) through both seedlings and sprouts, with *Q. rubra* having the highest amount of new seedling recruitment. The study concluded that through the reintroduction of fire, *Quercus spp*. may become overstory dominants, however multiple understory fires may be necessary to reduce *A. rubrum* (a shade-tolerant species) establishment and its potential competition with *Quercus spp.* regeneration.

(3.4.2) Herbicide and Mechanical Cutting Applications

Herbicide and mechanical cutting applications are other silvicultural methods that have proven successful in controlling *R. maximum* establishment. Yawney (1962) used a combination of mechanical cutting and chemical applications treatments to determine its effectiveness for eradication of *R. maximum*. A total of three treatments: 1) stem cutting only, 2) stem cutting and stump spraying with a mixture of 2,4,5-Trichlorophenoxyacetic acid in diesel oil, and 3) basal spraying with a mixture of 2,4,5-Trichlorophenoxyacetic acid in diesel oil were tested on *R. maximum* thickets in the Fernow Experimental Forest located in West Virginia. Ten *R. maximum* thickets were included in each treatment with live stems tallied before and two years after treatments were applied.

Cutting followed by stump spraying and basal spraying without cutting proved to be highly successful in controlling *R. maximum*. In the cutting followed by stump spraying treatment, only 19 new sprouts appeared in two of the ten *R. maximum* clumps. Basal spraying treatments were shown to be as effective; however mortality of *R. maximum* stems occurred at a much slower rate. Only the lower branches were affected the first year after herbicide application, with the full effect of the treatment becoming evident only after the second growing season. The study reported that the mechanical stem cutting only treatment resulted in significant sprouting. Furthermore it was concluded that this treatment provides only temporary control and that in that a few years after cutting, sprouts will present an even greater problem than what existed before.

Romancier (1971) conducted a similar study in which herbicide applications of 2-4-5 Trichlorophenoxyacetic acid were combined with prescribed fire to eradicate *R. maximum* thickets. In the fall of 1964, a prescribed burn in the Bent Creek Experimental Forest near Asheville, North Carolina was set in order to control *R. maximum* so that pine seedlings could be planted. Twenty-one months after the fire, *R. maximum* stems were measured for number and length of sprouts, as well as the amount of fire-caused top-kill. After the thickets were measured, different combinations of chemical treatments were applied (as a basal and foliar spray) to *R. maximum* groups and then measured again three years later.

The study found that topkill increased an average of 65 to 91% even without the application of herbicide and was likely due to the delayed mortality effects of the prescribed burn. The treatments in which chemicals were applied showed that the average number of sprouts per plant dropped from 36 to 2. The study concluded that a fire/chemical combination treatment is very effective treatment for controlling *R. maximum* in areas that are valuable for timber production.

Much of the herbicide applications done today use vegetable oil as an herbicide carrier instead of diesel fuel or kerosene. The herbicide 2-4-5 Trichlorophenoxyacetic acid used in the two studies previously discussed is not available anymore due to toxicity concerns. Imazapyr (Arsenal® SL) and triclopyr (Garlon® 4), are two presently available herbicides that are frequently used for woody plant control. Impazapyr and triclopyr were found to be successful as foliar applications in controlling *Rhododendron ponitcum* L. (an invasive rhododendron species found throughout the UK) in Beech forests in the Black Sea Mountain region of Turkey (Esen and Zedaker 2004). Mature eastern beech stands with continuous *R. ponticum* understories were selected as study sites in the Black Sea Region and treated with a foliar spray herbicide application using either imazapyr or triclopyr. Foliar herbicide application was found to be both economically and biologically effective as a woody control technique reducing the basal area of *R. ponticum* 81% for sites treated with triclopyr and 94% on sites treated with imazapyr. The study attributes the enhanced woody control of impazapyr in comparison to triclopyr to a study conducted by Essen et al. (2002) that found impazapyr to have greater herbicide translocation to *R. maximum* roots than triclopyr.

3.5 *Fuel Loading*

Fire exclusion on public lands may have increased fuel loads in the southern Appalachians and prediction can be difficult due to fuels being closely associated with site quality and forest cover type (Waldrop et al. 2007). Large increases in fuel loading on the forest floor can create fire hazards resulting in a greater intensity fire occurring than what many regions might have historically experienced. Fuel is added to the forest floor each year as leaves, twigs, or needles are dropped directing the ignition, buildup, and wildfire behavior more than any other variable (Brown and Davis 1973).

Fuels are classified by time-lag classes, which define the time required for the moisture content of a piece of fuel to equilibrate with the surrounding air (Brown and

Davis 1973). One-hour fuels are those < 0.25 in. in diameter, 10-hr fuels are 0.25 – 1 in., and 100-hr fuels are 1 – 3 in. in diameter. One thousand hour fuels are those greater than 3 in. in diameter. Smaller fuels have a greater importance in determining wildfire behavior due to their shorter time-lag than larger fuels. Larger coarse woody debris can play an important role in carbon and nitrogen cycling in forest systems due to its long residence time in both terrestrial and aquatic systems (Creed 2004).

Clinton and Vose (1996) found that light limitation in the understory may not be the only factor that reduced survivorship of *Acer rubrum* under *R. maximum* thickets. In their study which looked at seedling survivorship under three different treatments (*R. maximum* thickets, shadecloth mimicking *R. maximum* light levels, and open understory), soil moisture was found to substantially lower under *R. maximum* than in open and shadecloth treatments. The study concluded that the lower soil moisture under *R. maximum* compared to open and shadecloth treatments may explain low seedling survivorship beneath *R. maximum*.

Nilsen et al. (2001) also investigated whether water availability for seedlings under a *R. maximum* thicket was significantly lower than in a forest where *R. maximum* was not present. A total of 90 plots were placed in the two different forest types and microclimate resource availability was measured on a temporal and spatial scale. Seasonal soil water availability was determined monthly and taken at the center of each plot at a depth of 0-15 cm. Soil moisture in both forest types decreased from its highest value in April to its lowest value in July and then increased throughout the rest of the growing season (end of September). While both forest types followed a temporal trend concerning soil moisture availability, volumetric water content was consistently higher

(6%) throughout the growing season in forests without *R. maximum* presence. The study concluded that besides light, soil moisture was the second most significant factor associated with seedling survivorship.

IV) *Objectives and Hypotheses to be Tested*

Objective 1. Determine the effectiveness of seven different silvicultural treatments for the control of *R. maximum* as a forest weed.

> **H_o.1:** *R. maximum* stem mortality is the same for each of the seven different silvicultural treatments.
>
> **H_a.1:** *R. maximum* stem mortality is not the same for each of the seven different silvicultural treatments.

Approach: A randomized complete block design was used to analyze four replications. Each replication contains a control and seven different silvicultural treatments applied to 0.5 acre plots containing at least 50% coverage of *R. maximum*. The treatments include:

1) mechanical cutting alone
2) herbicide basal application
3) mechanical cutting followed by herbicide foliar spray
4) prescribed burning alone
5) burning followed by herbicide basal application
6) herbicide application followed by burning
7) mechanical cutting followed by burning
8) Control

Contrast statements (burn vs. non-burn, cut vs. non-cut, herbicide vs. non-herbicide) from the randomized complete blocked design were generated to test for significant differences in *R. maximum* stem mortality between each of the main effects. The diameter of *R. maximum* stems were recorded at ground line diameter (GLD) on plots pre-treatment and post-treatment (replication 4) as well as two and three years after treatments were applied (replication 1, 2, and 3).

Objective 2. Measure the amount of fuel loading (tons per acre) under *R. maximum* thickets before and after implementing seven silvicultural treatments.

H_o.2: There is no significant difference in fuel loading before and after implementing seven silvicultural treatments in forests where *R. maximum* is present.

H_a.2: There is a significant difference in fuel loading before and after implementing seven silvicultural treatments in forests where *R. maximum* is present.

Approach: Lay out fuel transects within each plot to record 1-, 10-, 100-, 1000-hr and litter fuel loadings. Fuel loadings were recorded pre-treatment and post-treatment (replication 4) as well as two and three years after treatments were applied (replications 1, 2, and 3). Fuel load data was analyzed as a randomized complete block design using four replications. The randomized complete block design was used to generate contrast statements (burn vs. non-burn, cut vs. non-cut, herbicide vs. non-herbicide) to determine significant differences in fuel loading between the main effects.

Objective 3. Measure the density of canopy tree seedlings inside established plots to determine what effect each of the seven treatments has on promoting canopy tree seedling regeneration on the forest floor.

> **H_o.1:** There is no significant difference between each of the sivlvicultural treatments in promoting canopy tree seedling regeneration on the forest floor.
>
> **H_a.1:** There is a significant difference between each of the sivlvicultural treatments in promoting canopy tree seedling regeneration on the forest floor.

Approach: Monitor the density and species composition of canopy tree seedlings within a .01 acre subplot located within each 0.5 acre plot. Seedlings will be monitored in replications 1, 2, and 3 starting at the beginning of the growing season in April 2008 and again in September 2008. Hemispherical photographs will be taken at specific locations along each transect to estimate the amount of direct light entering each regeneration plot. Data derived from hemispherical photographs will be used to determine how successful different silvicultural methods are in opening up the *R. maximum* canopy and whether direct light levels affect the growth and establishment of regenerating seedlings on the forest floor.

V) *Methods*

The data collection for this study included intensive field sampling of four different variables: overstory survey, *R. maximum* stem count, fuel loading, and regeneration of canopy tree seedlings. Much of the sampling protocol has been based upon Harrell's (2006) master's thesis in order to obtain extended 2 and 3 year data on plots previously established (*see section II Project History). Research sites chosen for this study are located in southwest Virginia (*Figure 1)*.

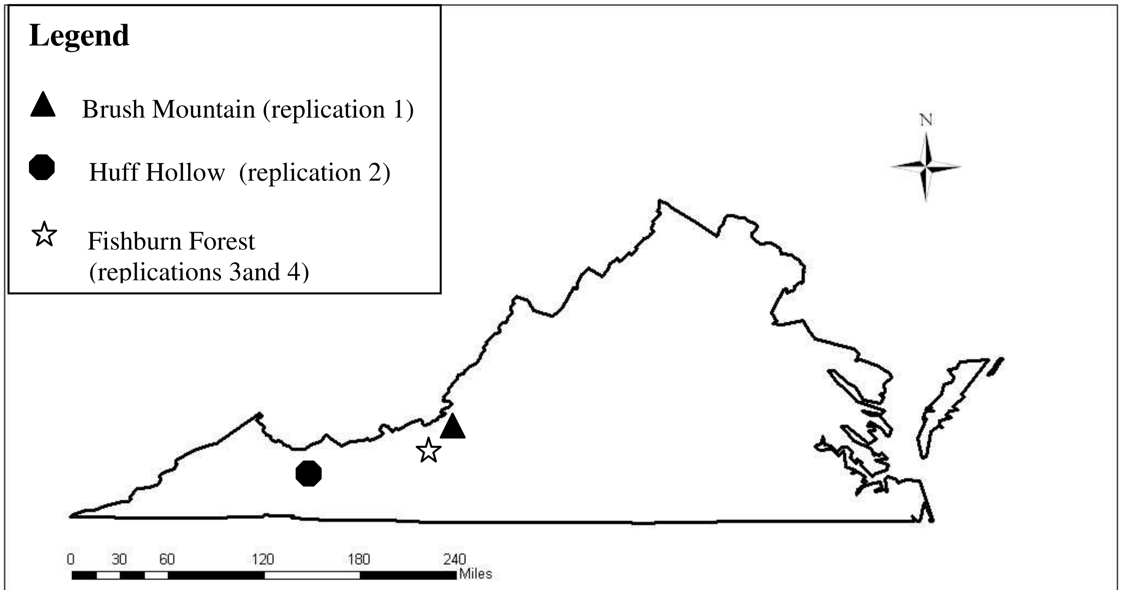


Figure 1: Study site locations. Virginia, USA

5.1 *Site Selection:*

Replication 1 Brush Mountian:

The Brush Mountain burn sites are located in the Jefferson National Forest two miles north of Blacksburg, Virginia and approximately one mile east of Highway 460. The non-burn sites are located on the same slope adjacent to the highway. The burn plots are located on the north facing aspect with steep slopes ranging from 40 to 60%. The soil series at these sites is in the Weikert (Lithic Dystrudepts) series. Mean annual precipitation is approximately 42 in. and mean annual temperature is approximately 52 F^o.

Replication 2 Huff Hollow:

The Huff Hollow site is located north of Marion, Virginia in Smyth County. Plots are located on the northwest facing aspect of Little Brushy Mountain with slopes ranging from 25 to 35%. This site is considerably more mesic than the other replications causing an over-abundance of *R. maximum* in cove positions along the mountain (Harrell 2006). Soils at replication 2 are in the Montevallo (Typic Dystrudepts) series. Mean annual temperature at the site is approximately 63 F^o and mean annual precipitation is approximately 53 in.

Replication 3 Fishburn Forest:

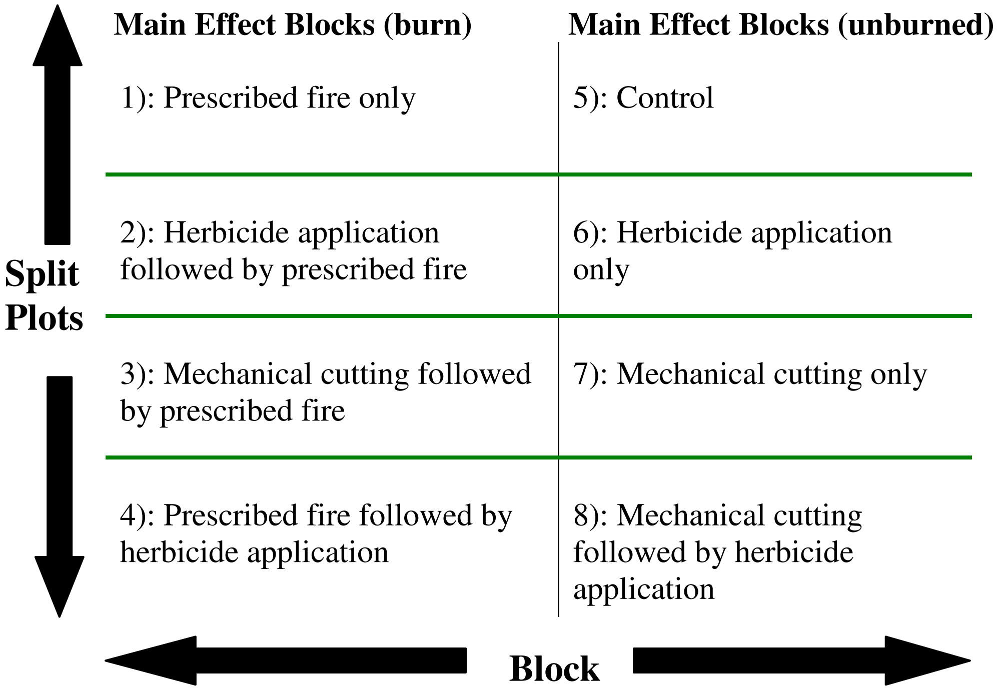
Replication 3 is located in the Fishburn Forest, a 1200 acre mixed oak experimental forest owned by Virginia Tech and located in Blacksburg, Virginia. Burn plots for replication 3 are located on north-facing slopes on the southern boundary of the forest and non-burn plots are located on north-western facing slopes situated along Coal Hollow road. The soils in the Fishburn Forest are acidic well drained soils with a mixture of Berks (Typic Dystrudepts) and Weikert (Lithic Dystrudepts) series. Mean annual precipitation is approximately 42 in. and mean annual temperature is approximately 52 F^o.

Replication 4 Fishburn Forest:

Plots in replication 4 are located in the northern boundary of the Fishburn forest below the radio tower with northeastern aspects and slopes at inclines of 30 to 40%. The soils in the Fishburn Forest are acidic well drained soils with a mixture of Berks (Typic Dystrudepts) and Weikert (Lithic Dystrudepts) series. Treatment plots in replication 4 are all located along the same slope with the exception of the cut only and control plot which is located in a different drainage with a similar aspect. Mean annual precipitation is approximately 42 in. and mean annual temperature is approximately 52 F^o.

