Effects of prescribed burning, mechanical and chemical treatments to curtail rhododendron dominance and reduce wildfire fuel loads

by

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(ABSTRACT)

Rosebay rhododendron (*Rhododendron maximum* L.) is an ericaceous shrub commonly found in riparian areas of the Appalachian Mountains. After more than a century of fire exclusion in the U.S., the distribution of *R. maximum* and its dominance of forest understories have increased. Rhododendron expansion has caused a decline in overstory regeneration and the potential for dangerous fuel conditions around suburban structures near the wildland-urban interface. The purpose of this study was to determine the effects of seven silvicultural treatments on both the fuel loading within an *R. maximum* thicket and the control of *R. maximum* as a forest weed. The final objective of the project was to determine the cost effectiveness of each implemented treatment.

Due primarily to moisture conditions, a single prescribed burn was relatively ineffective in reducing fuel loading and causing *R. maximum* mortality. Mechanical cutting caused a drastic shift in the size-class distribution of *R. maximum* but resulted in heavy sprouting and increased fuel loading. Herbicide application did not reduce or increase fuel loading and was important in *R. maximum* control only when combined with other treatments. The prescribed burning treatment was the least expensive individual treatment while mechanical cutting was the most expensive. Combination treatments showed increased effectiveness in controlling *R. maximum* but were more expensive than the individual treatments. The results of the treatments from this study will be used over the long term to demonstrate to land managers the effects of vegetation control on rhododendron.

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Introduction and Justification

In recent years much attention has been focused on the evergreen component of the understories in the southern Appalachians (Nilsen et al. 2001, Baker and Van Lear 1998, Dobbs 1998, Clinton 1995, Dobbs 1995, Boettcher and Kalisz 1990, Phillips and Murdy 1985). Of increasing ecological importance are the species comprising these understories, primarily *Kalmia latifolia* L. and *Rhododendron maximum* L. In the wake of policy changes regarding fire suppression beginning in the 1920s and the drastic alteration of forest composition in the southern Appalachians following the chestnut blight, scientists are cognizant of changes to forest structure and subsequent research has sought to quantify and explain these changes (Vandermast et al. 2002, Baker and Van Lear 1998, Pyne 1982)

One such change in forest structure is the increasing abundance and impending dominance of rosebay rhododendron (*Rhododendron maximum* L.) as an understory species in the southern Appalachians. *R. maximum* is a large ericaceous shrub characterized by its sclerophyllous leaves and showy flowers (Monk et al. 1985). It is commonly found in moist riparian areas where it forms dense thickets that function as a continuous sub-canopy, preventing sunlight from reaching to the forest floor (Clinton et al. 1994) and creating large fuel complexes or "roughs" that serve to increase the risk of catastrophic wildfire (Van Lear and Waldrop 1989). Approximately 1.2 million hectares (2,965,265 ac) throughout the southern Appalachians are covered with this arborescent shrub (Dobbs 1995).

The recent proliferation of *R. maximum* has been well documented over the past two decades. Several authors partially attribute the increase in rhododendron coverage to canopy gap disturbances such as the loss of the American chestnut (*Castanea dentata*) and partial harvesting, or high grading (Hedman and Van Lear 1995, Phillips and Murdy 1985). In addition to canopy gap disturbances, other catalysts thought to be involved in the expansion of *R. maximum* coverage are the cessation of regular burning and cattle grazing (McGee and Smith 1967).

Researchers have noted the ecological consequences of the increasing abundance of *R. maximum*. Baker and Van Lear (1998) observed that future plant diversity within riparian ecosystems would be negatively correlated with *R. maximum* thicket cover and density in the absence of major disturbance. In addition to a decline in plant diversity, Nilsen et al. (1999) explain that resource and mycorrhizae limitations commonly found in *R. maximum* thickets might be the most important factors in regulating canopy tree seedling survival in the southern Appalachians. Similarly Phillips and Murdy (1985) predicted that *R. maximum* would interfere with the regeneration of dominant canopy species and they also include that *R. maximum* would become a defining factor in the alteration of forest structure within their study area.

As more research is conducted on the recent expansion of *R. maximum*, the wildfire risk and the potential effects of the plant on biodiversity and canopy tree regeneration become clear. What remains unclear, however, is the silvicultural prescription for the control of *R. maximum* in the southern Appalachians. "Critical adjustments in forest management protocols and forestry practices may be required based on the mechanisms by which *R. maximum* inhibits canopy tree seedling recruitment" (Nilsen et al. 1999). At present little information exists on the long-term efficacy and cost efficiency of *R. maximum* control measures. Our goal with this study is to explore several potential treatment options for the reduction of *R. maximum* in order to assist land managers in planning and justification for silvicultural treatment on lands dominated by *R. maximum*.

Literature Review

Ecological Role

The genus *Rhododendron* is found all over the world with over 900 species and many more hybrids (Cox 1979, La Croix 1973). The term rhododendron means literally, "rose tree," and fittingly describes this group of hardy shrubs known for their ornamental value worldwide. Rhododendrons are in the *Ericaceae*, the heath family, an important and widely variable family with members ranging from herbaceous perennials without chlorophyll to the economically important shrubs in the genus *Vaccinium*, or blueberry (Radford et al., 1968). Almost all members of the *Ericaceae* share a preference for acidic soils, with most rhododendrons showing optimal growth in soils with a pH between 4.5 and 5, but having populations found in soils with pH as low as 3 (Boettcher and Kalisz 1990, Berrisford 1973, La Croix 1973).

Rhododendron maximum, or "Great Rhododendron," is a large evergreen shrub, both common and widespread in eastern North America from Georgia and Alabama to Nova Scotia (Cox 1979). Generally preferring stream banks and mesic woodlands, the ericad usually occurs in scattered colonies all over the Appalachians and into the proximal Piedmont, almost exclusively below 3000 ft. (915 m) where it joins the range of its high elevation counterpart, *Rhododendron catawbiense* (Monk et al. 1985, Cox 1979, Radford et al. 1968). *R. maximum* often exhibits multiple stems growing from the same root stock and can reach heights of 40 ft. (12m) in the wild. The multiple stem habit of *R. maximum* causes the plant to form dense thickets called rhododendron "slicks" or "hells" by indigenous peoples.

Within a rhododendron thicket there is often complete or nearly complete exclusion of any other woody or herbaceous species in the understory and herb layers of the forest (Clinton and Vose 1996, Clinton 1995, Clinton et al. 1994, Hedman and Van Lear 1995). The concern for the land manager is the lack of advanced regeneration and subsequently the sustainability of present forest composition. Thus the environment within a typical rhododendron thicket in the southern Appalachians has, of recent, become the topic of intensive research. Researchers have sought to understand the soil and microsite characteristics responsible for the lack of overstory regeneration including the availability of photosynthetically active radiation (PAR), nutrient dynamics, presence/absence of mycorrhizae, seedbed properties, hydrologic processes, temperature, and allelopathy (Walker et al. 1999, Baker and Van Lear 1998, Nilsen et al. 1999, Clinton and Vose 1996, Clinton 1995, Hedman and Van Lear 1995).

The most distinct characteristic of an *R. maximum* thicket that is responsible for decreased biodiversity and limited regeneration is the lack of usable sunlight (PAR) reaching the forest floor. Baker and Van Lear (1998) observe that *R. maximum* excludes other species from multiple canopy strata and thus reduces species richness. Low light levels under dense thickets are also responsible for the lack of potential midstory and overstory trees. The light environment below *R. maximum* canopies is usually exactly the percentage of full sun that is the light compensation point for most woody species (2%) (Clinton 1995). Most woody species are unable to become established in an environment where available sunlight is so restricted (Clinton 1995). None of the literature cites light limitation as being the sole malefactor responsible for decreased regeneration survival, but rather this limitation is seen as an accessory which, when combined with other limiting factors, effectively disallows successful competition (Nilsen et al. 2001, Walker et al. 1999, Baker and Van Lear 1998, Clinton and Vose 1996, Clinton 1995, Clinton et al. 1994). Without successful canopy-tree species competition in the understories of *R. maximum*-dominated areas, it is thought to be unlikely that present overstory composition will perpetuate after natural overstory mortality occurs (Baker and Van Lear 1998, Clinton 1995).

Other important factors in the description of areas defined by *R. maximum* dominance are soil characteristics. Rhododendrons prefer a cool, moist, well-drained acidic soil with a deep humus layer (Nilsen et al. 1999, Hedman and Van Lear 1995, La Croix 1973). High rainfall and low temperatures are known to slow the breakdown of organic matter by bacteria and fungi, resulting in the formation of an acid soil. Thus with adiabatic cooling and a proclivity for higher rainfall in mountainous areas, it is clear why rhododendrons are generally found in mountain settings (La Croix 1973).

In search of chemical and physical properties of the preferential humic soils, Boettcher and Kalisz (1990) observed the effect of single trees on immediate edaphic features both for sites covered with *R. maximum* and sites lacking the plant. Results of the experiment show that levels of mineralizable N, pH, Ca, Mg, and K were lower on sites with *R. maximum* coverage than on sites where the plant was absent. This study also reported that *R. maximum* forms a litter layer that is slow to decompose and causes the mineral soil to retain fewer basic cations, thus decreasing pH.

In 1999, Nilsen et al. concur with Boettcher and Kalisz (1990) when they described a similar relationship between *R. maximum* and nutrient availability. Soil below *R. maximum* thickets is commonly deficient of many essential nutrients and this fact may be important in understanding seedling survival and growth (Nilsen et al. 1999). Further then, Nilsen et al. (2001) found that among other factors, low cation availability on *R. maximum* microsites led to decreased *Quercus rubra* seedling survivorship for their study.

Soil factors in rhododendron slicks may also be confounded by the richness of phenolics and other organic substances in the foliage and roots of *R. maximum*. The release of said compounds is known to result in intensified leaching and further soil acidification (Boettcher and Kalisz 1990). In effect, once *R. maximum* becomes established on a site, it will alter soil characteristics to further favor its own physiology. It should also be noted that rhododendrons often occur on soils with low available calcium. For this reason, rhododendrons are thought to be "lime-haters," however the opposite is true. These plants, like many others, are unable to discriminate between necessary elements and, if given the opportunity, will uptake large amounts of calcium at the exclusion of other crucial elements such as iron, manganese, and magnesium (Berrisford 1973, La Croix 1973).

In relation to soil nutrient availability, the ability of mycorrhiza to colonize rootstocks in tree seedlings may be an important process under the shade of *R. maximum*. In a mycorrhizal relationship, the mycobiont can assist the host plant by: increased acquisition of water through increased absorptive surface area, increased uptake of nutrients such as N, P, Mg, Cu, Cl, Ca, and K, and degradation of minerals and organic substances not previously available to the host (Smith and Read 1997). Several authors have explored a plants' ability to discourage mycorrhizal synthesis on other species. A combination of limited resources and the inhibition of mycorrhiza under *R. maximum* may be the foremost mechanism in the regulation of seedling survival in the southern Appalachians (Nilsen et al. 1999). In eastern hemlock (*Tsuga canadensis)* seedlings, percent mycorrhizal colonization was found to be three times higher outside of *R. maximum* thickets than within (62% compared to 19%, respectively) (Walker et al. 1999). Because of a lack of evidence to support the accumulation of biotoxic substances in the soil under *R. maximum*, it is more realistic to conclude that *R. maximum* has indirect effects of allelopathy on mycorrhiza and subsequently on tree seedlings because the environment below an *R. maximum* canopy is not conducive to mycorrhizal development (Walker et al. 1999). In light of recent data, the allelopathic effect of *R. maximum* on other species is now described as "not likely to be an important cause for the inhibition of seedling survival within thickets of *R. maximum*" (Nilsen et al. 1999).

Little formal research has been conducted specifically on the litter layer properties underneath an *R. maximum* thicket. There are, however, observations and generalizations that have been made about the properties of the litter layer and how they are related to seedling establishment and survival. The thick litter layer composed of the sclerophyllous *R. maximum* leaves may cause difficulty for seed germination because of limited water availability and the inability of seeds to reach mineral soil (Clinton and Vose 1996). Both the water stress and physical barrier characteristic of the litter provide no adversity for *R. maximum* as it is thought that rhododendrons do not produce seedlings within a closed thicket but rather reproduce vegetatively through a process called layering (Plocher and Carvell 1987). Layering allows a plant to reproduce and spread vegetatively when low-hanging branches reach the ground and then are able to root and form a new plant, a clone of the original individual.

Rhododendron maximum and fire

Historically wildland fire is believed to have played an important role in shaping the structure and function of forests in the southern Appalachian Mountains. Scientists have traced the effects of fire on vegetation in North America back to pre-Native American settlement. During this time period, fire was lightning-induced and served to perpetuate pine-grassland ecosystems and adjacent hardwood communities (Van Lear and Waldrop 1989).

After the arrival of peoples from Asia, forest and range fire became much more frequent due to anthropogenic ignition (Van Lear and Waldrop 1989). Native Americans used burning for hunting, fuel management, and the cultivation and encouragement of food source plants (Pyne 1982). The typical Native American fire regime of this time period was characterized by a very short fire return interval (10 – 12 years) and low intensity burning due to a lack of time between burns, during which heavy fuels could not accumulate. This Native American fire regime was then succeeded by a duration of high intensity burning of logging slash at the hands of timber companies in the late 1800s. European settlers of this time were cutting over much of the virgin or first growth forests in the southern Appalachians and leaving large tracts of land with heavy loads of logging slash. The slash then cured and became highly susceptible to wildfires, most of which were caused by sparks from steam-powered harvesting and transporting machines. (Van Lear and Waldrop 1989).

Soon after timber companies dominated burning in the southern Appalachians, the era marked by fire suppression began in the early 20th century (Pyne 1982). After devastating wildfires burned through the western US in 1910, forest policy began to focus on fire protection and eventually led to the passage of the 10 A.M. policy. The 10 A.M. policy stated that any wildfire must be contained before the next day's burning period, or 10 A.M (Pyne 1982). Through tough legislation regarding fire policy and clear monetary losses in wildfire-devastated areas, foresters began to view fire as a negative catalyst for forest health. Few foresters of this time recognized the importance of fire in creating and maintaining ecosystems in the south (Van Lear and Waldrop 1989). This fact explains the origin of many ecosystems that are a result of fire suppression in the south today, including the cove hardwood forests with dense *R. maximum* subcanopies.

Researchers have attributed the recent proliferation of *R. maximum* largely to fire exclusion (Vose 2003, Baker and Van Lear 1998, Phillips and Murdy 1985, McGee and Smith 1967). Periodic low-intensity fire in the southern Appalachians has historically aided in the limiting of *R. maximum* to smaller parcels located more exclusively in stream bottoms and more mesic areas. Thus, land managers have been working to reintroduce a fire regime into forests where *R. maximum* has expanded and begun to negatively affect forest health.