5.2 *Plot Design*:

A majority of the half-acre plots were square (148 ft. x 148 ft.) except where *R. maximum* coverage is clustered near a creek bottom. In this case, plots were made rectangular in length with a minimal allowable width of 90 ft. Another requirement for establishing the plots was that each one had to have at least 50 % *R. maximum* cover within the boundary of the plot. Plots within a replication were situated as close to each other as possible to ensure that treatments were applied to similar site conditions. However, due to the restraints of prescribed burning boundaries as well as irregular coverage of *R. maximum* along a hill slope, some plots could not be established next to each other. In this case areas with similar slopes, aspects, elevation, and *R. maximum* coverage were chosen.



Main Effect Blocks (burn)	Main Effect Blocks (unburned)
1): Prescribed fire only	5): Control
2): Herbicide application followed by prescribed fire	6): Herbicide application only
3): Mechanical cutting followed by prescribed fire	7): Mechanical cutting only
4): Prescribed fire followed by herbicide application	8): Mechanical cutting followed by herbicide application

Figure 2 . Block design used in each of the 4 replications.

Sampling was done along a diagonal transect, originating at corner chosen at random, that bisected the plot. Along this transect four different sampling units were established to collect data on canopy overstory, *R. maximum* stem count, fuel loading, and seedling regeneration (*Figure 3*).

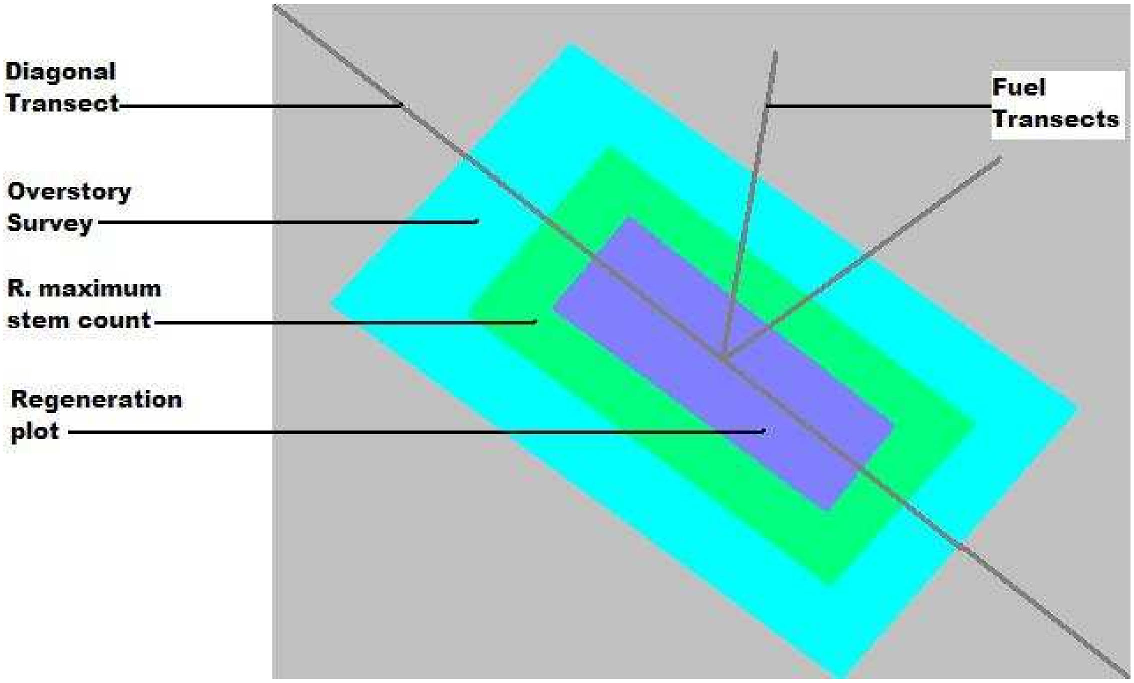


Figure 3*: Sampling Design. Total plot treatment area is 0.5 acre, overstory survey plot is 0.10 acre, the interior R. maximum stem count plot is 0.02 ac, and the regeneration plot is .01 ac. From the midpoint of the diagonal transect, two 50 ft. fuel transects were oriented in the direction of a random azimuth.*

(5.2.2) Rhododendron maximum Stem Count:

The *R. maximum* stem count was sampled within a 0.02 acre subplot along the diagonal transect. The dimensions of the *R. maximum* stem count subplot were 12 ft. by 73 ft. Within the subplot the diameter of live only stems were measured in 0.5 in. intervals at ground line diameter (GLD), which means the diameter was measured as close to the ground as possible. Measurements were taken on replication 4 pre-treatment (before any treatment was administered) and post-treatment (8-10 months following silvicultural treatments). Measurements were taken 2 and 3 years after treatments were applied on replications 1, 2, and 3 in order to determine the effectiveness of each treatment combination in controlling *R. maximum* growth and spread.

(5.2.3) Canopy Tree Regeneration:

Canopy tree seedlings were monitored in a 0.01 acre subplot located along the main diagonal transect in each plot. The dimensions of the regeneration subplot were 12 ft. by 36 ft. Within the subplot canopy tree seedlings were tagged and identified by species. Seedlings were monitored at the beginning of growing season in April 2008 and again in September 2008. Seedling counts at the end of the growing in September 2008 were used to compare the density and composition of seedlings between different treatment areas.

Hemispherical photographs were taken at 3 locations along the regeneration subplot to evaluate treatment success in opening up the *R. maximum* canopy as well as seedling responses to light. Photographs were taken in August 2008 during full canopy closure of the overstory and January 2009 during leaf off. Images were recorded using a Nikon 8mm fisheye lens attached to a digital Nikon camera. The camera was positioned approximately 3 ft. from the forest floor and aligned with magnetic north. Photographs were taken during overcast days or at times when the sun was obscured from the landscape. Photographs were analyzed using the software program Gap Light Analyzer (Frazer 1999) in order to derive canopy openness (% open sky) and total light (direct + diffuse light) entering each regeneration subplot. Total light is measured as the daily light integral (DLI) which refers to the total Photosynthetic Photon Flux Density received during one day in a particular location. DLI is measured in mols ft^{-2} d^{-1}, referring to the number of moles of light (mol) per square foot (ft^{-2}) per day (d^{-1}).

(5.2.4) Fuel Transects:

Two fuels transects located at the midpoint of the diagonal transect were established on each plot and measured according to Brown (1974) and Brown et al. (1982). Each fuel transect was 50 ft. in length and was orientated towards a direction determined by a random azimuth. Each 50 ft. transect includes a 6 ft. vertical plane in which intersections of down and dead fuel were tallied. Along the first 6 ft. of the 50 ft. transect, 1 hr. fuels (<0.2 in. diameter) and 10 hr. fuels (0.25 – 1 in. in diameter) were tallied. From 0 to 12 ft. along the transect, 100 hr. fuels (1 -3 in. diameter) fuels were tallied. One thousand hr. fuels (3 in. diameter or greater) were tallied at any location along the 50 ft. transect. For 1000 hr. fuels, the diameter was recorded as well as the condition of the fuel (sound or rotten).

(5.2.5) Fuel Transect Sub-Sample:

Each fuel transect was further sub-sampled in order to obtain measurements for slope, duff depth, litter depth, bulk density (litter and duff) and specific gravity (litter and duff). The slope of each fuel transect was recorded with a clinometer facing downslope at 90° from the contour. Slope measurements are used as a slope correction factor in Brown (1974) and Brown et al. (1982) fuel loading equations. Duff and litter depth were be recorded at three different locations along the 50 ft. fuels transect. The litter layer was defined as the surface layer of the forest floor that consisted of freshly fallen leaves, needles, twigs, bark and fruits. The duff layer was the fermentation and humus layer of the forest floor beginning at the bottom of the litter layer and extending down to the top of the mineral soil (Brown 1974).

Bulk density is a measurement of the oven dry weight of a substance (pounds) per unit volume (in^3). At the same three locations along the 50 ft. fuel transect that litter and duff depth were recorded, samples of litter and duff within a $1ft^2$ sub-plot were collected and dried in an oven at 149 F^o for at least 48 hr. Bulk densities calculated from the three locations on each 50 ft. transect were averaged in order to get an overall value for bulk density.

On each fuels transect, 10 pieces of 1hr. fuels, 5 pieces of 10 hr. fuels, and all pieces of 100 hr. and 1000 hr. fuels that intersected the transect were collected to obtain measurements for specific gravity. Specific gravity is defined by the oven dried weight of a piece of woody fuel (pounds) divided by the volume (in^3) (ASTM 2004). For 1000 hr. fuels, a disk was cut using a hand saw in order to transport the fuel back to the laboratory. Fuels were dried at 149 F^o for at least 48 hr. or until oven dried. Weights for the fuels are recorded on an electronic scale (pounds) and volume was recorded (in^3) or water displacement.

(5.2.6) Fuel Calculations:

Measurements taken from the fuel transects are used to calculate fuel loading values as described by Brown (1974) and Brown et al. (1982). Fuel loading equations were calculated to enable comparisons of treatment effects on fuel loadings before, one year after, and two years after treatments have been applied to the research plots. The following equations were used in determining fuel loading in tons/acre (Brown 1974; Brown et al. 1982):

A): 1 hr. 10 hr. and 100 hr. tons/acre = $(11.64 * n * d^2 * s * a * c) / NL$

Where:

11.64 =	**Units conversion constant**
n =	Number of woody piece intersections
d^2 =	Average squared quadratic mean diameter (inches squared)
s =	Specific gravity
a =	Nonhorizontal angle correction factor
c =	Slope correction factor = $\sqrt{}(1 + (\text{percent slope}/100)^2)$
N =	Number of sample points
L =	Length of the sampling plane

***The squared average quadratic mean diameter variable values will be used from Loucks et al. (2008). For 1-hr fuels, the quadratic mean diameter value was 0.0212 in. The 10-hr fuel class used is 0.242 in., and the 100-hr class used is 2.517 in.*

B): 1000 hr. Fuels tons/acre = $(11.64 * n * \sum d^2 * s * a * c) / NL$

Where:

11.64 =	**Units conversion constant**
n =	Number of woody piece intersections
$\sum d^2$ =	Sum of squared diameters
s =	Specific gravity
a =	Nonhorizontal angle correction factor
c =	Slope correction factor = $\sqrt{}(1 + (\text{percent slope}/100)^2)$
N =	Number of sample points
L =	Length of sampling plane

C): duff tons/acre = (dd * dbd * 1.815)

Where:

dd =	**Average duff depth in inches**
dbd =	Duff bulk density in lbs/ft3
1.815 =	Constant

D): Litter tons/acre = (ld * lbd * 1.815)

Where:

Ld =	**Average litter depth in inches**
lbd =	Litter bulk density in lbs/ft^3
1.815 =	Constant

5.3 *Treatment Methodology*

Each of the four replications consisted of seven plots, each with a different treatment, and a control plot in which no treatment was applied. Mechanical cutting, herbicide, and prescribed burning were used as applications by themselves as well as in combination with one another (*Figure 2*).

(5.3.1) Mechanical Cutting:

Mechanical cutting as an individual treatment, involved each *R. maximum* stem being cut 6 to 8 in. from the ground using chainsaw crews ranging from 2 to 3 people. When mechanical cutting was combined with prescribed fire, *R. maximum* stems were cut similarly to the individual treatment and followed with prescribed fire. Mechanical cutting was a two phase treatment with the *R. maximum* stem being cut, allowed to sprout, and then foliar sprayed with herbicide using water as a carrier. In each plot where mechanical cutting was applied, *R. maximum* stems were felled down slope with slash left in place.

(5.3.2) Herbicide Application:

Herbicide applications were conducted using two different application methods: basal and foliar spray. Basal applications were used for plots containing the following treatments: herbicide only, prescribed burning followed by herbicide, and herbicide application followed by burning. For each of the basal application treatments, 0.5 acre plots were divided equally with a 20% solution of Garlon 4® (triclopyr ester) applied on one side and a 9% solution of Stalker® (impazapyr) applied on the other. Each solution was mixed in a Hy-Grade EC® vegetable oil carrier. For basal applications, the bark on all *R. maximum* stems was fully coated 16 in. from the ground. Careful attention was paid to allow as little herbicide as possible to reach the forest floor.

As mentioned in the mechanical cutting treatment section, foliar applications were used on plots containing the treatment in which mechanical cutting was followed by herbicide. With this treatment an average of 10 months was allowed for stump sprouts to appear following the mechanical cutting. A foliar application is then applied to the stump sprouts using two different solutions of herbicide. Once again the 0.5 acre plot is equally divided with different solutions of herbicide applied to each side. On one side a 5% foliar solution of Garlon 4 in a water carrier was applied and on the other side a 2.5% solution of Stalker in a water carrier was applied. Both solutions used Timbersurf 90 as a surfactant for increased leaf cuticle penetration. For both basal and foliar herbicide applications, a D.B. Smith Field King™ deluxe model backpack sprayer was used with a round adjustable brass nozzle.

(5.3.3) Prescribed burning:

Prescribed burning was applied to half of the plots in each replication. Brush Mountain (replication 1) and Huff Hollow (replication 2) were burned in the spring of 2005 with the USDA Forest Service conducting the burn. Fishburn Forest (replication 3) was burned in the spring of 2006 with the Virginia Tech wildland fire crew conducting the burn. The other Fishburn Forest burn (replication 4) occurred in spring of 2008 and was conducted by the Virginia Tech wildland fire crew. In each prescribed burn, the goal was to ensure high enough temperatures to cause *R. maximum* mortality without compromising the health of overstory and duff conditions in the forest. Obtain the desired fire behavior is difficult due to fluctuating weather conditions within the short timeframe available for burning.

(5.3.4) Data Analysis:

Each replication was analyzed as a randomized complete block design. Due to the constraints in choosing areas where prescribed burning can take place, randomization of main effect blocks (burning or non-burning) could not be accomplished. The randomized complete block design was used to set up contrast statements between each of the silvilcultural methods that were used (i.e. burning v. non-burning, cutting v. non-cutting, and herbicide v. non-herbicide). The PROC GLM procedure for this paper was generated using SAS software, version 9.1.3 for the ANOVA analysis for all data under the split-plot and randomized complete block design (Copyright © 2003 SAS

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Table 1: *Sources of variation and degrees of freedom for statistical analysis using split plot and randomized complete block designs (rcbd).*

Split Plot (Sources)		**df**
Replications – blocks (r)	= r-1	3
Burn Status – main plots (b)	= br-1	1
Error 1	= (r-1)(b-1)	3
Treatment – Cut/Herb/None (t)	= t-1	2
Treatment*burn status interaction	= (b-1)(t-1)	2
Error 2	= (r-1)(t-1) + (r-1)(b-1)(t-1)	12
Total		21

Randomized Complete Block Design (Sources)		**df**
Replications – blocks (r)	= r-1	3
Treatments - (t)	= t-1	7
Error	= (r-1)(t-1)	21
Total		31

VI) *Results and Discussion*

6.1 *Fire Weather and Behavior*

The prescribed burns for replications 1, 2, and 3 were conducted under Harrell's 2006 study (*Table 2)*. Replication 1 and 2 were burned during April 2005 and replication 3 was burned in February 2006. Only replication 1 achieved the fire behavior that was desired because wetter and colder conditions during the burning dates for replication 2 and 3 prevented good burning conditions. The steeper headslopes located on replication 1 also allowed for much more intense fire behavior with 90% or more of the burn area affected (*Table 3*).

Replication 4 was burned on April 17, 2008 with the help of the Virginia Tech wildland fire crew. Weather for this burn was favorable with a temperature ranging from 62 to 70° F, a relative humidity around 23, and wind coming from the WNW at 2 to 5 mph with gusts up to 7 mph. Due to a 4 p.m. burning ban, ignition could not take place until later in the day, however despite the late burning time the prescribe fire was deemed successful. A backing fire was set along the NE and SW facing ridges which burned down the slope 100 ft. within the fire line. Once a proper buffer was established from the backing fire, 3 fire crew members established a head fire originating from the creek drainage in order to ignite the *R. maximum* thickets along the northern slope. This resulted in desired fire behavior with flames from burning *R. maximum* thickets reaching up to 15 ft. Over 90% of the ground area in the burn plots was affected by fire. Flames outside of *R. maximum* thickets in the open overstory ranged from 2 to 4 ft. with greater flame lengths occurring in isolated patches of concentrated fuel. The litter layer was over

50% consumed with the duff layer largely intact. No overstory mortality was observed from this prescribed fire.