Hooper (1969) documents limited success in rhododendron control through the use of fire and stresses the importance of using a very hot fire, noting that most stems over 1 ½ inches (3.81 cm) in diameter were unaffected by the burn. Similar results were observed by Romancier (1971) when he reported that after a prescribed burn in a rhododendron thicket, only aboveground mortality of *R. maximum* occurred and basal sprouting led to significant competition. Higher intensity prescribed fires in the southern Appalachians successfully reduced the understory dominance of *K. latifolia*, another common ericaceous shrub (Elliot et al. 1999). This reduction in the dominance of *K. latifolia* was transient, however, and was only useful in providing a short duration during which overstory regeneration could out compete the vigorous shrub. *K. latifolia* generally occupies a different ecotone than *R. maximum* in the distribution of southern Appalachian forests. *K latifolia* does possess much of the same crowding and dominance characteristics as *R. maximum*, however, and offers clear insight into the potential effects of prescribed fire on problematic species.

Based on findings by Hooper (1969), Romancier (1971), and Elliot et al. (1999), the eradication of *R. maximum* may not be feasible through the use of prescribed burning only, but may require a combination of several silvicultural treatments. The limited success found using fire to eliminate *R. maximum* is observed when fire was employed to remove an existing thicket. Fire is more effective as a tool to use to hedge *R. maximum* thickets and prevent further spread.

Wildfire

Wildfire in the southern Appalachian mountains is primarily caused by arson and is a formidable threat to both forest health and the safety of structures in remote areas. *R. maximum* is known to have very active fire behavior. Whole forests are in danger of being destroyed by wildfire because *K. latifolia* and *R. maximum* form roughs of highly flammable fuels that allow fire to carry into the hardwood canopy (Van Lear and Waldrop 1989). As increasingly more landowners desire to buy property and build homes at the edges of towns, the fire activity at the wildland-urban interface becomes a pertinent issue. As mentioned, many ecosystems of the southern Appalachian mountains are fire-adapted communities and require maintenance through periodic fire (Van Lear and Waldrop 1989). The threat of fire to persons and property is clear and is exacerbated by the fact that throughout the southern Appalachians *R. maximum* is commonly planted in yards and near homes for its showy flowers and attractive evergreen foliage.

Fuel Loading

Fuel loading is the primary issue when land managers are seeking to predict fire behavior potential and plan control measures. A complete estimate of fuel loading includes forest floor fuels as well as aboveground biomass of herbaceous vegetation and shrubs (Brown et al. 1982). The behavior of a fire across any fuel complex depends on the fire behavior of all living species present, the bulk density of the forest floor, and the specific gravity of dead and downed fuels (Brown et al. 1982). As mentioned, fire behavior in rhododendron thickets can be intense if allowed to reach the subcanopy created by the rhododendrons (Van Lear and Waldrop 1989). Fuel loads in the South can reach tremendous tonnages, and generally the forest understories are the typical fire hazards, representing impenetrable and dangerous thicks (Pyne 1982). It is also held that traditional understory burning throughout the South served to control the density of roughs and kept fuel loadings at a level where devastating wildfire was unlikely (Vose 2003, Brose et al. 2001, Pyne 1982). Though *R. maximum* represents a potentially important fuel source in the southern Appalachians, fuel moisture conditions within an *R. maximum* thicket are usually too wet to allow fire to reach into the canopy and often drought is a pre-requisite for wildfire in these mesic areas.

Other Silvicultural Techniques

The potential effects of dense *R. maximum* thickets on commercial tree regeneration have been recognized since the 1960s when silviculturalists began experimenting with several treatments to manipulate the *R. maximum* dominated understories. In addition to prescribed fire, both mechanical clearing and the use of herbicides have been tried in attempt to create a suitable environment for pine and hardwood regeneration.

Mechanical Cutting

Mechanical cutting or clearing of an *R. maximum* thicket can be accomplished with the use of chainsaws or a tractor equipped with a brush blade and roller chopper (Romancier 1971). Tractors are useful tools in silviculture but can be hazardous to use in steep, mountainous terrain where *R. maximum* is common. In addition to the inherent danger of operating a dozer in the mountains, this type of mechanical control can also lead to significant soil erosion in sensitive riparian areas and is expensive (Romancier 1971). Chainsaw removal offers another option in mechanical cutting. Chainsaw crews are able to work on steep terrain and are more versatile while offering no significant soil disturbance and comparable speed. Such crews are also relatively expensive to operate.

Mechanical cutting is useful only in eliminating the aboveground portion of *R. maximum* thickets. The stumps and rootstocks of the plant are known to persist after disturbance and produce abundant basal sprouts, often replacing one stem with 10 or more sprouts (Plocher and Carvell 1987, Romancier 1971, Hooper 1969) and severely increasing competition. Like fire, it is recommended that the use of mechanical cutting or clearing be used in conjunction with another treatment to kill a meaningful portion of rhododendron (Romancier 1971).

Chemical application

Chemical application has been cited as the most effective individual treatment for the control of *R. maximum* because proper application at the proper time can cause complete mortality of both aboveground and belowground portions of the plant (Romancier 1971). With chemical application it is imperative that the correct mixture in the correct carrier be applied in the most effective manner. Several chemicals have been applied to rhododendrons in control efforts but the most effective have been 2,4,5-T, 2,4-D + dicamba + triclopyr, ammonium sulphamate, glyphosate, imazapyr and triclopyr (Green 2003, Romancier 1971). In 1971 it was documented that the most successful results using chemicals to control *R. maximum* were through the use of a basal spray of 2,4,5-T esters in a fuel oil or kerosene carrier (Romancier 1971). Presently very little fuel oil and kerosene is used as an herbicide carrier as the industry has shifted toward more vegetable-based oils.

Imazapyr (2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-3-

(pyridinecarboxylic acid)) is a systemic herbicide used on a variety of herbaceous, viny, and woody plants (Green 2003, Esen 2000). Imazapyr has been shown to be very effective in the control of *Rhododendron ponticum* L., an equivalent pest species to *R. maximum*. *R. ponticum* is common and problematic throughout the UK and is prevalent in Beech (*Fagus orientalis* Lipsky) forests in the Black Sea Mountain region of Turkey (Green 2003, Esen 2000). Imazapyr has been shown in some cases to give complete control of *R. ponticum* with one application (Green 2003).

Triclopyr ([(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid) is a synthetic auxin-type post-emergence herbicide that is commonly used and effective for woody plant control (Esen 2000, Lewer and Owen 1990). Garlon 4 is an oil-soluble commercial product of triclopyr and, because of excellent plant surface penetration, is generally applied by foliar or basal spray (Esen 2000). Foliar sprays have been used on rhododendrons with much success but are known to be most effective on younger, more succulent sprouts or smaller bushes and seedlings. For mature plants, stem injection and basal spray application are the preferred methods to get maximum translocation of the chemical within the plant (Green 2003). Our study used both basal and foliar spray technique for the application of triclopyr to rhododendron.

The objectives of this study were:

1. Observe the fuel loading of an *R. maximum* thicket before and after implementing seven silvicultural treatments
2. Determine the efficacy of seven different silvicultural options for the control of *R. maximum* as a forest weed.
3. Determine cost effectiveness for each individual *R. maximum* treatment.

Materials and Methods

Site Selection

Three different locations were chosen as replicates for this study (Figure 1):

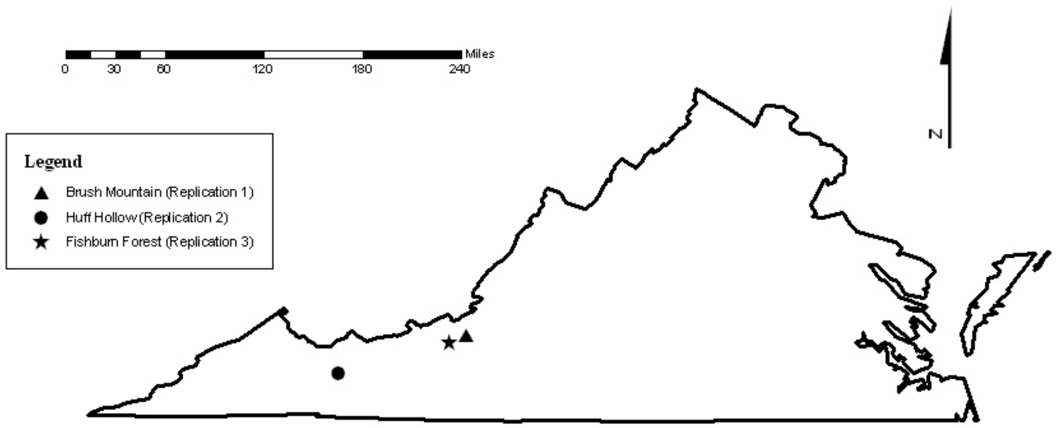

Figure 1: Study site locations. Virginia, USA

Important considerations in site selection were that the area was prescribed for burning in the spring of 2005 or 2006 and that the area had enough accessible and regularly shaped Rhododendron coverage to account for the 2 acres needed for burned plots as required by the plot design. Two of the three sites, Brush Mountain and Huff Hollow, were placed on the Jefferson National Forest in southwestern Virginia (Figure 1).

The Brush Mountain (Replication 1) burn sites are two miles north of Blacksburg, VA, and approximately one mile east of highway 460 while the non-burn sites are on the same slope but adjacent to the highway (Figure 1). The Brush Mountain plots are in drainage areas in both headslope and footslope positions along the north side of the ridge. The burn plots, at an average, are no more than 300 feet (91.44m) from the ridge. Rhododendron coverage at the Brush Mountain site is scarcer and led to more difficult and labor-intensive plot layout. The soil series at these sites is Weikert, a loamy-skeletal, mixed, active, mesic Lithic Dystrudepts. Mean annual precipitation is approximately 42 inches (106.68 cm) and mean annual temperature is approximately 52° F (11.11°C).

The Huff Hollow site (Replication 2) is north of Marion, VA, off of highway 42. The plots at Huff Hollow are positioned along the northwest-facing slope of a small toe ridge near the southwestern terminus of Little Brushy Mountain. This site is notably more mesic and sheltered than the more exposed areas on Brush Mountain. These moist cove-type conditions have created an environment where *R. maximum* can and does flourish to the point of overabundance. Soils at the Huff Hollow site are in the Montevallo series, loamy-skeletal, mixed, subactive, thermic, shallow Typic Dystrudepts. Mean annual temperature at the site is approximately 63° F (17.22°C) and mean annual precipitation is approximately 53 inches (134.62 cm).

The third site chosen for this study is the Fishburn Forest (Replication 3), a 1,400 acre (567 ha) experimental forest owned by Virginia Tech located east of Prices Fork, VA. Burn plots at the Fishburn were located on a north-facing slope near the southern boundary of the forest, just south of Slate Branch creek. Non-burn plots were established primarily along Coal Hollow Road on a northwestern-facing slope along the southwestern corner of the forest.

Plot Design

Each replication of the experiment is a block in a split-plot design and contains eight individual ½-acre (0.202 ha) treatment combinations. Because of the inherent difficulty of burning individual ½-acre treatment areas, the replications (Table 1) were divided into two main plots (burn vs. non burn) and individual treatments were randomly assigned within each main effect plot location. The design includes three levels of the split-plot treatments that are shared by both the burn and non-burn main effects. These treatments are herbicide, cutting, and no treatment (control). The final two treatments are separate from the split-plot design. One plot is the same as the burn and herbicide plot but was performed in the opposite order having the herbicide treatment first, followed by the prescribed burn. The other plot utilized both cutting and subsequent herbicide application to sprouting foliage.

The two main plots within each replication were installed as closely to each other as the rhododendron distribution would allow. Where the distribution required some distance between the main plots, consideration was made to locate plots on sites with similar elevation, slope, aspect, species composition, and rhododendron coverage. Care was taken to ensure that the eight treatment areas were split onto similar sites in order to reduce the variation within the replication (Appendix B).

The ½-acre (0.202 ha) plots were generally made square (148ft x 148ft (45.11 m x 45.11 m)) except for places where *R. maximum* was found to be scarcer and coverage area would dictate otherwise. Sampling within each treatment area was conducted along a transect that diagonally bisected the plot with the origin corner chosen at random. Three different sampling units were observed along the transect including an overstory survey, a live rhododendron stem count, and two separate fuel transects.

Some plots utilized patches of *R. maximum* that followed a drain and were more linear in shape. For these plots the minimum allowable width was 90 ft (27.43 m) and the sampling transect and width of subsequent sampling plots were adjusted to fit the linear shape.

The eight plot treatment areas are:

1. Prescribed fire only
2. Prescribed fire followed by herbicide application
3. Mechanical cutting followed by prescribed fire
4. Herbicide application followed by prescribed fire
5. Mechanical cutting only
6. Mechanical cutting followed by herbicide application
7. Herbicide application only
8. Control

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	2
Burn status – main plots (b)	= br-1	1
Error 1	= (r-1)(b-1)	2
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)	8
		17

Randomized Complete Block (8 treatments)

Sources		df
Replications – blocks (r)	= r-1	2
Treatments – (t)	= t-1	7
Error	= (r-1)(t-1)	14
		23

Overstory Survey

The overstory was sampled within a 1/10th acre (0.04 ha) plot in each treatment area. The 1/10th acre (0.04 ha) plot was arranged along the diagonally bifurcating transect and for square plots was a rectangle 181 ft (55.17 m) by 24 ft (7.32 m). Inside of the plot the sampling consisted of identifying each tree species and then visually classifying all individuals greater than 2 inches (5.1 cm) DBH into 2-inch (5.1 cm) diameter classes. Overstory data were not collected or analyzed as an independent part of this research but were collected for future reference with the possibility that the overstory composition, density or size may lend insight into the rhododendron dynamics on individual plots.

R. maximum Stem Count

The live rhododendron stem count was made within a rectangle that was oriented along the transect through the diagonal of each plot. The rectangle is 1/50th of an acre (0.008 ha) with dimensions of 12 ft (3.66 m) by 73 ft (22.25 m) (Figure 2). Inside of the plot, all living Rhododendron stems were measured for a ground line diameter (GLD) and recorded in 1 cm classes to satisfy allometric stem and foliar equations created by Baker and Van Lear (1998). These regression equations were developed using data from 41 randomly chosen *R. maximum* stems (Baker and Van Lear 1998).

Live rhododendron stems were also recorded both before and after each treatment for the purpose of determining the effectiveness of each treatment and treatment combination on the desired goal of controlling rhododendron growth and spread.

Fuel Transects

Fuel measurements for this study were conducted according to Brown (1974) and Brown et al. (1982). Since the Brown handbook for determining fuel loading was developed primarily for coniferous forests of the western United States, the methods to follow have been slightly modified and expanded to account for differing vegetation and forest floor conditions found the southeastern United States. The variables required to calculate fuel loading values for each treatment area are:

1. Number of intersections of each time-lag fuel class along a transect
2. Squared average quadratic mean diameter of woody debris from fuel classes 1-hr, 10-hr, and 100-hr
3. Diameter of each piece of 1000-hr fuel
4. Specific gravity values for woody debris from each fuel class
5. Litter depth
6. Bulk density value for the litter layer
7. Duff depth
8. Bulk density value for the duff layer
9. Percent slope (slope correction factor)

For this study, two 50 ft (15.2 m) fuel transects with random azimuths were oriented from the midpoint (104ft (31.7m)) of the diagonally bifurcating transect. Each 50 ft (15.2 m) transect would then represent a 6 ft (1.8 m) high vertical plane through which the number of intersections of downed woody material was tallied, according to Brown (1974) and Brown et al., (1982). The number of intersections of 1-hr fuels (<0.25 in (0.6 cm)) and 10-hr fuels (0.25 – 1in (0.6 – 2.5 cm)) were tallied along the transect between 0 and 6 ft (1.8 m). The number of intersections of 100-hr fuels (1 – 3 in (2.5 – 7.6 cm)) was tallied between 0 and 12 ft (3.7 m). The size class greater than 3 in (7.6 cm) in diameter, 1000-hr fuel, was recorded if any piece of that size crossed the plane at any point along the transect. For the 1000-hr fuel class the diameter of the woody material was measured at the point where it crossed the transect and the condition of the piece was classified as either sound or rotten. For rotten logs that had broken into pieces, the log was visually reconstructed to allow for diameter estimation.