Table 2: Prescribed burn site characteristics, weather, and fire behavior for replications.

Variable	**Replication 1 (Brush Mountain)**	**Replication 2 (Huff Hollow)**	**Replcation 3 (Fishburn Forest)**	**Replication 4 (Fishburn Forest)**
Date	4/19/05	4/17/05	2/10/2006	4/17/08
Temperature	62 - 75	62 – 68	42 - 46	62-70
Relative Humidity %	35	26	29	23
Ignition Technique	Helicopter ping-pong ball	Drip torch	Drip Torch	Drip Torch
Slope Position	Headslope	Footslope/adjacent to creek	Footslope/adjacent to creek	Headslope
Burn Size (ac)	630	100	32	27
Predicted Fuel Moisture (%) (1-hr, 10-hr, 100-hr)	(9/10/11)	(9/10/11)	(9/10/11)	(12/13/14)
Expected flame length (ft) *	2.7	2.6	2.7	2.3
Actual Flame Length (ft)	4-8	0.5 - 1.5	0.5 – 1.5	2 – 13
Fireline Intensity (Btu/ft/s) *	49	46	47	43

* Based on fire behavior calculations made with BehavePlus2 fire modeling system v. 2.0.2

Table 3**:** Visual estimation for percentage of ground area burned for each burned treatment plot

Treatment	**Replication 1 (Brush Mountain)**	**Replication 2 (Huff Hollow)**	**Replication 3 (Fishburn Forest)**	**Replication 4 (Fishburn Forest)**
Burn	95	85	90	95
Burn Herbicide	90	70	80	95
Cut Burn	95	80	90	90
Herbicide Burn	95	80	85	95
Mean	94 **a**	79 **c**	86 **b**	94 **a**

*Means followed by the same letter within a row are not significantly different at the α = .05 level.

6.2 *R. maximum stem mortality*

All plots were chosen to have similar *R. maximum* coverage; however pre-treatment data showed some significant differences across treatment areas for the average number of stems per acre of *R. maximum* that were 3 in. or less in diameter (*Table 4*). Differences in the amount of pre-treatment stems per acre for lower diameter classes demonstrate that *R. maximum* thickets can be variable in composition across sites. Despite this variability, total pre-treatment basal area (for all *R. maximum* stems 0.5 to 3.0 in. in diameter) was found to have similar basal area (24.5 ft^2 /ac and 26.4 ft^2 /ac) for burned and unburned treatment areas (p = 0.56 @ $\alpha = 0.05$).

Table 4: Pre-treatment average stems per acre between treatment types for various *R. maximum* stem diameters.

	----------------------*R. maximum* stem class (in.)------------------------------					
Treatment Type	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**
Burn	1313 **c**	250 **c**	325 **b**	300 **b**	138 **b**	200 **b**
Herbicide Burn	913 **d**	188 **c**	238 **c**	375 **b**	200 **a**	275 **a**
Cut Burn	1288 **c**	50 **d**	125 **c**	163 **c**	50 **c**	275 **a**
Burn Herbicide	663 **e**	213 **c**	88 **d**	213 **c**	50 **c**	175 **b**
Control	2150 **b**	863 **a**	475 **a**	525 **a**	225 **a**	125 **b**
Herbicide	1650 **c**	463 **b**	313 **b**	325 **b**	150 **b**	175 **b**
Cut	1413 **c**	350 **c**	188 **c**	150 **c**	150 **b**	75 **c**
Cut Herbicide	2425 **a**	400 **b**	225 **c**	213 **c**	200 **a**	150 **b**

*Means followed by the same letter within a column are not significantly different at the $\alpha = .05$ level.

6.3 *Prescribed burning treatments*

Treatments involving prescribed burning had significantly fewer pre-treatment total stems per acre than non-burning treatments (*Appendix E Table 1*). To account for this discrepancy, the burned and non-burned treatments were analyzed for the percent change in the total stems that occurred from pre-treatment to post, year 2, and year 3 sampling periods (*Table 5*). Both burned and non-burned treatments experienced similar percent increases in stems per acre during post-treatment and a similar decrease during year 2. Burned treatments in Year 3 experienced a significantly greater percent decrease in *R. maximum* stems from pre-treatment levels compared to non-burned treatments.

Table 5: Percent change in total number of stems from pre-treatment levels for burned and non-burned treatments throughout the duration of the project. The contrast statement analysis is within a randomized complete block design with α = 0.05.

	n	**Burn**	**Non-Burn**	**F-Value**	**P**
Post-treament	32	148% (increase)	130% (increase)	0.35	0.55
Year 2	24	13% (decrease)	4% (decrease)	0.46	0.51
Year 3	24	70% (decrease)	20% (decrease)	9.30	0.01

Stems per acre for the burn only treatment increased during post-treatment, while basal area decreased (*Figure 4*). The increase in the total amount of stems per acre during post-treatment sampling was due to *R. maximum* stump sprouting. The average number of 0.5 in. diameter stems increased from 3,225 stems per acre pre-treatment to 5,405 stems per acre post-treatment. During year 3 both total stems per acre and basal area dropped below pre-treatment levels.

The burn only plots demonstrated delayed mortality with basal area being at its lowest levels during year 3. *Rhododendron maximum* stems that experienced delayed mortality may have exhausted their resources in resprouting and thereby could not support the amount of stump sprouts that occurred post treatment. This could explain the decrease in total stems per acre that occurred from post-treatment to year 3.

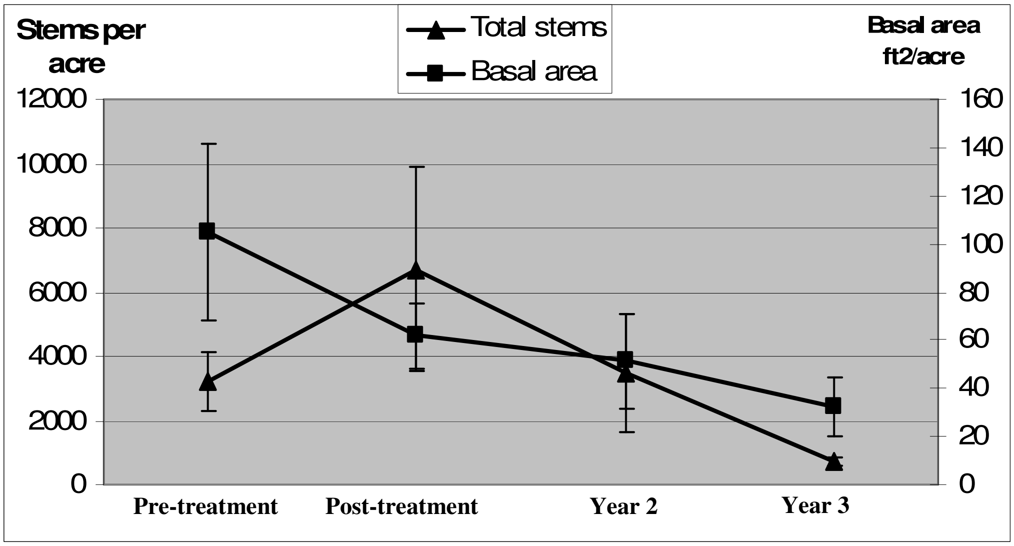

Figure 4: Average amount of total stems per acre and basal area for the burn only treatments.

6.4 Herbicide application treatments

Applications of impazapyr and triclopyr showed limited effectiveness in eliminating *R. maximum* stems larger than 0.5 in. in diameter *(Appendix E Tables 2 and 3*). Control of 0.5 in. diameter *R. maximum* stems was so substantial that it resulted in significantly less total *R. maximum* stems per acre when compared to non-herbicide applications post treatment and 2 years following treatments (*Table 6*). Total stems per acre in herbicide treatments continued to decline, however non-significant p-values occurred during year 3 due to non-herbicide treatments also demonstrating success in reducing the total amount of *R. maximum* stems per acre.

Table 6: Total stems per acre for herbicide vs. non-herbicide treatments. The contrast statement analysis is within a randomized complete block design with α = 0.05.

		(average total stems per acre)			
	n	**Herbicide**	**Non-Herbicide**	**F-Value**	**P**
Pre-treatment	32	3122	3369	.54	0.46
Post-treament	32	2188	6734	14.53	0.00
Year 2	24	1988	4021	7.03	0.01
Year 3	24	1713	2508	1.23	0.28

Two different herbicides, Garlon (triclopyr) and Stalker (imazapyr), were applied on different halves of the treatment. Essen and Zedaker (2004) found that foliar-applied imazapyr had significantly greater *R. maximum* basal area control and sprout suppression than foliar-applied triclopyr when applied to *R. ponticum* and *R. flavum*. Personal observations note that both herbicides alone were inadequate as basal applications to control *R. maximum* stems greater than 0.5 in. in diameter. It is likely that other treatment methods such as hack and squirt (herbicide is injected after a wound is placed in the stem), spraying stumps after a stem has been cut, or foliar sprays could be a more successful method in treating larger diameter *R. maximum* stems with herbicide. *Rhododendron maximum* stems with diameters of 0.5 in. were significantly less in herbicide plots than in non-herbicide plots. This shows that herbicide treatments can be a very viable option in combination with other treatments such as mechanical cutting or burning that could potentially control larger diameter *R. maximum* stems, but result in substantial sprouting.

6.5 *Mechanical Cutting Treatments*

Mechanical cutting treatments were much more successful in eliminating larger diameter classes of *R. maximum* stems in comparison with the other silvicultural treatments. This was expected because mechanical cutting treatments effectively sever the main stem of *R. maximum* plants. Following mechanical cutting, substantial basal sprouting occurs. Cutting the stem of *R. maximum* can result in 10 or more sprouts per severed stem (Romancier 1971). This was clearly shown from this research project with Mechanical cutting treatments had significantly more 0.5 in. diameter stems per acre than non-cutting treatments (*Appendix E Tables 2, 3, and 4*) resulting in greater total stems per acre for all three years of sampling (*Table 7).*

Table 7: Total stems per acre for cutting vs. non-cutting treatments. The contrast statement analysis is within a randomized complete block design with α = 0.05.

		(average total stems per acre)			
	n	**Cut**	**Non-Cut**	**F-Value**	**P**
Pre-treatment	32	3229	3225	.01	0.94
Post-treament	32	6358	5002	6.07	0.02
Year 2	24	4844	1900	13.82	0.00
Year 3	24	3211	1450	5.63	0.03

All three mechanical cutting treatments were successful in controlling *R. maximum* stems except for the 0.5 in. stem class. The amount of *R. maximum* basal sprouts following mechanical cutting treatments could be an indicator of the future composition of *R. maximum* thickets. Each of the three different mechanical cutting treatments showed differences in amount *R. maximum* basal sprouting that occurred over time (*Figure 5*).

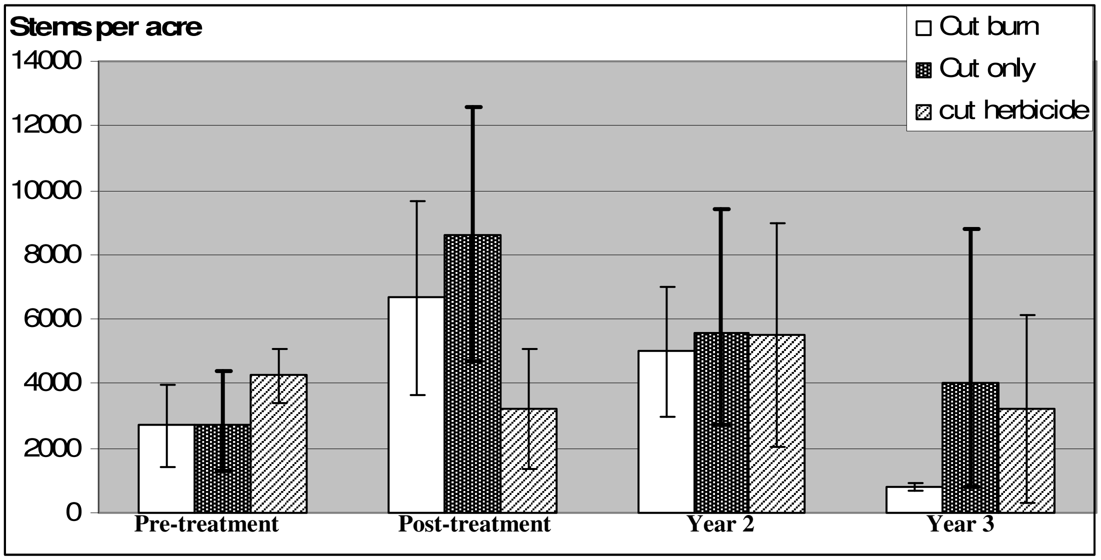

Figure 5: 0.5 inch stems per acre for mechanical cutting treatments over the duration of the research project.

The mechanical cutting only plot showed the greatest average increase in the 0.5 in. stem class increasing from 1,214 stems per acre pre-treatment to 8,550 stems per acre post-treatment, resulting in an average of 6 stump sprouts for every one *R. maximum* stem severed. Much of the research reporting on basal sprouting following mechanical cutting treatments has not reported on the long-term basal sprouting following this type of treatment. Our study found that three years following a mechanical cutting only treatment, stump sprouts were reduced to an average of 4 stems per *R. maximum* stem severed. Results from this study showed that while significant basal sprouting will occur following mechanical cutting treatment, competition for resources such as nutrients, water, and light, likely prevents *R. maximum* stump sprouts from persisting at post treatment levels.

Mechanical cutting followed by herbicide treatment was the most effective at controlling post-treatment sprouting. There was an increase of 0.5 in. *R. maximum* stems 2 years following this treatment, which could be attributed to sprouts that became established after the herbicide application was performed; however these levels dropped during year 3 sampling. Harrell (2006) observed that sprouts persisting after the foliar herbicide application were of poorer quality than those found in other cut plots and may not possess the vigor to repopulate a site with a *R. maximum* thicket of pre-treatment proportion. Multiple herbicide applications following cutting could result in even more successful reduction in *R. maximum* sprouting.

Mechanical cutting followed by prescribed burning resulted in basal sprouting similar to mechanical cutting alone. It was hoped that the downed woody fuel resulting from the cutting would increase fire intensity when burned and thereby eliminate basal sprouting. This was not the case and could possibly be due to less than ideal fire behavior. Stems per acre in the 0.5 in. diameter class from pre-treatment to post-treatment levels increased from 1,288 to 6,650 resulting in an average of 5 sprouts for every *R. maximum* stem severed. Three years after the mechanical cutting followed by burning treatment was applied, *R. maximum* stump sprouts dropped to levels below pre-treatment. Delayed mortality effects were found to occur with the aboveground portion of the *R. maximum* plant in prescribed burning only treatment areas (*Figure 4*). The shallow root systems of *R. maximum* plants may also experience delayed mortality effects, thereby being unable to sustain the sprouts that occur post-treatment.

VII *Fuel Loading*

7.1 Pre-treatment data

Treatment areas for this project showed no significant differences in pre-treatment fuel loading within the randomized complete block design contrast statements used for analysis. The one exception was for 10-hr. fuels which were significantly greater in pre-treatment burn plots than in non-burn plots (*Appendix E Table 5*). Tons per acre of 1000-hr fuels and duff were found to be highly variable between pre-treatment sites and therefore were excluded from further analysis.

Pre-treatment litter levels were found to be high on our sites (*Table 8*). Stottlemeyer et al. (2006) reported an average of 1.7 tons per acre of litter on xeric to mesic sites in the Chauga ridges region of the southern Appalachians. Loucks (2008) reported an average of 3.1 tons per acre of litter on oak-hickory forests in eastern Kentucky. This discrepancy could be due to our sites being specifically chosen to have a high *R. maximum* dominance. Many who have done research on *R. maximum* have noted that fuel loading under thickets include a thick litter layer that is slow to decompose (Plocher and Carvell 1987, Clinton and Vose 1996, and Monk et al. 1985).

Table 8: Mean pre-treatment tons per acre of fuel load components on all treatment types.