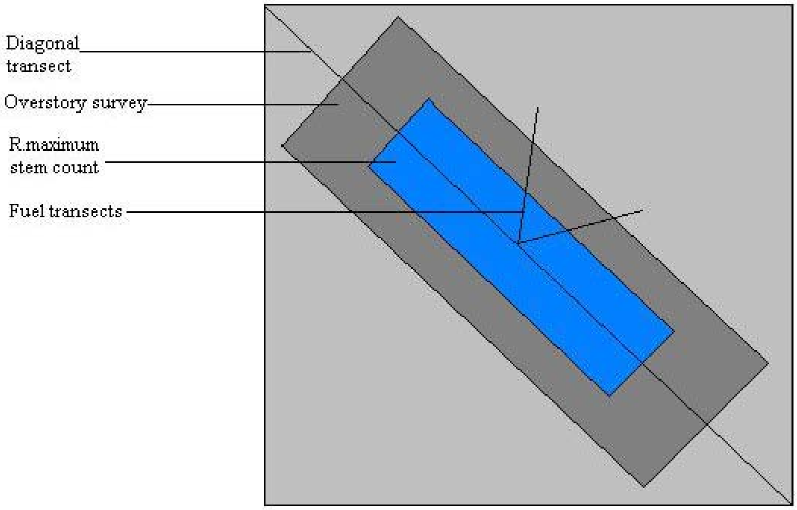

Figure 2: Sampling design. Total plot treatment area is ½ acre (0.202 ha), overstory survey plot is 0.10 ac (0.040 ha), and the interior *R. maximum* stem count plot is 0.02 ac (0.008 ha). From the midpoint of the diagonal transect, two 50 ft. (15.24 m.) fuel transects were oriented in the direction of a random azimuth.

Sub-Sampling of the Fuel Transect

To expand the number of intersections of each time-lag fuel class along the transect into fuel loading measurements, requisite were both specific gravity and mean squared diameter of the material in each time-lag fuel class. To obtain specific gravity measurements, ten pieces of 1-hr fuels, five pieces of 10-hr fuels, and all pieces of 100-hr fuels found to be crossing the transect were collected. If a piece of 100-hr fuel was longer than 6 in (15.2 cm), a sufficiently-sized sample was taken for analysis. Each size class sample was placed in a plastic bag and labeled with site information for future reference. To satisfy each squared average quadratic mean diameter variable of Brown's equations, values were used from Matthews' (2004) master's thesis. For 1-hr fuels, the quadratic mean diameter value was 0.136 in (0.345 cm). The 10-hr fuel class used 0.478 in (1.214 cm), and the 100-hr class used 1.778 in (4.516 cm).

The fuel loading and calculation literature provides specific gravity values for common western US species, but lacks information for use in the southeastern US (Brown 1974). For this reason, specific gravity values relevant to present fuel complexes were calculated based on the fuels encountered on the study sites. For this experiment, specific gravity is defined as the oven dry weight of a piece of woody fuel divided by the green volume (ASTM 2004). The green volume (cm^3) of the collected fuels was determined through submersion testing, or water displacement. The woody pieces were then dried at 149° F (65°C) for at least 48 hours, or until oven dry. Fuel loading calculations for 1-hr, 10-hr, and 100-hr fuels utilized individual specific gravity values from each treatment area instead of a composite value, as other researchers have done (Matthews 2004, Brown 1974).

For 1000-hr fuels, a disk was removed from the material with a saw because of the inherent difficulty of transporting woody materials larger than 3 in (7.6 cm) in diameter. As mentioned, 1000-hr fuels were classified as either sound or rotten. Sound and rotten logs were classified as such in order to distinguish between specific gravity values for the wood. Though no specific gravity values were found in the literature for 1-hr, 10-hr, and 100-hr fuel classes in the southern Appalachians, review of several papers (Adams and Owens 2001, Harmon et al. 2000, Vose et al. 1999, Schowalter et al. 1998, Mattson et al. 1987) and a small subsample (n=10 for each) of 1000-hr fuels resulted in values of 0.5478 g cc^{-1} and 0.2989 g cc^{-1} for sound and rotten wood, respectively. These values are congruous with the values, 0.54 g cc^{-1} and 0.28 g cc^{-1}, found by Matthews 2004

Completion of the fuel loading equations also necessitates bulk density values. Bulk density is a measurement of the oven dry weight of a substance per unit volume. For this study bulk density values were derived for both litter (O_i) and duff (O_e and O_a) layers of the forest floor. The litter layer is defined as the surface layer of the forest floor that consists of freshly fallen leaves, needles, twigs, bark, and fruits. The duff layer is 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). Both litter and duff were taken in 1ft^2 samples at each treatment area and placed in separate plastic bags to transport to the laboratory for oven drying.

Lastly, Brown (1974) and Brown et al. (1982) require a slope correction factor to complete the equations for fuel loading. A clinometer was used to measure the slope factor in degrees when facing downslope, 90 degrees off of the contour. The following formulae were used in determining fuel loading in tons/acre (Brown 1974; Brown et al. 1982):

(a) 0 – 3 inch material:

$$= (11.64 * n * d^2 * s * a * c) / NL$$

where:

$11.64 =$ units conversion constant

$n =$ number of woody piece intersections

$d^2 =$ average squared quadratic mean diameter

$s =$ 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

(a) 3+ inch material:

$$= (11.64 * n * \sum d^2 * s * a * c) / NL$$

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 the sampling plane

(c) duff:

= (dd * dbd * 1.815)

where:

dd = average duff depth in inches

dbd = duff bulk density in lbs/ft^3

1.815 = constant

(c) litter:

= (ld * lbd * 1.815)

where:

ld = average litter depth in inches

lbd = litter bulk density in lbs/ft^3

1.815 = constant

Treatment Methodology

Our research project consisted of the implementation of three different rhododendron fuel treatments on forested sites displaying an abundance of rhododendron. These three individual treatments were mechanical cutting, prescribed fire, and herbicide application and were carried out as follows:

Mechanical cutting

This treatment was implemented individually as well as in conjunction with prescribed fire and herbicide application. Chainsaw crews ranging from two to five persons were employed to cut all living rhododendron stems within the boundaries of each half acre plot. The cutting treatment was performed on each stem below eight inches from the ground in an effort to minimize the difficulty of navigating through sites after treatment and maximize the amount of downed biomass. Rhododendron stems were felled downslope and the slash was left in place. Man-hours required to cut each plot was recorded for subsequent cost analysis.

Prescribed Fire

Prescribed burning was implemented on half of the plots at each of our replications. Brush Mountain (replication 1) and Huff Hollow (replication 2) were burned in the spring of ’05 and the Fishburn forest (replication 3) was burned in the spring of ’06. The former two burns were conducted by the USDA Forest Service while the latter was performed by the Virginia Tech wildland fire crew.

Our primary goal in prescribed burning was to get the maximum amount of rhododendron mortality without compromising overstory health or forest litter and duff conditions. Hooper (1969) found that a head fire was more effective than a backfire in killing rhododendron stems due to the inherent lack of intensity in backfiring. Our objective for prescribed burning became to light a head fire that would burn "hot and steady" (Hooper 1969) through each of our study thickets.

There is little evidence in the literature to suggest that the timing of prescribed burning will contribute to the effectiveness of a burn in killing rhododendron stems. It is worth noting, however, that Hooper (1969) recommended that a late spring fire might have given a better kill of both *K. latifolia* and *R. maximum* for his study. In the late spring and into the summer, root reserves have been depleted and sent to the tops of the plants where the plant is actively growing. This may cause increased mortality of rhododendron stems during burning (Van Lear 2006, pers. comm,). All of our burns were conducted during the spring fire season.

Herbicide Application

Two different herbicide application methods were used in this experiment. Basal application with backpack sprayers was used for the burn and herbicide, herbicide and burn, and herbicide only treatments. The cut and herbicide treatment called for a foliar application to young stump sprouts, also with the use of a backpack sprayer. The backpack sprayers used for this research were D.B. Smith Field King™ deluxe model sprayers with a round adjustable brass nozzle.

Basal bark application was performed with a 20 percent solution of Garlon 4 and a nine percent solution of Stalker in a Hy-Grade EC® vegetable oil carrier. For basal application technicians were instructed to fully coat the bark on the bottom 16 inches of all *R. maximum* stems with the herbicide mixture, being careful to spray as little mixture on the forest floor as possible.

A foliar spray was used exclusively for our cut and herbicide treatment. For this treatment all *R. maximum* stems were felled on the plots and stumps were allowed to sprout before the herbicide treatment was applied. A foliar spray of Garlon 4 in a water carrier was applied at a rate of 5 percent, while Stalker in a water carrier was applied at a two and one half percent solution. Both Garlon 4 and Stalker used Timbersurf 90 as a surfactant for increased leaf cuticle penetration.

Data Analysis

As mentioned in the plot design, this experiment was set up according to a split-plot design. Main effect treatments to be tested were burning and not burning. The three levels of the split-plot were main effect only, main effect and cutting, and main effect and herbicide. Due to the inherent difficulty of and planning for prescribed burning, we were unable to randomize the assignment of main effect treatments over the landscape. Within the main effects, however, random assignment was used for each split-plot. Because our experiment was an unbalanced split-plot design we were unable to use two of our treatment areas in our split-plot analysis. Explained, our seventh and eighth treatment areas were not equal levels of split-plot treatment across the main effects. Thus our split-plot analysis was only able to utilize six out of eight treatment areas in each replicated block.

To utilize all of our data, we also analyzed the experiment as a randomized complete block design with eight individual treatment areas. In performing this analysis, randomization was compromised through the assignment of main plots. This analysis was used to look for hypothesized differences in the data. We set up contrast statements between each different silvicultural tool we used (i.e., burning v. not burning, cutting v. not cutting, and herbicide v. no herbicide). The PROC GLM procedure in the Statistical Analysis System v. 9.1.3 was used for the analysis of all data for this experiment.

Pre-treatment data for each fuel and stem class was placed in the model statement during analysis. If pre-treatment data was significant ($\alpha = 0.05$) for an individual class, it was left in the model as a covariate.

Financial Analysis

For the financial analysis in this project, cost data were collected for each performed treatment. Actual prescribed burning costs for our treatment areas were obtained from Forest Service personnel and were averaged across all burns to give one representative mean cost per acre for prescribed burning (Sutherland 2006, pers. comm.).

Mechanical cutting costs were calculated through the recording of the average number of man-hours required to treat each plot. These man-hours were then averaged by treatment across the three replications. The average number of man-hours then was multiplied by the government standard GS-04 step 1 wage, 13.78 USD, and expanded to a per acre cost (Leonard 2006, pers. comm.).

Herbicide application cost determination required both herbicide costs and labor costs. All herbicides, carriers, and costs were obtained from CWC chemical in Roanoke, VA. Each herbicide and carrier cost was broken down to a per ounce basis, then multiplied by the average application rate for each treatment area. Labor costs were then calculated the same as the mechanical cutting treatment, and added to the herbicide chemical cost.

For the financial analysis portion of this work, financial value through treatment costs were compared against ecological value through treatment efficacy to determine the feasibility and overall value of each treatment.

Results and Discussion

Fire Weather and Behavior

Replication 1 was burned on Tuesday, April 19, 2005. Weather was favorable (Table 2) with temperatures 62 – 75 degrees F (16.7 – 23.9 °C), an RH around 35 during most of the burn, and wind from the WNW at 5 – 7 mph, gusting to 10. A backing fire was lighted with a torch from the ridge on the southern edge of the 600-acre (242.8 ha) burn unit. The fire backed down the slope approximately 150 ft. (45.72 m) before the rest of the burn unit was aerially ignited by the helicopter and ping-pong ball method. Head fire behavior was erratic throughout the unit but burned steady and hot through the *R. maximum* thickets, all located in a headslope position. Flame lengths were generally between 2 and 4 ft (0.61 – 1.22 m) within the thickets and reached 4 to 8 ft (1.22 – 2.44 m) in the relatively open understory. Replication 1 was the only burn unit in our study that achieved target fire behavior. All burn sites at Brush Mountain burned 90 percent or more of the plot area (Table 3). No measurable overstory mortality occurred.

Table 2: Prescribed burn site characteristics, weather, and fire behavior by replication

Variable	Replication 1 (Brush Mountain)	Replication 2 (Huff Hollow)	Replication 3 (Fishburn Forest)
Temperature	62 - 75	62 - 68	42 - 46
Relative humidity (%)	35	26	29
Ignition technique	Helicopter ping-pong ball	Drip torch	Drip torch
Slope position	Headslope	Footslope / adjacent to creek	Footslope / adjacent to creek
Burn size (ac)	630	100	32
Predicted fuel moisture (%) (1-hr / 10-hr / 100-hr)	(9 / 10 / 11)	(9 / 10 / 11)	(9 / 10 / 11)
Expected flame length (ft)*	2.7	2.6	2.7
Actual flame length (ft)	4 - 8	0.5 - 1.5	0.5 - 1.5
Fireline intensity (Btu/ft/s)*	49	46	47

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

Replication 2 was an approximately 1400-acre (566.6 ha) burn unit (Table 2), burned over two days in April 2005. Study plots for this project were burned with drip torch crews on the second burn day, Sunday April 17, 2005. Rep 2 is a much wetter area than replication 1 and resultant fire behavior was lacking. Flame lengths <1 ft. (0.305 m) crept slowly through the understory in most of the study plots only partially consuming the litter layer and consuming none of the duff layer. In addition to lower fire intensity, replication 2 also burned less total ground area than the other two replications (Table 3).

The Virginia Tech wildland fire crew burned the third replication of our experiment on Friday, February 10, 2006. Conditions were fair (Table 2) but not conducive to the elevated fire behavior for which we had planned. Temperatures held steady between 42 and 46 degrees F (5.6 – 7.8 °C) with light and variable winds gusting to 7 mph. Relative humidity on the ridge dropped to 29 at 1500 hours but fire behavior was never strong within the dense shade of the *R. maximum* thicket. Also within the thicket, ice crystals were found below the litter layer on top of the duff layer. Flame lengths generally did not exceed one foot (0.305 m), except on the ridge where some torching of young *P. strobus* regeneration occurred.

Though predicted fuel moistures were the same for all three of our replications, it is unlikely that actual fuel moistures were the same for each of our burns. As slope position was the confounding factor for fire behavior in my experiment, I posit that drier fuels persisted higher on a slope, while wetter fuels remained in the bottoms. Thus Brush Mountain burned hotter and more completely because the plots were in a headslope position, while the other two replications burned lightly due to being lower on the slope.