	Litter	1-hour	10-hour	100-hour
Burn	5.1 **b**	0.44 **a**	0.93 **b**	2.06 **a**
Herbicide Burn	8.2 **a**	0.38 **a**	1.16 **a**	1.70 **a**
Cut Burn	6.3 **b**	0.34 **a**	0.83 **b**	1.49 **a**
Burn Herbicide	3.7 **c**	0.26 **a**	0.84 **b**	2.42 **a**
Control	5.4 **b**	0.30 **a**	0.61 **c**	1.22 **a**
Herbicide	4.6 **b**	0.45 **a**	0.65 **c**	0.85 **a**
Cut	6.0 **b**	0.35 **a**	0.56 **c**	1.17 **a**
Cut Herbicide	2.8 **c**	0.38 **a**	0.47 **c**	2.24 **a**
Average	**5.2**	**0.36**	**0.78**	**1.64**

*Means followed by the same letter within a column are not significantly different at the $\alpha = 0.05$ level.

7.2 Prescribed Burning

Prescribed burning treatments had no significant effects on 1, 10, and 100-hr. fuel loading throughout the duration of the project (*Appendix E Tables 6, 7, and 8*). Once again this can be attributed to less than ideal fire behavior in replications 2 and 3 (Table 3). A prescribed fire with enough fire intensity should consume much of the 1-hr. and 10-hr. fuels however this was not the case in this study.

Prescribed burning did have an effect on the amount of litter consumed. The randomized complete block design contrast analysis showed that post-treatment tons per acre of litter were significantly less in burning treatments compared to non-burning treatments (*Table 9*). Two and three years following prescribed burning treatments litter levels rose, resulting in non-significant p values. Despite this increase, average tons per acre of litter for treatments involving prescribed burning were 1.83 tons less during year three than they were at pre-treatment levels. One of the main goals of many prescribed fires is to reduce the fuel load in order to prevent larger, hazardous fires from occurring and reducing litter contributes to this goal.

Table 9: *Average tons per acre of litter for burn vs. non-burning treatments. The contrast statement analysis is within a randomized complete block design with α = 0.05.*

	(average tons per acre of litter)				
	n	**Burn**	**Non-Burn**	**F-Value**	**P**
Pre-treatment	32	5.3	4.6	.65	.429
Post-treatment	32	2.59	3.59	8.78	.007
Year 2	24	3.70	4.15	3.89	.068
Year 3	24	3.47	3.98	1.11	.310

7.3 Mechanical cutting

The mechanical cutting treatments had the most significant effect on 1, 10, and 100-hr. fuel loading on the forest floor. Mechanical cutting treatments had significantly greater tons per acre of fuels than non-cutting treatments post-treatment, 2 years, and 3 years following treatment (*Table 10*). This was expected since the stems were left undisturbed on the forest floor after being cut.

Table 10: *Average tons per acre of 1, 10, and 100-hr fuel loading for cut vs. non-cut treatments. The contrast statement analysis is within a randomized complete block design with α = 0.05.*

Post-Treatment Fuel Class (n=32)	**Cut**	**Non-Cut**	**F-Value**	**P**
1hr	0.54	0.27	11.17	0.00
10hr	1.46	0.59	20.72	0.00
100hr	5.83	1.88	19.56	0.00

Year 2 Fuel Class (n=24)	**Cut**	**Non-Cut**	**F-Value**	**P**
1hr	0.48	0.21	30.66	<.0001
10hr	1.79	0.70	13.67	0.00
100hr	8.65	1.92	29.96	<.0001

Year 3 Fuel Class (n=24)	**Cut**	**Non-Cut**	**F-Value**	**p**
1hr	0.41	0.24	12.57	0.00
10hr	2.28	0.79	6.29	0.02
100hr	10.18	2.02	17.77	0.00

While the efficacy of eliminating *R. maximum* stems through mechanical cutting is clearly observable, there should be concern about the amount of fuel loading that is generated. It was anticipated that the mechanical cutting followed by prescribed burning would be successful in eliminating much of the fuel loading from cutting; however this didn't happen due to lack of high fire intensity with the prescribed burns. Prescribed fire followed by cutting could work if precise care were taken to have the intense fire behavior necessary to fully consume much of the down fuels. In this case the amount of slash resulting from cutting *R. maximum* thickets could cause high flame lengths so extra caution should be practiced for both the safety of the fire personnel and eliminating the risk of the fire escaping the containment lines. Another option could be to initiate multiple low intensity burns until fuel loading is reduced to a level found suitable for specific management objectives.

7.4 Herbicide applications

Treatments involving herbicide applications had no significant impact on fuel loading (*Appendix E Tables 6, 7, and 8*). Herbicide applications did not achieve the *R. maximum* stem mortality desired; therefore fuel loads were not affected.

VIII) Canopy Tree Seedling Regeneration

Seedling regeneration was monitored on the forest floor three years following treatments on replications 1, 2, and 3 (*Table 11*). Seedling regeneration for replication 4 was not included for analysis due to the different timing in which silvicultural treatments were administered. Seedlings were numbered and identified by species in each regeneration plot to determine the density of seedlings per acre for each treatment area.

Results showed that burning had an effect on the percentage of root sprouts present in each plot treated with prescribed fire. The herbicide followed by burning treatment had the greatest average seedlings per acre and the control plot had the least. None of the main effects were shown to influence the amount of canopy tree seedlings present within the sampling sites (*Table 12*).

Table 11**:** Average number of canopy tree stems per acre for each treatment type. Stems were measured three years following treatment application.

Treatment Area	Average stems per acre	Percent seedlings	Percent root sprouts
Herbicide Burn	5767 **a**	85.6	14.4
Cut Herbicide	4330 **b**	100	0
Cut Burn	2900 **c**	80.2	15.8
Burn Herbicide	2900 **c**	88.5	11.5
Cut	2500 **d**	100	0
Burn	2300 **d**	57.9	42.1
Herbicide	1500 **d**	93.5	6.5
Control	450 **e**	100	0

*Means followed by the same letter within a column are not significantly different at the $\alpha = 0.05$ level

***Table 12*:** Average stems per acre contrast statement analysis within a randomized complete block design with α=0.05. Seedlings were counted three years following silvicultural treatments.

	Average seedlings per acre			
Treatment type	**Burn**	**Non-burn**	**F-value**	**P**
	3467	2150	2.12	.167
	Cut	**Non-cut**		
	3233	2553	.53	.478
	Herbicide	**Non-herbicide**		
	3229	2000	3.20	.095

Hemispherical photographs were taken within each regeneration plot to measure the amount of canopy openness as well as the amount of diffuse and direct light entering each regeneration plot. Canopy openness was found to be weakly correlated to seedling density (*Figure 6*).

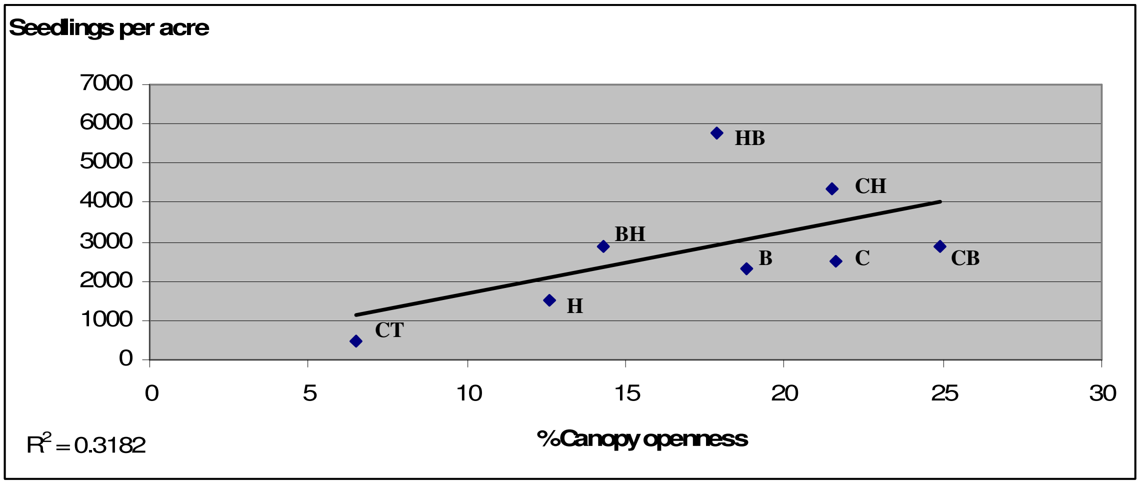

Figure 6: Canopy openness (% open sky) vs. average seedlings per acre for each treatment type. $\mathbf{R^2}$ = 0.3182, **y** = 162.23x + 8.2772. Treatment abbreviations are as follows: **B**=Burn, **HB**=Herbicide Burn, **CB**=Cut Burn, **BH**=Burn Herbicide, **CT**=Control, **H**=Herbicide, **C**=Cut, **CH**=Control Herbicide.

The average amount of canopy openness (% open sky) for each treatment type was calculated for the months of January and August *(Figure 7)*. Mechanical cutting treatments removed the *R. maximum* secondary canopy and therefore increased the amount of light reaching the forest floor. The average difference in canopy openness for all treatments involving mechanical cutting between January to August was 24%. This means that the leaves alone from the canopy overstory blocked out 24% of the open sky during the summer months. The average canopy openness for mechanical cutting treatments during August was 23%. This means that during the summer month of August an average of 77% of sunlight can be obstructed from reaching reaching the forest floor without the influence of *R. maximum*.

The results from the control plots show how much of the open sky is blocked out under a *R. maximum* thicket when no treatment is administered. During August when leaves were on the canopy overstory, the control plots had an average canopy openness of 6%, meaning that 94% of open sky was blocked under a *R. maximum* thicket.

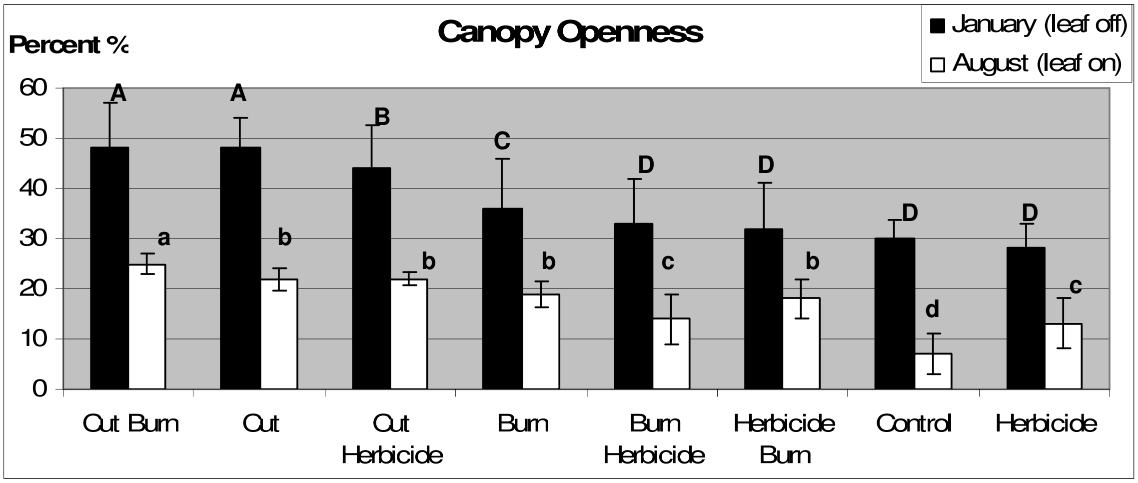

Figure 7: Average percent canopy openness for each treatment area during January (leaf off) and August (leaf on) 2008. *Means followed by the same letter within a column are not significantly different at the α = 0.05 level. Upper case letters refer to leaf off only and lower case letters refer to leaf on only.

Mechanical cutting treatments allowed for greater canopy openness by reducing the *R. maximum* canopy completely (*Figure 7*). Percent canopy openness during January for the burn herbicide, herbicide burn, and herbicide only treatments were significantly similar to the control plot. This demonstrates the inadequacy of basal herbicide applications to effectively eliminate *R. maximum*. The burn treatment during January had significantly higher percent canopy openness than the herbicide and control treatments. This indicates that prescribed fire has the potential to effectively increase forest floor light levels.

The amount of solar radiation transmitted through a canopy plays a critical role by directly influencing seedling growth, the growth of competing vegetation, and the microclimate and moisture regime of a site (Hale and Brown 2005). It was hypothesized that the amount of light reaching the forest floor would be the most important indicator of how many seedlings would be established in a plot. The average number of seedlings for each treatment area were plotted against the amount of total light (mols ft^{-2} d^{-1}) entering each regeneration plot during the summer month of August when seedlings experience much of their growth (*Figure 8).*

Results from the regeneration plots show that the number of seedlings per acre is moderately correlated ($R^2 = 0.5684$) with total light entering each plot (*Figure 8*) and the amount of total light entering a plot is strongly influenced ($R^2 = 0.9001$) by the amount of *R. maximum* basal area (*Figure 9*). Two plots involving mechanical cutting (Cut Burn and Cut Herbicide) had the highest amount of total light entering each plot (88 and 86 mols ft^{-2} d^{-1}) and had the second and third highest number of seedlings per acre (2,900 and 4,300 seedlings per acre). Personal observations note that the shade on the forest floor caused by the increased fuel loading from mechanical cutting treatments could prevent seedling regeneration from reaching its full potential.

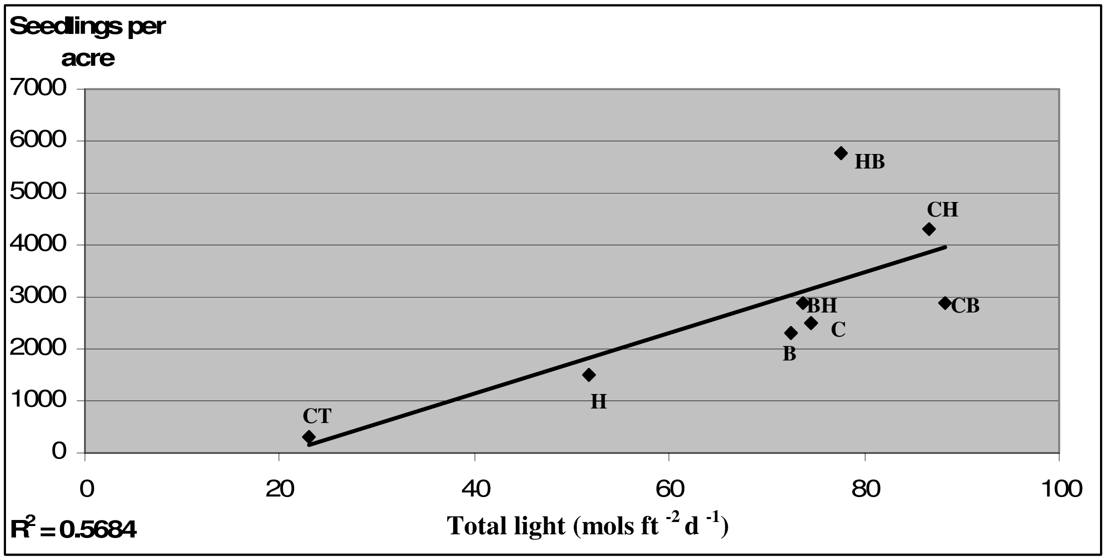

*Figure 8***:** Total light (mols ft^{-2} d^{-1}) and average seedlings per acre for each treatment type. **R^2** = 0.5684, **y** = 58.334x – 1187.1. Treatment abbreviations are as follows: **B**=Burn, **HB**=Herbicide Burn, **CB**=Cut Burn, **BH**=Burn Herbicide, **CT**=Control, **H**=Herbicide, **C**=Cut, **CH**=Control Herbicide.