Table 3: Percentage of ground area burned for each burned plot

Treatment	Brush Mountain	Huff Hollow	Fishburn Forest
B	95	85	90
BH	90	70	80
CB	95	80	90
HB	95	80	85
Mean	94	79	86

Fuel loading

Fine woody fuels

No significant treatment area differences were found for any fuel class in the pre-treatment fuel loading data at the $\alpha = 0.05$ level. In the 1-hr fuel class the burn and herbicide plots and the cut only plots showed a slight significant difference ($\alpha = 0.1$) from the herbicide-only plots (Table 4). For 10-hr fuels, the cut and herbicide and cut only plots were slightly different than the herbicide and burn combination plots. One-hr fuel loading values on sites dominated by *R. maximum* were found to be similar to 1-hr fuel loadings found by other researchers on analogous sites in the southern Appalachian and Piedmont regions. Stottlemeyer et al. (2006) reported between 0.22 and 0.29 t ac^{-1} of 1-hr fuels on xeric to mesic sites in the Chauga ridges region of the southern Appalachians. Waldrop et al. (2004) report between 0.27 and 0.41 t ac^{-1} of 1-hr fuel in forests in the Piedmont region of South Carolina, varying across landscape ecosystem classification. Our 1-hr fuels, ranging from 0.14 to 0.34 t ac^{-1}, were congruent with these findings.

Table 4: 1-hr, 10-hr, and 100-hr pre-treatment fuel loading by treatment area

Treatment area	1-hr fuel loading	10-hr fuel loading	100-hr fuel loading
	- - - - - - - - - - - - tons per acre - - - - - - - - - - - -		
Burn only	0.24767ab[a]	0.5110ab	1.968a
Burn and herbicide	0.14133b	0.4027ab	2.388a
Cut and burn	0.23833ab	0.5637ab	2.428a
Herbicide and burn	0.21133ab	0.7467a	1.817a
Cut only	0.14067b	0.3607b	1.143a
Cut and herbicide	0.23867ab	0.3850b	2.315a
Herbicide only	0.34033a	0.4700ab	1.336a
Control	0.22730ab	0.5100ab	1.213a

[a] Means followed by the same letter within a column are not significantly different at the $\alpha = 0.1$ level.

Burn status, split-plot, and the interaction of burn status and split-plot all showed no post-treatment statistical significance in fuel loading (t ac^{-1}) for 1-hr fuels (Appendix C, Table 1). RCBD contrast analysis showed significant difference in the 1-hr fuel loading between cut plots and non-cut plots (Table 5). This was expected because the cut treatment prescribed felling *R. maximum* stems and leaving them in place, increasing fuel loading. Our cut-only plots, with the least amount of pre-treatment 1-hr fuel loading, showed the heaviest post-treatment fuel loading in the 1-hr class. No literature was found with any information regarding fuel loading after the severing of all *R. maximum* stems over a treatment area.

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

	Mean (t ac^{-1})			
Variable	Burn	Non-burn	F-value	p
1-hr	0.2464	0.2971	0.80	0.3853
10-hr	0.5935	0.6731	2.93	0.1091
100-hr	3.3318	2.9225	0.01	0.9130
1000-hr sound	2.0273	6.6696	6.70	0.0225
1000-hr rotten	3.1363	2.2838	3.59	0.0805
litter	3.2710	4.1400	9.46	0.0082
duff	11.6774	13.3488	0.50	0.4901
total	24.2837	30.3348	2.48	0.1379

Variable	Herbicide	Non-herbicide	F-value	p
1-hr	0.2599	0.2836	0.65	0.4339
10-hr	0.6635	0.6031	0.41	0.5335
100-hr	2.9695	3.2848	0.35	0.5631
1000-hr sound	5.3877	3.3093	5.24	0.0395
1000-hr rotten	2.4866	2.9335	0.54	0.4748
litter	3.7255	3.6856	0.06	0.8161
duff	11.7566	13.2696	0.02	0.8798
total	27.2491	27.3695	0.25	0.6237

Variable	Cut	Non-cut	F-value	p
1-hr	0.3369	0.2327	7.59	0.0155
10-hr	0.7911	0.5386	12.13	0.0037
100-hr	5.0612	1.9667	14.28	0.0020
1000-hr sound	7.1782	2.6506	0.05	0.4024
1000-hr rotten	2.8537	2.6238	0.14	0.7157
litter	4.5157	3.2194	9.72	0.0076
duff	12.8787	12.2937	0.12	0.7350
total	33.6153	23.5257	6.89	0.0200

It was predicted that prescribed burning would have a significant effect in reducing the 1-hr fuel loading when compared to unburned plots however such was not the case. Neither the split-plot nor the RCBD analysis showed a significant burning effect on the 1-hr fuel class. Burn-only plots were found to have increased in 1-hr fuel loading from 0.25 t ac^{-1} to 0.30 t ac^{-1} between pre- and post-treatment (Tables 4 and 6). We attribute the lack of significance of the burning treatment to the mild fire behavior achieved on two out of three of the study sites in this experiment. The increased 1-hr fuel loading on burn only plots is thought to be the result of understory and small shrub vegetation being killed by the fire and falling to the ground. These data clearly indicate the need for consistently repeating prescribed burning in order to successfully manipulate the fuels on a site.

Ten-hr fuels showed a slight relationship in the split-plot variable but no significance in the burn status or interaction term (Appendix C, Table 2). When separated by the LSD procedure, the mean 10-hr fuel loading for the main effect plus cut plots were significantly greater than the main effect only plots. The RCBD contrast analysis picked up the same trend but was highly significant (Table 5). This trend again reflects the large increase in fuel when mechanical treatment is used to control *R. maximum*.

The quantity of 10-hr fuel found before treatment in this study on sites dominated by *R. maximum* was much less than that found by other researchers. Our range of pre-treatment 10-hr fuel loading was between 0.36 and 0.75 t ac^{-1}, roughly half of a combined range, 0.98 to 1.65 t ac^{-1}, found by Stottlemeyer et al. (2006) and Waldrop et al. (2004). The highest value of 10-hr fuel loading reported for this study, 1.41 t ac^{-1}, (Table 6) was found after treatment in the cut and herbicide plot. This value is lower than the 10-hr fuel value found before treatment by Waldrop et al. (2004) in mesic areas in the piedmont region of South Carolina. It ultimately unclear why the 10-hr fuel loading for this study was comparatively less than other research has shown. It is possible however that the dense *R. maximum* canopy is “catching” and holding these fuels as they fall from the overstory, leading to decreased 10-hr fuel loading on the forest floor. It is also speculated that due to decreased wind and precipitation effects, fuels may have limited mobility on the forest floor through an *R. maximum* slick, resulting in lower observed fuel loading values.

Statistical significance for 100-hr fuels followed much the same pattern as the 10-hr fuels (Table 5 and Appendix C, Table 3). Split-plot mean separation analysis revealed that the main effect plus cut plots were significantly different from both the main effect only plots and the main effect plus herbicide plots. RCBD analysis also showed cutting to be highly significant in explaining 100-hr fuel loading (Table 5).

Herbicide treatment was not expected to be important in any relationship to fine woody fuel loading. It was predicted that any *R. maximum* kill attained by the herbicide treatment would not result in any fallen fuel within the months of time that passed between treatment and re-measurement of the plots. Statistical analyses supported this prediction on all sites and over all fuel classes for our experiment. Fuel structure on the herbicide plots is expected to change in the future however, and will be monitored in future research.