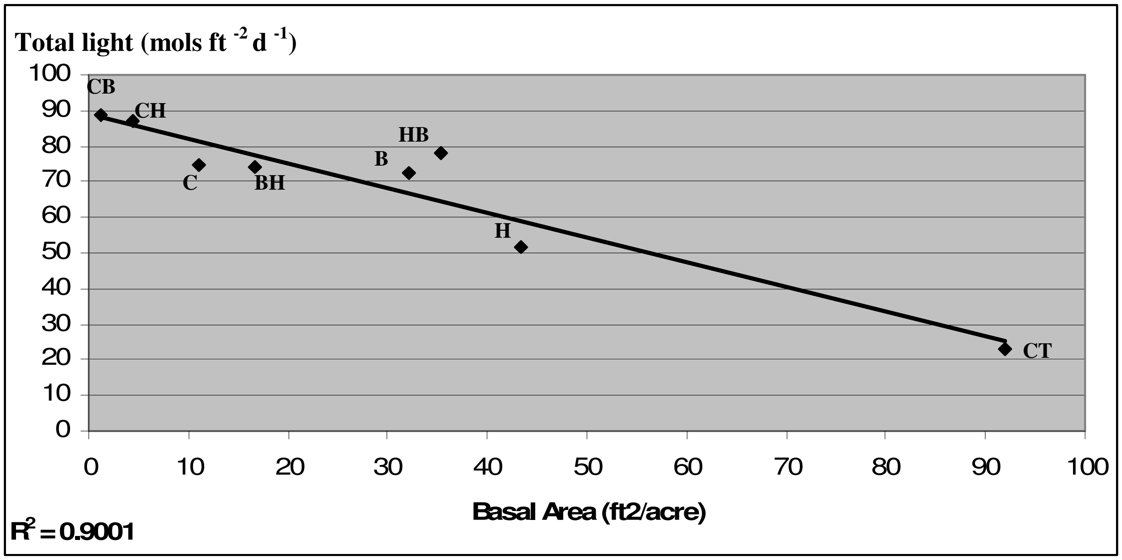

*Figure 9***:** *R. maximum* basal area (ft^2 / acre) and total light (mols ft^{-2} d^{-1}) for each treatment type. R^2 = 0.9001, **y** = -0.6939x + 89.211. Treatment abbreviations are as follows: **B**=Burn, **HB**=Herbicide Burn, **CB**=Cut Burn, **BH**=Burn Herbicide, **CT**=Control, **H**=Herbicide, **C**=Cut, **CH**=Control Herbicide.

Factors other than light could have influenced seedling regeneration within the treatment plots. The herbicide followed by burning treatment had the highest average number of seedlings per plot (5767 seedlings per acre), but had the third highest total light levels. Burning followed by herbicide had the fourth highest number of seedlings (2900 seedlings per acre), but had the fifth highest total light levels.

When sampling regeneration within each plot, seedlings were identified by species in order to determine differences in seedling composition between treatment areas. The percent frequency of plots having seedling or sprouts was calculated for plots treated with prescribed fire versus plots where fire was not administered (*Table 13).* Overall plots with prescribed burning applications had a greater number of seedlings present.

Prescribed burning has been shown to affect the outcome of regeneration within forested areas of the southern Appalachians and oaks in particular have been shown to benefit from prescribed fire (Arthur 1998, Brose 2001, Wang 2005). Fire can reduce the thickness of the forest floor creating a favorable seedbed for acorns as well as eliminate the midstory and understory strata (Barnes and Van Lear 1998). Chestnut oak (*Quercus prinus*) was the only oak species found to have a significantly higher percent frequency of occurrence in burn plots than in non-burn plots.

Red maple (*Acer rubrum*), which is mostly known to increase in the absence of fire, was present in all burn plots. Red maple is an aggressive stump sprouter (Burns and Honkala 1990), so a one time prescribed burn may actually benefit its reproduction. Silver maple (*Acer saccharinum*), which has similar sprouting abilities as red maple, also had a significantly greater percent frequency in burn plots.

Table 13: Percent frequency of seedlings by species in plots with and without the application of prescribed fire

		(% Frequency)		
	Species	**Non-burn**	**Burn**	**p**
Red Maple	*Acer rubrum*	**67**	**100**	**0.04**
Silver maple	*Acer saccharinum*	**0**	**25**	**0.05**
Black birch	*Betula lenta*	**8**	**8**	**1.00**
Pignut hickory	*Carya glabra*	**0**	**8**	**0.33**
Tulip poplar	*Liriodendron tulipifera*	**25**	**25**	**1.00**
Blackgum	*Nyssa sylvatica*	**42**	**50**	**0.50**
Sourwood	*Oxydendrum arboreum*	**17**	**17**	**1.00**
Black cherry	*Prunus serotina*	**8**	**8**	**1.00**
White oak	*Quercus alba*	**8**	**17**	**0.90**
Chestnut oak	*Quercus prinus*	**8**	**58**	**0.00**
Red oak	*Quercrus rubra*	**50**	**33**	**0.14**
Black oak	*Quercus velutina*	**25**	**33**	**0.33**
	# of Plots	**12**	**12**	
	# of Seedlings	**202**	**376**	**0.11**

IX) Conclusions

Silvicultural treatments for controlling *R. maximum* thickets had variable results with both successful and unsuccessful aspects to each approach. Results from this study can serve as a guide for possible management strategies, depending on the specific objectives of the land manager. Finding the most effective approach to control *R. maximum* establishment is increasingly important as this plant continues to establish itself as a dominant force in the forest dynamics of the southern Appalachians.

Mechanical cutting had the most significant effect on eliminating larger diameter *R. maximum* stems, however substantial sprouting did occur. Mechanical cutting followed by either prescribed fire or foliar herbicide application was successful in reducing stump sprouting. Prescribed burning following a mechanical cutting treatment reduced *R. maximum* seedlings below pre-treatment levels. One of the negative aspects of the mechanical cutting treatment was the increase in fuel loading on the forest floor. It was hoped that the mechanical cutting followed by prescribed burning would have reduced the amount of fuel loading on the forest floor, however a lack of fire intensity prevented this from happening.

Rhododendron maximum stems exhibited delayed mortality in plots where prescribed burning was used as a single treatment. A lack of fire intensity with two of the prescribed burns could have resulted in this particular treatment not reaching its full potential. Personal observations note that where *R. maximum* thickets did experience intense fire behavior, the outside edges of the *R. maximum* thicket experienced much of the fire effects thereby creating a buffer for much of the interior of the thicket. Multiple prescribed fires could be successful for reducing *R. maximum* thickets by reducing this outside edge effect as well as drying out the fuels underneath thickets for increased fire behavior.

Herbicide basal applications were unsuccessful in reducing *R. maximum* stems greater than 0.5 in. in diameter. It is not known whether a basal application was the appropriate method or if the herbicide mixture was correct. More research is needed to determine which methods of herbicide applications can correctly deter *R. maximum* growth and establishment. A disadvantage of herbicide application is that it is difficult to maneuver through *R. maximum* thickets with an herbicide applicator. Cost analysis research has shown that herbicide application can be up to 13 times more expensive than prescribed burning alone (Harrell 2006). Foliar herbicide application to treat stump sprouts following mechanical cutting was found to be very successful and would be a logical choice for deterring future *R. maximum* establishment when used with other treatments that result in high stump sprouting.

Seedlings per acre were found to be influenced by the amount of light entering each plot. Mechanical cutting treatments which were successful in eliminating the *R. maximum* canopy had high levels of seedling density. It was interesting to find that the herbicide followed by burning treatment areas, which were not found to have the highest amount of diffuse and direct light entering each plot, had the highest density of seedling establishment. Herbicide treatments were found to successfully eliminate smaller diameter *R. maximum* stems which could have benefited seedling regeneration. Prescribed burning could have further created beneficial forest floor conditions for seedling establishment by reducing the litter layer.

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Apendix A: Site Characteristics

Table 1: Plot characteristics for Brush Mountain, Huff Hollow, and Fishburn Forest. Plot identification: R (replication), H (herbicide), B (burned), and C (cut).

Plot	Pre-Treatment	Post-Treatment	Year 2	Year 3	Slope (%)	Aspect
R1B	3/29/05	10/18/05	12/13/07	6/18/08	25	1
R1BH	3/30/05	10/18/05	12/13/07	6/10/08	40	344
R1CB	4/1/05	8/9/06	12/13/07	6/19/08	50	345
R1HB	3/30/05	10/18/05	11/16/07	6/10/08	20	333
R1C	7/22/05	8/9/06	11/16/07	6/17/08	5	340
R1CH	7/20/05	8/23/06	11/03/07	6/17/08	7	340
R1H	5/30/06	8/23/06	11/02/07	7/7/08	6	331
R1Control	6/6/06	8/9/06	11/02/07	7/7/08	40	332
R2B	3/19/05	10/10/05	12/14/07	6/25/08	15	310
R2BH	3/19/05	7/24/06	12/14/07	6/25/08	15	333
R2CB	3/19/05	10/10/05	12/14/07	6/25/08	20	306
R2HB	3/19/05	10/10/05	12/14/07	6/25/08	20	338
R2C	5/23/05	10/21/05	12/14/07	6/24/08	35	330
R2CH	6/20/05	7/24/06	12/14/07	6/24/08	23	332
R2H	5/23/05	10/21/05	12/14/07	6/24/08	26	320
R2Control	6/21/05	7/24/06	12/14/07	6/24/08	28	325
R3B	9/1/05	7/11/06	9/28/07	6/6/08	35	21
R3BH	9/1/05	8/22/06	10/12/07	8/21/08	25	304
R3CB	8/25/05	7/11/06	9/28/07	6/9/08	38	3
R3HB	9/13/05	8/22/06	10/12/07	8/21/08	8	322
R3C	4/4/06	7/11/06	10/12/07	6/6/08	45	10
R3CH	4/4/06	8/23/06	11/09/07	6/22/08	55	355
R3H	4/11/06	8/22/06	11/0907	6/9/08	35	309
R3Control	4/11/06	8/23/06	11/09/07	6/9/08	30	309
R4B	7/17/07	6/26/08	….............	….............	34	49
R4BH	8/24/07	7/25/08	….............	….............	40	45
R4CB	6/26/07	6/22/08	….............	….............	35	39
R4HB	6/25/07	6/26/08	….............	….............	36	48
R4C	7/18/07	6/20/08	….............	….............	38	330
R4CH	7/20/07	7/25/08	….............	….............	40	67
R4H	8/8/07	7/1/08	….............	….............	44	63
R4Control	7/20/07	6/30/08	….............	….............	35	332

Appendix B: Maps

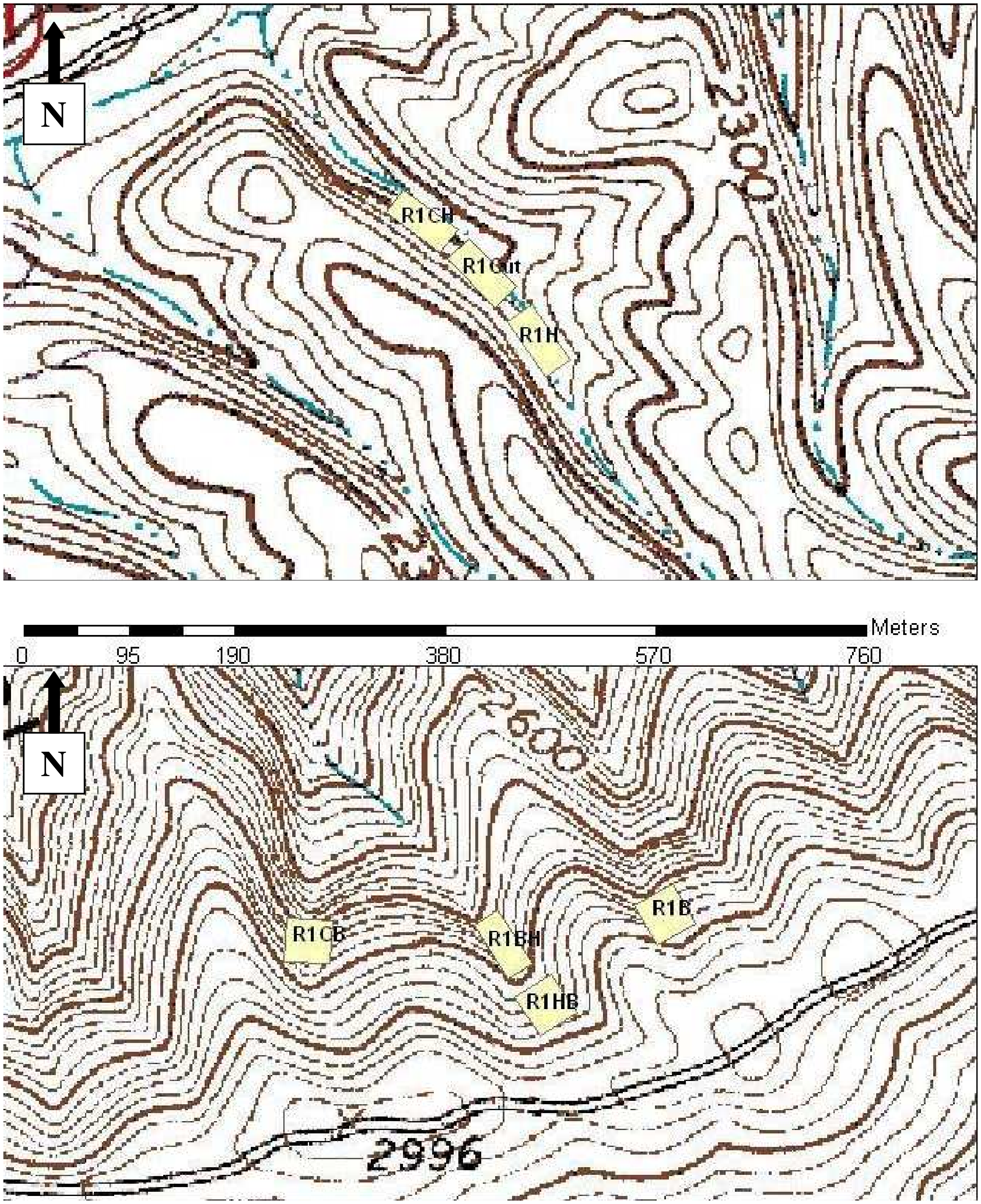

Figure 1: Plot layout for replication 1 (Brush Mountain)

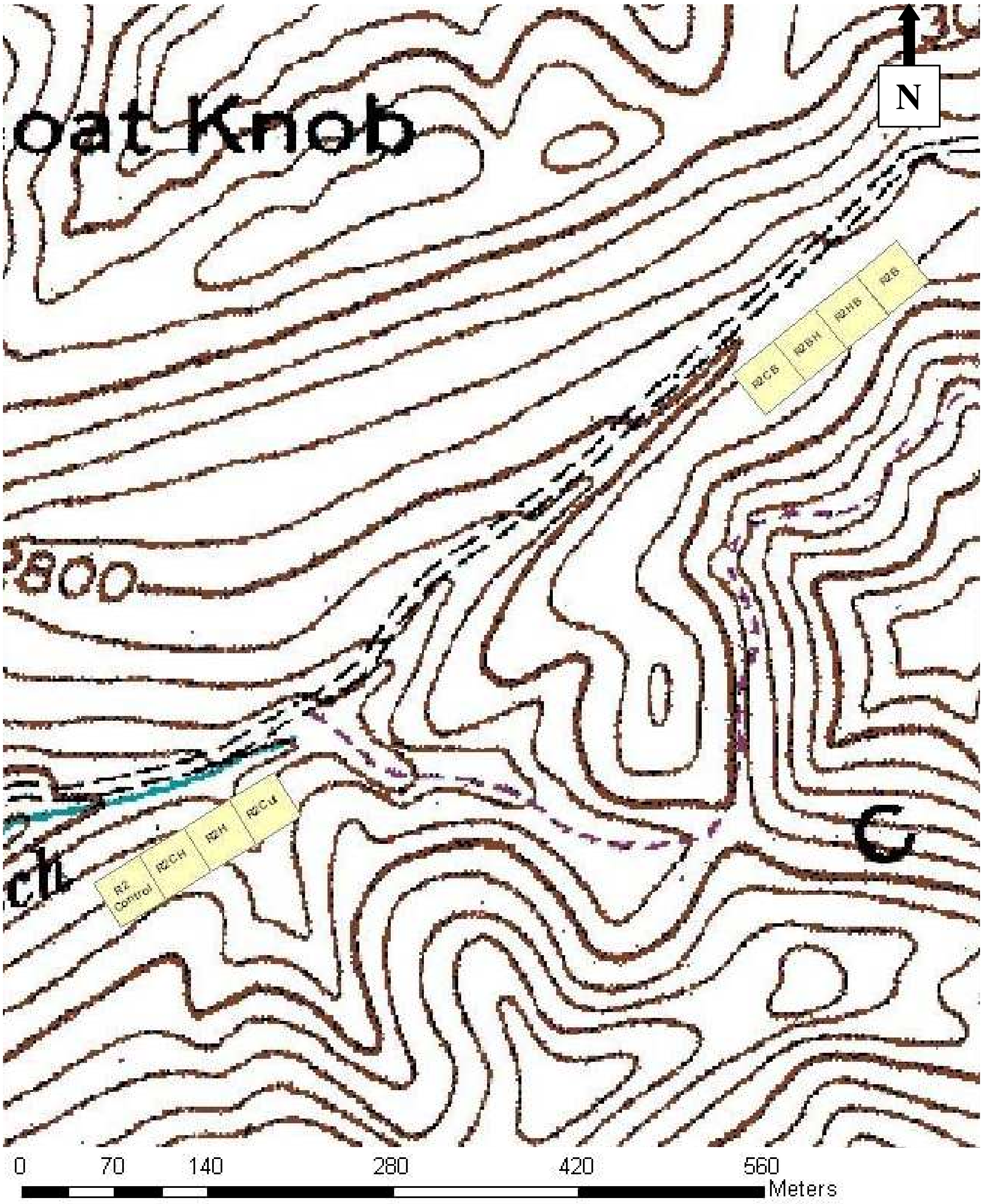

Figure 2: Plot layout for replication 2 (Huff Hollow)

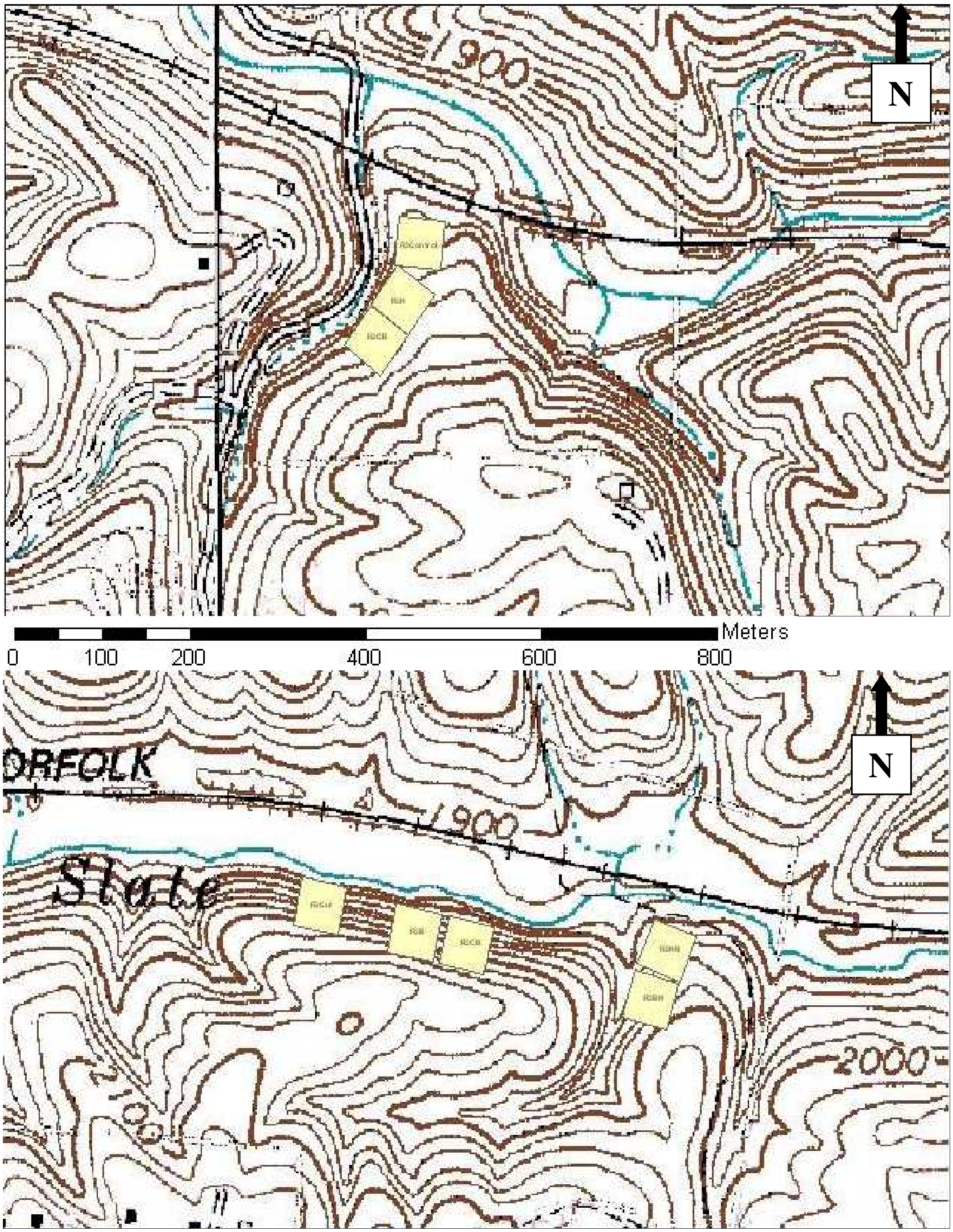

Figure 3: Plot layout for replication 3 (Fishburn Forest)

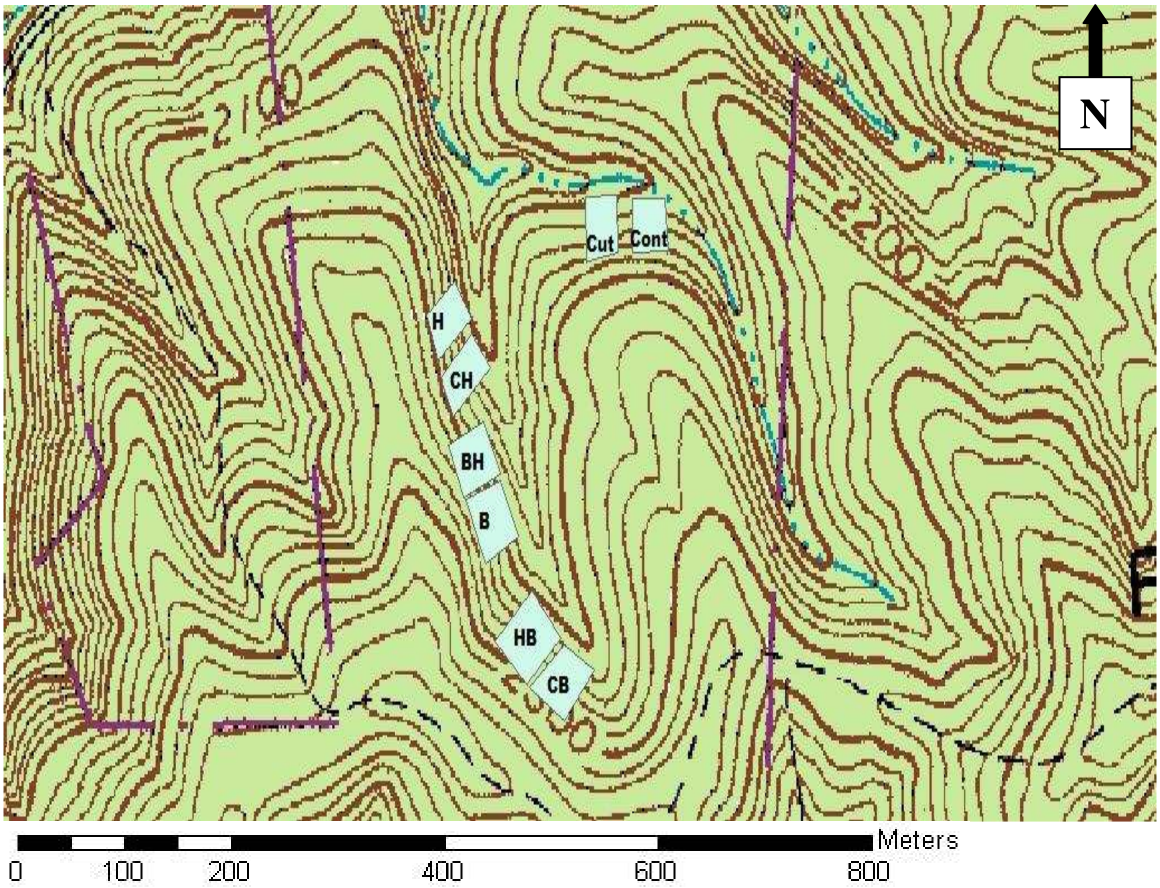

Figure 4: Plot layout for replication 4 (Fishburn Forest)

Appendix C: Timeline of Events

Date	Event
2007	
5/28-6/22	Site search and plot establishment for replication 4
6/25-6/26	Recorded pre-treatment data for R4 CB and HB
6/27-6/28	Preformed cutting treatment for R4 CB
6/29	Performed herbicide treatment for R4 HB
7/18-7/20	Recorded pre-treatment data for R4 C, CH, and control
7/23-7/24	Performed mechanical cutting treatment for R4 C
7/25-7/26	Performed mechanical cutting treatment for R4 CH
8/8	Recorded pre-treatment data for R4 H
8/10	Performed herbicide application for R4 H
8/24	Recorded pre-treatment data for R4 BH
9/28	Recorded Year 2 data for R3 B and CB
10/12	Recorded Year 2 data for R3 BH, HB, C
10/26	Performed foliar herbicide application for R4 CH
11/02	Recorded Year 2 data for R2 CH, H, and Control
11/09	Recorded Year 2 data for R3 CH, H and Control
11/16	Recorded Year 2 data for R1 HB and C
12/13	Recorded Year 2 data for R1 B, BH, CB
12/14-12/15	Recorded Year 2 data for all of R2
2008	
3/10	Working plan submitted
4/17	Prescribed burn for replication 4
5/2	Performed basal herbicide application for R4 BH and foliar herbicide application on R4 CH
6/6-6/10	Recorded Year 3 data for R3 CB, B, C, H, Control and R1 BH and HB
6/17-6/19	Recorded Year 3 data for R1 C, CH, B, CB
6/22-6/30	Recorded Year 3 data for R3 CH and all of R2. Recorded Post-treatment data on R4: B, CB, HB, Cut, and Control.
7/1	Recorded Post-treatment data on R4 H
7/7	Recorded Year 3 data for R1 H and Control
7/25	Recorded Post-treatment data on R4 BH
8/21-8/22	Recorded Year 3 data for R3 BH and HB and Post-treatment data on R4 CH.
8/25-8/29	Took hemispherical photographs for R1, R2, and R3
2009	
1/5-1/9	Took hemispherical photographs for R1, R2, and R3

Appendix D: GPS Coordinates

Plot	Latitude	Longitude	Elevation
R1B	N 4129398.76	W 556934.91	618
R1BH	N 4129514.72	W 556857.32	857
R1CB	N 4129467.31	W 556681.88	864
R1HB	N 4129446.91	W 556946.40	894
R1Cut	N 4126973.14	W 548787.25	687
R1CH	N 4127026.40	W 548724.89	639
R1H	N 4126914.24	W 548833.39	678
R1Control	N 4129469.16	W 556681.87	865
R2B	N 4093267.50	W 457371.71	852
R2BH	N 4093254.80	W 457324.18	874
R2CB	N 4093229.06	W 457295.87	875
R2HB	N 4093208.87	W 457266.10	850
R2Cut	N 4092714.32	W 456710.30	709
R2CH	N 4092666.81	W 456600.29	839
R2H	N 4092701.53	W 456682.05	830
R2Control	N 4092688.75	W 456649.35	834
R3B	N 4114336.83	W 546512.55	593
R3BH	N 4114349.21	W 546744.78	569
R3CB	N 4114304.12	W 546616.31	621
R3HB	N 4114389.77	W 546723.84	568
R3Cut	N 4114394.74	W 546284.38	468
R3CH	N 4114548.00	W 544531.73	598
R3H	N 4114564.91	W 544583.43	536
R3Control	N 4114642.84	W 544633.32	569
R4 B	N4116163.203	W546132.527	590
R4 BH	N4116111.261	W546149.487	627
R4 CB	N4116056.67	W546147.897	578
R4 HB	N4116037.589	W546148.957	611
R4 Cut	N4116012.413	W546157.787	613
R4 CH	N4155946.162	W546171.748	595
R4 H	N4115906.516	W546188.708	585
R4 Control	N4115863.055	W546203.019	580

Appendix E: Analysis

Table 1: Total stems per acre for burn vs. non-burn treatments. The contrast statement analysis is within a randomized complete block design with α = 0.5.

		(average total stems per acre)			
	n (# of plots)	**Burn**	**Non-Burn**	**F-Value**	**p**
Pre-treatment	32	2669	3822	11.88	0.002
Post-treament	32	3941	4981	0.76	0.393
Year 2	24	2329	3679	3.10	0.100
Year 3	24	796	3050	13.38	0.003

Table 2: Post Treatment rhododendron stem class contrast statement analysis within a randomized complete block design

A) **(Mean Stems per acre)**

Stem Class	**Burn**	**Non Burn**	**F-Value**	**p**
0.5	3306.25	3665.625	0.09	0.7658
1	50	490.625	5.24	0.0325
1.5	56.25	250	9.38	0.0059
2	84.375	200	3.29	0.0841
2.5	71.875	90.625	0.41	0.5293
3	75	56.25	0.35	0.5629
3.5	46.875	43.75	0.03	0.8568
4	84.375	75	0.07	0.7951
4.5	59.375	43.75	0.38	0.5453
5	34.375	28.125	0.11	0.7428
5.5	28.125	15.625	0.97	0.337
6	28.125	12.5	1.44	0.2438
6.5	6.25	3.125	0.23	0.6396
>7	9.375	6.25	0.27	0.607
Total	3940.625	4981.25	0.76	0.3928

B)

Stem Class	Herbicide	Non Herbicide	F-Value	p
0.5	1206.25	5765.625	14.66	0.001
1	215.625	325	0.32	0.5758
1.5	156.25	150	0.01	9.222
2	109.375	175	1.06	0.315
2.5	90.625	71.875	0.41	0.5293
3	81.25	50	0.96	0.3384
3.5	50	40.625	0.3	0.5894
4	100	59.375	1.3	0.2673
4.5	71.875	31.25	2.56	0.1249
5	40.625	21.875	0.99	0.3299
5.5	15.625	28.125	0.97	0.337
6	31.25	9.375	2.82	0.108
6.5	9.375	0	2.03	0.1687
>7	9.375	6.25	0.27	0.607
Total	**2187.5**	**6734.375**	**14.53**	**0.001**

C)

Stem Class	Cut	Non Cut	F-Value	p
0.5	6233.333	3378.846	12.77	0.0018
1	79.16667	376.9231	2.37	0.1388
1.5	41.66667	276.9231	7.45	0.0126
2	4.166667	303.8462	11.25	0.003
2.5	0	123.0769	18.44	0.0003
3	0	126.9231	10.16	0.0044
3.5	0	71.15385	16.85	0.0005
4	0	136.5385	11.99	0.0023
4.5	0	78.84615	9.88	0.0049
5	0	38.46154	6.64	0.0176
5.5	0	34.61538	7.1	0.0145
6	0	32.69231	5.83	0.0249
6.5	0	5.769231	1.22	0.282
>7	0	17.30769	4.09	0.056
Total	**6358.333**	**5001.923**	**6.07**	**0.0224**

Table 3: Year 2 Post Treatment rhododendron stem class contrast statement analysis within a randomized complete block design

A)

	(Mean Stems per acre)			
Stem Class	**Burn**	**Non Burn**	**F-Value**	**p**
0.5	1958.333	2783.333	1.05	0.3236
1	25	183.3333	8.77	0.0103
1.5	45.83333	166.6667	5.77	0.0307
2	54.16667	158.3333	6.12	0.0268
2.5	54.16667	91.66667	2.77	0.1185
3	58.33333	79.16667	0.34	0.5685
3.5	45.83333	58.33333	0.35	0.5635
4	62.5	54.16667	0.18	0.6743
4.5	16.66667	45.83333	1.28	0.2769
5	4.166667	20.83333	2.87	0.1123
5.5	0	12.5	3	0.1052
6	0	12.5	3	0.1052
6.5	4.166667	4.166667	0	1
>7	0	8.333333	1.87	0.1934
Total	**2329.167**	**3679.167**	**3.1**	**0.1002**

B)

Stem Class	**Herbicide**	**Non-Herbicide**	**F-Value**	**p**
0.5	1508.333	3233.333333	4.58	0.0505
1	91.66667	116.6666667	0.22	0.6473
1.5	95.83333	116.6666667	0.17	0.685
2	41.66667	170.8333333	9.41	0.0084
2.5	62.5	83.33333333	0.85	0.3712
3	75	62.5	0.12	0.7312
3.5	45.83333	58.33333333	0.35	0.5635
4	29.16667	87.5	9.03	0.0095
4.5	25	37.5	0.24	0.6353
5	4.166667	20.83333333	2.87	0.1123
5.5	0	12.5	3	0.1052
6	0	12.5	3	0.1052
6.5	4.166667	4.166666667	0	1
>7	4.166667	4.166666667	0	1
Total	1987.5	4020.833333	7.03	0.019

C)

Variable	Cut	Non Cut	F-Value	p
0.5	4838.889	890	22.48	0.0003
1	5.555556	163.3333	8.16	0.0127
1.5	0	170	10.17	0.0056
2	0	170	15.28	0.0016
2.5	0	116.6667	25.1	0.0002
3	0	110	8.92	0.0098
3.5	0	83.33333	14.58	0.0019
4	0	82.35294	21.66	0.0004
4.5	0	50	3.53	0.0814
5	0	20	3.88	0.0691
5.5	0	10	1.8	0.2011
6	0	10	1.8	0.2011
6.5	0	6.666667	1.4	0.2564
>7	0	6.666667	1.2	0.3078
Total	**4844.444**	**1900**	**13.82**	**0.0023**

Table 4: Year 3 Post Treatment rhododendron stem class contrast statement analysis within a randomized complete block design

A)

(Mean Stems per acre)

Stem Class	Burn	Non Burn	F-Value	p
0.5	312.5	2575	9.38	0.0084
1	29.16667	233.3333	3.45	0.0843
1.5	79.16667	125	1.2	0.2922
2	75	129.1667	1.4	0.2572
2.5	91.66667	112.5	0.17	0.6883
3	95.83333	58.33333	1.26	0.281
3.5	45.83333	62.5	0.38	0.5462
4	37.5	60.71429	0.47	0.5048
4.5	20.83333	42.85714	0.05	0.8192
5	0	32.14286	5.73	0.0313
5.5	0	7.142857	1	0.3343
6	8.333333	21.42857	0	1
6.5	0	0	….	….
>7	0	3.571429	1	0.3343
Total	**795.8333**	**3050**	**13.38**	**0.0026**

B)

Stem Class	**Herbicide**	**Non Herbicide**	**F-Value**	**p**
0.5	958.3333	1929.166667	1.73	0.2099
1	191.6667	70.83333333	1.21	0.29
1.5	125	79.16666667	1.2	0.2922
2	108.3333	95.83333333	0.07	0.7892
2.5	125	79.16666667	0.81	0.3827
3	100	54.16666667	1.88	0.1921
3.5	45.83333	62.5	0.38	0.5463
4	41.66667	50	0.12	0.7372
4.5	8.333333	29.16666667	1.36	0.2636
5	4.166667	33.33333333	3.46	0.0838
5.5	0	8.333333333	1	0.3343
6	0	16.66666667	3.39	0.0867
6.5	0	0	….	….
>7	4.166667	0	1	0.3343
Total	**1712.5**	**2508.333333**	**1.23**	**0.2869**

C)

Stem Class	**Cut**	**Non Cut**	**F-Value**	**p**
0.5	3211.111	1450	13.48	0.0025
1	5.555556	206.6667	3.14	0.0981
1.5	0	163.3333	14.26	0.002
2	0	163.3333	11.89	0.0039
2.5	0	163.3333	9.67	0.0077
3	0	123.3333	12.75	0.0031
3.5	5.555556	83.33333	7.8	0.0144
4	0	73.33333	8.51	0.0113
4.5	0	30	2.64	0.1267
5	5.555556	26.66667	1.7	0.2131
5.5	0	6.666667	0.6	0.4515
6	0	13.33333	2.04	0.1755
6.5	0	0	….	….
>7	0	3.333333	0.6	0.4515
total	**3211.111**	**1450**	**5.63**	**0.3226**

Table 5: Pre-treatment fuel class contrast statement analysis within a randomized complete block design

(tons per acre)

Variable	Burn	Non Burn	F-Value	P
1hr	0.36	0.37	0.07	0.79
10hr	0.94	0.57	10.83	0.00
100hr	1.80	1.49	1.86	0.18
litter	5.35	4.66	.65	0.42
total	**8.45**	**7.09**	**4.24**	**0.06**

Variable	Cut	Non Cut	F-Value	P
1hr	0.35	0.37	0.95	0.81
10hr	0.62	0.84	3.57	0.07
100hr	1.64	1.65	0.00	0.96
litter	3.34	2.94	1.29	0.26
total	**5.95**	**5.8**	**0.38**	**0.54**

Variable	Herbicide	Non Herbicide	F-Value	P
1hr	0.37	0.36	0.02	0.88
10hr	0.78	0.73	0.18	0.67
100hr	1.81	1.49	0.64	0.43
litter	3.19	2.98	0.39	0.54
total	**6.15**	**5.56**	**0.23**	**0.63**

Table 6: Post-treatment fuel class contrast statement analysis within a randomized complete block design

(tons per acre)

Variable	Burn	Non Burn	F-Value	P
1hr	0.36	0.41	0.45	0.51
10hr	0.79	1.04	1.90	0.18
100hr	3.37	3.29	0.02	0.87
litter	2.59	3.59	8.78	0.001
total	**7.11**	**8.33**	**1.14**	**0.29**

Variable	**Cut**	**Non Cut**	**F-Value**	**P**
1hr	0.54	0.27	11.17	0.00
10hr	1.46	0.59	20.72	0.00
100hr	5.83	1.88	19.56	0.00
litter	3.34	2.94	1.29	0.26
total	**11.17**	**5.68**	**27.38**	**<.0001**

Variable	**Herbicide**	**Non Herbicide**	**F-Value**	**P**
1hr	0.34	0.43	1.25	0.27
10hr	0.94	0.89	0.06	0.81
100hr	3.20	3.52	0.13	0.71
litter	3.19	2.98	0.39	0.54
total	**7.67**	**7.82**	**0.25**	**0.61**

Table 7: Year 2 Post-treatment fuel class contrast statement analysis within a randomized complete block design

(tons per acre)

Variable	**Burn**	**Non Burn**	**F-Value**	**P**
1hr	0.27	0.37	2.96	0.10
10hr	1.11	1.11	0.00	1.00
100hr	3.87	4.87	0.50	0.49
litter	3.70	4.15	8.78	0.07
total	**8.95**	**10.5**	**0.20**	**0.66**

Variable	**Cut**	**Non Cut**	**F-Value**	**P**
1hr	0.48	0.21	30.66	<.0001
10hr	1.79	0.70	13.67	0.00
100hr	8.65	1.92	29.96	<.0001
litter	3.34	2.94	1.29	0.26
total	**14.26**	**5.77**	**30.67**	**<.0001**

Variable	**Herbicide**	**Non Herbicide**	**F-Value**	**P**
1hr	0.28	0.35	2.04	0.17
10hr	0.97	1.25	0.98	0.34
100hr	3.72	5.17	1.47	0.24
litter	3.19	2.98	0.39	0.54
total	**8.16**	**9.75**	**0.18**	**0.67**

Table 8: Year 3 Post-treatment fuel class contrast statement analysis within a randomized complete block design.

Variable	Burn (tons per acre)	Non Burn	F-Value	P
1hr	0.21	0.38	3.70	0.07
10hr	1.01	1.68	1.37	0.26
100hr	4.43	5.23	0.03	0.87
litter	3.47	3.98	8.78	0.00
total	**9.12**	**11.27**	**1.33**	**0.26**

Variable	Cut	Non Cut	F-Value	P
1hr	0.41	0.24	12.57	0.00
10hr	2.28	0.79	6.29	0.02
100hr	10.18	2.02	17.77	0.00
litter	3.34	2.94	1.29	0.26
total	**16.21**	**5.99**	**25.08**	**0.00**

Variable	Herbicide	Non Herbicide	F-Value	P
1hr	0.28	0.31	0.08	0.77
10hr	1.20	1.5	0.26	0.61
100hr	3.30	6.85	3.58	0.07
litter	3.19	2.98	0.39	0.54
total	**7.97**	**11.64**	**3.07**	**0.101**

Table 9: ANOVA for testing the **post treatment** interaction of burn status and split plot on the number of **0.5 inch** class rhododendron stems per acre **(N = 24)**

Source	df	Type III SS	Mean Square	F value	p
burn status	1	1870416.6	1870416.6	0.25	0.6493
split plot	2	203475625	101737812.5	6.29	0.0136
bs*sp interaction	2	35770208.3	27885204.3	1.11	0.3627

Table 10: ANOVA for testing the **post treatment** interaction of burn status and split plot on the number of **1.0 class** rhododendron stems per acre **(N = 24)**

Source	df	Type III SS	Mean Square	F value	p
burn status	1	2130103.1	2130104.1	2.93	0.1852
split plot	2	1410625	705312.5	2.64	0.112
bs*sp interaction	2	1043958.3	521979.1	1.96	0.1841

Table 11: ANOVA for testing the **post treatment** interaction of burn status and split plot on the number of **1.5 class** rhododendron stems per acre **(N = 24)**

Source	**df**	**Type III SS**	**Mean Square**	**F value**	**p**
burn status	1	338437	338437	7.37	0.0729
split plot	2	385208	192604.1	5.42	0.0211
bs*sp interaction	2	188125	94062.5	2.65	0.1117

Table 12: ANOVA for testing the **post treatment** interaction of burn status and split plot on the number of **2.0 class** rhododendron stems per acre **(N = 24)**

Source	**df**	**Type III SS**	**Mean Square**	**F value**	**p**
burn status	1	192604.1	192604.1	15.99	0.028
split plot	2	490208.3	245104.1	4.97	0.0268
bs*sp interaction	2	227708.3	113854.1	2.31	0.1419

Table 13: ANOVA for testing the **post treatment** interaction of burn status and split plot on the number of **2.5 class** rhododendron stems per acre **(N = 24)**

Source	**df**	**Type III SS**	**Mean Square**	**F value**	**p**
burn status	1	17604.1	17604.1	2.4	0.2189
split plot	2	105625	52812.5	6.04	0.01
bs*sp interaction	2	12708.3	6354.1	0.73	0.5

Table 14: ANOVA for testing the **post treatment** interaction of burn status and split plot on the number of **3.0 class** rhododendron stems per acre **(N = 24)**

Source	**df**	**Type III SS**	**Mean Square**	**F value**	**p**
burn status	1	7.573065	7.573065	0	1
split plot	2	70000	35000	3.21	0.0764
bs*sp interaction	2	2500	1250	0.11	0.8926

Table 15: ANOVA for testing the **post treatment** interaction of burn status and split plot on the number of **3.5 class** rhododendron stems per acre **(N = 24)**

Source	**df**	**Type III SS**	**Mean Square**	**F value**	**p**
burn status	1	2604.1	2604.1	0.54	0.5158
split plot	2	28958.3	14479.1	9.27	0.0037
bs*sp interaction	2	13958.3	6979.1	4.47	0.0355

Table 16: ANOVA for testing the **post treatment** interaction of burn status and split plot on the number of **4.0 class** rhododendron stems per acre **(N = 24)**

Source	**df**	**Type III SS**	**Mean Square**	**F value**	**p**
burn status	1	15000	15000	1.06	0.3792
split plot	2	68125	34062	5.54	0.0197
bs*sp interaction	2	8125	4062	0.66	0.5342

Table 17: ANOVA for testing the **post treatment** interaction of burn status and split plot on the number of **4.5 class** rhododendron stems per acre **(N = 24)**

Source	**df**	**Type III SS**	**Mean Square**	**F value**	**p**
burn status	1	1666.6	1666.6	0.29	0.6301
split plot	2	32500	16250	7.31	0.0084
bs*sp interaction	2	833.3	416.6	0.19	0.83

Table 18: ANOVA for testing the **post treatment** interaction of burn status and split plot on the number of **5.0 class** rhododendron stems per acre **(N = 24)**

Source	**df**	**Type III SS**	**Mean Square**	**F value**	**p**
burn status	1	416.6	416.6	0.1	0.7688
split plot	2	13958.3	6979.1	2.79	0.101
bs*sp interaction	2	2708.3	1354	0.54	0.5954

Table 19: ANOVA for testing the **post treatment** interaction of burn status and split plot on the number of **5.5 class** rhododendron stems per acre **(N = 24)**

Source	**df**	**Type III SS**	**Mean Square**	**F value**	**p**
burn status	1	1666.6	1666.6	0.67	0.47
split plot	2	12708.3	6354.1	4.36	0.0378
bs*sp interaction	2	1458.3	729.1	0.5	0.6186

Table 20: ANOVA for testing the **post treatment** interaction of burn status and split plot on the number of **6.0 class** rhododendron stems per acre **(N = 24)**

Source	**df**	**Type III SS**	**Mean Square**	**F value**	**p**
burn status	1	104.1	104.1	0.06	0.824
split plot	2	5625	2812.5	2.38	0.1345
bs*sp interaction	2	208.3	104.1	0.09	0.9161

Table 21: ANOVA for testing the **post treatment** interaction of burn status and split plot on the number of **6.5 class** rhododendron stems per acre **(N = 24)**

Source	**df**	**Type III SS**	**Mean Square**	**F value**	**p**
burn status	1	104.1	104.1	1	0.391
split plot	2	208.3	104.16	1	0.3966
bs*sp interaction	2	208.3	104.16	1	0.3966

Table 22: ANOVA for testing the **post treatment** interaction of burn status and split plot on the number of **>7.0 class** rhododendron stems per acre **(N = 24)**

Source	**df**	**Type III SS**	**Mean Square**	**F value**	**p**
burn status	1	1.24985	1.249851	0.68	0.4704
split plot	2	833.3	416.6	2	0.17
bs*sp interaction	2	0	0	0	1

Table 23: ANOVA for testing the **post treatment** interaction of burn status and split plot on the number of **total class** rhododendron stems per acre **(N = 24)**

Source	**df**	**Type III SS**	**Mean Square**	**F value**	**p**
burn status	1	2070937.5	2070937.5	0.23	0.6
split plot	2	140833958.3	70416979.2	4.36	0.0378
bs*sp interaction	2	15570625	7785312.5	0.48	0.6291

Table 24: ANOVA for testing the **post Year 2 treatment** interaction of burn status and split plot on the number of **0.5 class** rhododendron stems per acre **(N = 18)**

Source	**df**	**Type III SS**	**Mean Square**	**F value**	**p**
burn status	1	2347222	2347222	0.36	.6098
split plot	2	55108611	27554306	7.86	.0129
bs*sp interaction	2	2363611	1181806	0.34	.7234

Table 25: ANOVA for testing the **post Year 2 treatment** interaction of burn status and split plot on the number of **1.0 class** rhododendron stems per acre **(N = 18)**

Source	df	Type III SS	Mean Square	F value	p
burn status	1	233472.2	233472.2	8.58	0.09
split plot	2	147777.7	73888.8	3.42	0.084
bs*sp interaction	2	107777.7	53888.8	2.5	0.1438

Table 26: ANOVA for testing the **post Year 2 treatment** interaction of burn status and split plot on the number of **1.5 class** rhododendron stems per acre **(N = 18)**

Source	df	Type III SS	Mean Square	F value	p
burn status	1	281250	281250	3.25	0.2134
split plot	2	211944.4	105972.2	3.11	0.099
bs*sp interaction	2	142500	71250	2.09	0.1856

Table 27: ANOVA for testing the **post Year 2 treatment** interaction of burn status and split plot on the number of **2.0 class** rhododendron stems per acre **(N = 18)**

Source	df	Type III SS	Mean Square	F value	p
burn status	1	108888.8	108888.8	21.19	0.0441
split plot	2	400833.3	200416.6	12.6	0.0034
bs*sp interaction	2	241944.4	120972.2	7.61	0.0141

Table 28: ANOVA for testing the **post Year 2 treatment** interaction of burn status and split plot on the number of **2.5 class** rhododendron stems per acre **(N = 18)**

Source	df	Type III SS	Mean Square	F value	p
burn status	1	27222.2	27222.2	196	0.0051
split plot	2	83333.3	41666.6	9.84	0.007
bs*sp interaction	2	34444.4	17222.2	4.07	0.0605

Table 29: ANOVA for testing the **post Year 2 treatment** interaction of burn status and split plot on the number of **3.0 class** rhododendron stems per acre **(N = 18)**

Source	**df**	**Type III SS**	**Mean Square**	**F value**	**p**
burn status	1	20000	20000	1.92	0.3001
split plot	2	50277.7	25138.8	6.58	0.0204
bs*sp interaction	2	17500	8750	2.29	0.1635

Table 30: ANOVA for testing the **post Year 2 treatment** interaction of burn status and split plot on the number of **3.5 class** rhododendron stems per acre **(N = 18)**

Source	**df**	**Type III SS**	**Mean Square**	**F value**	**p**
burn status	1	3472.2	3472.2	0.48	0.5598
split plot	2	41944.4	20972.2	13.13	0.003
bs*sp interaction	2	6944.4	3472.2	2.17	0.1762

Table 31: ANOVA for testing the **post Year 2 treatment** interaction of burn status and split plot on the number of **4.0 class** rhododendron stems per acre **(N = 18)**

Source	**df**	**Type III SS**	**Mean Square**	**F value**	**p**
burn status	1	138.8	138.8	0.03	0.874
split plot	2	97500	48750	17.55	0.0012
bs*sp interaction	2	277.7	138.8	0.05	0.9515

Table 32: ANOVA for testing the **post Year 2 treatment** interaction of burn status and split plot on the number of **4.5 class** rhododendron stems per acre **(N = 18)**

Source	**df**	**Type III SS**	**Mean Square**	**F value**	**p**
burn status	1	6805.5	6805.5	3.06	0.2222
split plot	2	17500	8750	1.54	0.2724
bs*sp interaction	2	8611.1	4305.5	0.76	0.5003

Table 33: ANOVA for testing the **post Year 2 treatment** interaction of burn status and split plot on the number of **5.0 class** rhododendron stems per acre **(N = 18)**

Source	df	Type III SS	Mean Square	F value	p
burn status	1	2222.2	2222.2	2.29	0.2697
split plot	2	5833.3	2916.6	4.2	0.0566
bs*sp interaction	2	1944.4	972.2	1.4	0.3011

Table 34: ANOVA for testing the **post Year 2 treatment** interaction of burn status and split plot on the number of **5.5 class** rhododendron stems per acre **(N = 18)**

Source	df	Type III SS	Mean Square	F value	p
burn status	1	1250	1250	3	0.2254
split plot	2	2500	1250	3	0.1066
bs*sp interaction	2	2500	1250	3	0.1066

Table 35: ANOVA for testing the **post Year 2 treatment** interaction of burn status and split plot on the number of **6.0 class** rhododendron stems per acre **(N = 18)**

Source	df	Type III SS	Mean Square	F value	p
burn status	1	1250	1250	3	0.2254
split plot	2	2500	1250	3	0.1066
bs*sp interaction	2	2500	1250	3	0.1066

Table 36: ANOVA for testing the **post Year 2 treatment** interaction of burn status and split plot on the number of **6.5 class** rhododendron stems per acre **(N = 18)**

Source	df	Type III SS	Mean Square	F value	p
burn status	1	6.172609	6.172	0.18	0.7157
split plot	2	277.7	138.8	0.5	0.6243
bs*sp interaction	2	833.3	416.6	1.5	0.2798

Table 37: ANOVA for testing the **post Year 2 treatment** interaction of burn status and split plot on the number of **>7.0 class** rhododendron stems per acre **(N = 18)**

Source	df	Type III SS	Mean Square	F value	p
burn status	1	7.061144	7.061144	0	1
split plot	2	….	….	….	….
bs*sp interaction	2	….	….	….	….

Table 38: ANOVA for testing the **post Year 2 treatment** interaction of burn status and split plot on the number of **total class** rhododendron stems per acre **(N = 18)**

Source	df	Type III SS	Mean Square	F value	p
burn status	1	133472.2	133472.2	0.02	0.9
split plot	2	38204444	19102222	6.59	0.0204
bs*sp interaction	2	4084444	2042222	0.7	0.5227

Table 39: ANOVA for testing the **post Year 3 treatment** interaction of burn status and split plot on the number of **0.5 class** rhododendron stems per acre **(N = 18)**

Source	df	Type III SS	Mean Square	F value	p
burn status	1	17013889	17013889	2.24	0.2734
split plot	2	29383611	14691806	5.47	0.03
bs*sp interaction	2	17833611	8916806	3.32	0.0893

Table 40: ANOVA for testing the **post Year 3 treatment** interaction of burn status and split plot on the number of **1.0 class** rhododendron stems per acre **(N = 18)**

Source	df	Type III SS	Mean Square	F value	p
burn status	1	361250	361250	2.17	0.2784
split plot	2	396944.4	198472.2	2.64	0.132
bs*sp interaction	2	365833.3	182916.6	2.43	0.1498

Table 41: ANOVA for testing the **post Year 3 treatment** interaction of burn status and split plot on the number of **1.5 class** rhododendron stems per acre **(N = 18)**

Source	df	Type III SS	Mean Square	F value	p
burn status	1	50138.8	50138.8	11.65	0.0762
split plot	2	118611.1	59305.5	4.15	0.0581
bs*sp interaction	2	26922.2	13472.2	0.94	0.4293

Table 42: ANOVA for testing the **post Year 3 treatment** interaction of burn status and split plot on the number of **2.0 class** rhododendron stems per acre **(N = 18)**

Source	df	Type III SS	Mean Square	F value	p
burn status	1	45000	45000	5.14	0.1515
split plot	2	135277.7	67638.8	3.68	0.0738
bs*sp interaction	2	142500	71250	3.87	0.0667

Table 43: ANOVA for testing the **post Year 3 treatment** interaction of burn status and split plot on the number of **2.5 class** rhododendron stems per acre **(N = 18)**

Source	df	Type III SS	Mean Square	F value	p
burn status	1	16805.5	16805.5	0.87	0.4493
split plot	2	133611.1	66805.5	3.22	0.0943
bs*sp interaction	2	55277.7	27638.8	1.33	0.3169

Table 44: ANOVA for testing the **post Year 3 treatment** interaction of burn status and split plot on the number of **3.0 class** rhododendron stems per acre **(N = 18)**

Source	df	Type III SS	Mean Square	F value	p
burn status	1	3472.2	3472.2	0.27	0.6525
split plot	2	85833.3	42916.6	8.13	0.0118
bs*sp interaction	2	11944.4	5972.2	1.13	0.3692

Table 45: ANOVA for testing the **post Year 3 treatment** interaction of burn status and split plot on the number of **3.5 class** rhododendron stems per acre **(N = 18)**

Source	df	Type III SS	Mean Square	F value	p
burn status	1	6805.5	6805.5	0.8	0.4647
split plot	2	35277.7	17638.8	3.91	0.0655
bs*sp interaction	2	1944.4	972.2	0.22	0.8108

Table 46: ANOVA for testing the **post Year 3 treatment** interaction of burn status and split plot on the number of **4.0 class** rhododendron stems per acre **(N = 18)**

Source	df	Type III SS	Mean Square	F value	p
burn status	1	5000	5000	0.92	0.438
split plot	2	31111.1	15555.5	3.5	0.0809
bs*sp interaction	2	10000	5000	1.13	0.3711

Table 47: ANOVA for testing the **post Year 3 treatment** interaction of burn status and split plot on the number of **4.5 class** rhododendron stems per acre **(N = 18)**

Source	df	Type III SS	Mean Square	F value	p
burn status	1	0.8	138.8	0.05	0.8399
split plot	2	10833.3	5416	2.29	0.1631
bs*sp interaction	2	277.7	138.8	0.06	0.9433

Table 48: ANOVA for testing the **post Year 3 treatment** interaction of burn status and split plot on the number of **5.0 class** rhododendron stems per acre **(N = 18)**

Source	df	Type III SS	Mean Square	F value	p
burn status	1	11250	11250	3.86	0.1885
split plot	2	10000	5000	3	0.1066
bs*sp interaction	2	10000	5000	3	0.1066

Table 49: ANOVA for testing the **post Year 3 treatment** interaction of burn status and split plot on the number of **5.5 class** rhododendron stems per acre **(N = 18)**

Source	df	Type III SS	Mean Square	F value	p
burn status	1	555	555	1	0.4226
split plot	2	1111.1	555.5	1	0.4096
bs*sp interaction	2	1111.1	555.5	1	0.4096

Table 50: ANOVA for testing the **post Year 3 treatment** interaction of burn status and split plot on the number of **6.0 class** rhododendron stems per acre **(N = 18)**

Source	df	Type III SS	Mean Square	F value	p
burn status	1	3.653287	3.653287	0	1
split plot	2	4444.4	2222.2	3.2	0.0953
bs*sp interaction	2	0	0	0	1

Table 51: ANOVA for testing the **post Year 3 treatment** interaction of burn status and split plot on the number of **6.5 class** rhododendron stems per acre **(N = 18)**

Source	df	Type III SS	Mean Square	F value	p
burn status	1	…….	………….	……..	……
split plot	2	……	………	…….	……..
bs*sp interaction	2	……….	……….	………	……..

Table 52: ANOVA for testing the **post Year 3 treatment** interaction of burn status and split plot on the number of **>7.0 class** rhododendron stems per acre **(N = 18)**

Source	df	Type III SS	Mean Square	F value	p
burn status	1	138.8	138.8	1	0.4226
split plot	2	277.7	138.8	1	0.4096
bs*sp interaction	2	277.7	138.8	1	0.4096

Table 53: ANOVA for testing the **post Year 3 treatment** interaction of burn status and split plot on the number of **total class** rhododendron stems per acre **(N = 18)**

Source	**df**	**Type III SS**	**Mean Square**	**F value**	**p**
burn status	1	30420000	30420000	3.1	0.2204
split plot	2	9426944	4713472	2.38	0.1549
bs*sp interaction	2	11572500	5786250	2.92	0.1119

Table 54: ANOVA for testing the **post** interaction of burn status and split plot on **1-hr** fuel loading **(N = 24)**

Source	**df**	**Type III SS**	**Mean Square**	**F value**	**p**
burn status	1	0.18640150	0.18640150	0.06	0.8173
split plot	2	20.64314548	10.32157274	3.09	0.0827
bs*sp interaction	2	2.45035950	1.22517975	0.37	0.7005

Table 55: ANOVA for testing the **post** interaction of burn status and split plot on **10-hr** fuel loading (**N = 24**)

Source	**df**	**Type III SS**	**Mean Square**	**F value**	**p**
burn status	1	0.01305418	0.01305418	0.02	0.9028
split plot	2	15.39740067	7.69870033	9.18	0.0038
bs*sp interaction	2	0.59396501	0.29698251	0.35	0.7089

Table 56: ANOVA for testing the **post** interaction of burn status and split plot on **100-hr** fuel loading **(N = 24)**

Source	**df**	**Type III SS**	**Mean Square**	**F value**	**p**
burn status	1	9.10220139	9.10220139	4.06	0.0670
split plot	2	32.98871561	16.49435780	7.35	0.0082
bs*sp interaction	2	4.50239688	2.25119844	1.00	0.3955

Table 57: ANOVA for testing the **post** interaction of burn status and split plot on **litter** fuel loading **(N = 24)**

Source	**df**	**Type III SS**	**Mean Square**	**F value**	**p**
burn status	1	8.2925648	8.29256484	7.09	0.0762
split plot	2	1.3775063	0.68875312	0.99	0.4003
bs*sp interaction	2	1.4230688	0.71153437	1.02	0.3892

Table 58: ANOVA for testing the post interaction of burn status and split plot on **total** fuel loading **(N = 24)**

Source	df	Type III SS	Mean Square	F value	p
burn status	1	5.2786913	5.2786913	0.30	0.5927
split plot	2	4.3770177	1.4590059	0.08	0.9678
bs*sp interaction	2	9.6451791	4.8225895	0.28	0.7636

Table 59: ANOVA for testing the **post Year 2** interaction of burn status and split plot on **1-hr** fuel loading **(N = 18)**

Source	df	Type III SS	Mean Square	F value	p
burn status	1	0.00636250	0.00636250	0.01	0.9283
split plot	2	12.26452252	6.13226126	8.31	0.0112
bs*sp interaction	2	1.28920245	0.64460123	0.87	0.4539

Table 60: ANOVA for testing the **post Year 2** interaction of burn status and split plot on **10-hr** fuel loading (**N = 18**)

Source	df	Type III SS	Mean Square	F value	p
burn status	1	0.73538525	0.73538525	0.29	0.6025
split plot	2	25.48175168	12.74087584	5.09	0.0375
bs*sp interaction	2	2.33234612	1.16617306	0.47	0.6435

Table 65: ANOVA for testing the **post Year 2** interaction of burn status and split plot on **100-hr** fuel loading **(N = 18)**

Source	df	Type III SS	Mean Square	F value	p
burn status	1	5.20950409	5.20950409	1.06	0.3326
split plot	2	79.74437551	39.87218776	8.14	0.0118
bs*sp interaction	2	1.41421441	0.70710720	0.14	0.8678

Table 68: ANOVA for testing the **post Year 2** interaction of burn status and split plot on **litter** fuel loading **(N = 18)**

Source	df	Type III SS	Mean Square	F value	p
burn status	1	1.2073123		2.79	0.2371
split plot	2	4.3017664	2.15088322	6.31	0.0226
bs*sp interaction	2	0.1462766	0.07313829	0.21	0.8113

Table 70: ANOVA for testing the **post Year 2** interaction of burn status and split plot on **total** fuel loading **(N = 18)**

Source	df	Type III SS	Mean Square	F value	p

burn status	1	11.2833580	11.2833580	0.44	0.5243
split plot	2	283.8955165	141.9477583	5.57	0.0305
bs*sp interaction	2	15.4406767	7.7203384	0.30	0.7466

Table 63: ANOVA for testing the **post Year 3** interaction of burn status and split plot on **1-hr** fuel loading **(N = 18)**

Source	**df**	**Type III SS**	**Mean Square**	**F value**	**p**
burn status	1	4.89952603	4.89952603	1.72	0.2259
split plot	2	4.94446122	2.47223061	0.87	0.4557
bs*sp interaction	2	0.33164554	0.16582277	0.06	0.9438

Table 64: ANOVA for testing the **post Year 3** interaction of burn status and split plot on **10-hr** fuel loading (**N = 18**)

Source	**df**	**Type III SS**	**Mean Square**	**F value**	**p**
burn status	1	4.18168773	4.18168773	0.33	0.5793
split plot	2	45.48945217	22.74472609	1.82	0.2237
bs*sp interaction	2	1.73185402	0.86592701	0.07	0.9337

Table 65: ANOVA for testing the **post Year 3** interaction of burn status and split plot on **100-hr** fuel loading **(N = 18)**

Source	**df**	**Type III SS**	**Mean Square**	**F value**	**p**
burn status	1	4.6755660	4.6755660	0.28	0.6090
split plot	2	188.0905159	94.0452579	5.70	0.0289
bs*sp interaction	2	15.8449736	7.9224868	0.48	0.6355

Table 68: ANOVA for testing the **post Year 3** interaction of burn status and split plot on **litter** fuel loading **(N = 18)**

Source	**df**	**Type III SS**	**Mean Square**	**F value**	**p**
burn status	1	0.7110281	0.71102813	2.08	0.2857
split plot	2	3.5118563	1.75592813	1.58	0.2642
bs*sp interaction	2	2.3788688	1.18943438	1.07	0.3875

Table 70: ANOVA for testing the **post Year 3** interaction of burn status and split plot on **total** fuel loading **(N = 18)**

Source	**df**	**Type III SS**	**Mean Square**	**F value**	**p**
burn status	1	4.7310519	4.7310519	0.07	0.7944
split plot	2	540.2997391	270.1498696	4.15	0.0581
bs*sp interaction	2	38.2922525	19.1461263	0.29	0.7531