Table 6: 1-hr, 10-hr, and 100-hr post-treatment fuel loading by treatment area

Treatment area	1-hr fuel loading	10-hr fuel loading	100-hr fuel loading
	- - - - - - - - - - - - tons per acre	- - - - - - - - - - - -	
Burn only	0.2987a[a]	0.3447d	2.842b
Burn and herbicide	0.2053a	0.6493bcd	2.550b
Cut and burn	0.4450a	1.0677ab	10.178a
Herbicide and burn	0.1837a	0.4620cd	2.483b
Cut only	0.4997a	0.9550abc	5.072ab
Cut and herbicide	0.4590a	1.4143a	9.232a
Herbicide only	0.2997a	0.7777bcd	1.635b
Control	0.1717a	0.5123bcd	1.434b

[a] Means followed by the same letter within a column are not significantly different at the $\alpha = 0.1$ level.

1000-hr fuels

According to Brown (1974), 1000-hr fuels are those woody fuels which are greater than 3 inches in diameter. Brown outlined the distinction between two categories of 1000-hr fuels, sound and rotten. The importance of recognizing the two categories, from a fuel loading perspective, lies primarily in the difference in density and subsequent mass of sound and rotten roundwood.

Both 1000-hr sound and rotten fuels in our study were highly variable across the landscape. Different analyses presented different relationships. Split-plot analyses showed no significance in burn status, split plot, or the interaction of burn status and split plot for either sound or rotten 1000-hr fuel. The RCBD analyses used pre-treatment data as a covariate in the post-treatment analyses for both sound and rotten material. For sound fuels, burned plots were significantly different than non-burn plots, and herbicide plots were significantly different from non-herbicide plots (Table 5). Burn plots had less 1000-hr sound fuel loading than non-burn plots, and herbicide plots had greater 1000-hr fuel loading than non-herbicide plots (Table 5). It is possible that fire consumed the 1000-hr sound material on the burned plots however it is assumed that this is not the case, as we did not see evidence that the fire significantly consumed any of the other fuel classes. In the same way, herbicide plots may show a greater amount of 1000-hr sound fuel because the herbicides killed the *R. maximum* plants and caused them to fall. This conclusion, however, seems illogical as systemic herbicides take time to kill target vegetation and do not result in immediate downing of large woody plants. Due to the heterogeneity of course woody debris across the landscape, it is thought that the sample size for these fuels was not large enough to pick up or accurately represent any significant differences in fuel loading trends that could be applied to a whole forest unit.

Litter, duff, and total fuel loading

As previously mentioned, the litter layer in a forest is defined as the surface layer of the forest floor that consists of freshly fallen leaves, needles, twigs, bark, and fruits. Available literature supports the reduction of the litter layer mass of the forest floor by as little as 10 percent or as much as 50 percent after prescribed burning or a fell and burn treatment (Clinton et al. 1998, Elliot et al. 2002, Vose and Swank 1993). Our data show a 43 percent reduction (t ac^{-1}) in litter loading averaged across all treatment areas after low intensity prescribed burning.

In the RCBD post-treatment analysis, prescribed burning was shown to have significant effects on the litter layer of the forest floor (Table 5 and Appendix C, Table 6). The average depth of the litter layer across the twelve burn plots changed from 5.1 inches (12.3 cm) before burning to 1.8 inches (4.6 cm) after burning (data not shown). Prescribed burning on *R. maximum* sites is thus aiding oak regeneration through improved seedbed properties as Wang et al. (2005) report that optimum *Quercus alba* L. acorn germination occurs under litter depth of 2.5 to 5.0 cm.

Split-plot and RCBD analysis reveal the same trend in reporting the relationship between litter loading and mechanical cutting. Split-plot analysis does not show a burn status by split-plot interaction but does show that the split-plot term is significant (Appendix C, Table 6). Through Tukey's mean separation we found that the main effect plus cutting plots had significantly more litter mass than main effect and herbicide and main effect only plots. Grouped into the main effect plus cutting plots which are showing increased litter is the cut and burn plot. It is unclear exactly how a burned plot is showing increased litter loading after burning as burning was previously shown to reduce litter loading. Our thought is that the effects of burning on the litter were so dramatic that they were able to mask the increased litterfall from the downed vegetation in the cut and burn treatment.

RCBD analysis showed strong significance for the litter variable in the contrast statement for mechanically cut areas (Table 5). Our conclusion is that the overall fuel loading increase we see in cut areas is not only from downed woody vegetation but also from increased freshly fallen litter from cut *R. maximum* stems.

Duff loading across our treatment areas was consistently higher than other researchers have found. Clinton et al. (1998) report, before treatment, between 6.7 and 9.8 t ac^{-1} of duff across three white pine (*P. strobus*) and oak-dominated (*Quercus spp.*) stands on the Blue Valley Experimental Forest in Macon County, NC. Our mean duff loading before treatment ranged from 6.6 to 16.7 t ac^{-1}. These values are highly variable but represent the increased duff depth beneath *R. maximum* slicks in the southern Appalachians.

Clinton and Vose (1996) described a thick, recalcitrant litter layer under *R. maximum* thickets. Boettcher and Kalisz (1990) explained that this deep *R. maximum* litter layer, through leaching and exuding of phenolics and other organic compounds, seemed to interfere with the ability of the mineral soil to retain basic cations. Species composition and subsequent litter dynamics are import factors in explaining soil pH, macroinvertebrate populations and humus quality and depth over a landscape (Ponge and Chevalier 2006, Muys et al. 1992 (a)). Specifically, slow litter turnover causes soil acidification resulting in decreased soil macroinvertebrate populations (Muys and Lust 1992 (b)). Sclerophyllous litter and lacking soil macroinvertebrate population observations, compounded with extremely low light penetration and relatively cool conditions underneath *R. maximum* begin to explain the presence of a thick duff layer.

Duff depth, expressed as duff fuel loading, was not affected by any of our silvicultural treatments. It was presumed that prescribed fire would be our only treatment able to affect duff depth over the short term, and then only if a moderate- to high-severity burn with relatively long residence time was achieved. As our burning was exclusively low-severity with short residence time, our expectation was as observed, no significant differences in duff loading. This finding concurs with Waldrop et al. (2004), who found that low-intensity burning had no impact on the duff layer on mesic sites.

Total fuel loading showed no post-treatment significant differences for the burn status, split-plot, or interaction term. Total fuel loading also showed no significant differences across the eight treatment areas in the RCB design. The only trend drastic enough to be detected in the total fuel loading statistical analysis was the contrast statement analysis for mechanical cutting (Table 5). The cut plots again showed a significantly higher fuel loading than non-cut plots.

Because of the drastic nature of mechanical cutting, its treatment effects on changing the structure of fuel loading on *R. maximum*-dominated sites are seen in all of our analyses. It is our thought that while our other treatments showed few initial trends, they are potentially viable and effective treatment options. Prescribed burning, for example, may require multiple burns to show any appreciable change in fuel loading or restore forest health (Brose et al. 2001, Van Lear and Waldrop 1989).

As no literature was found to discuss herbicide application as related to fuels, it is unclear how our herbicide treatment will affect the fuel loadings on our sites. If maximum kill is achieved with our herbicides, then we expect there will be a large but continuous increase in the woody fuel biomass found on the forest floor as *R. maximum* stems die off and begin to fall. In treatment areas where herbicides caused little kill, it was observed that the stress put on the *R. maximum* plants sometimes caused partial crown mortality or increased leaf drop. I posit that herbicide application may cause a one-time increase in litter loading in *R. maximum* slicks in the southern Appalachians, however future fuel monitoring is necessary to determine if this phenomenon is detectable.

***Rhododendron maximum* live stems**

Live stem counts provide a simple way to observe and document the success of vegetation control measures. As the purpose of my silvicultural treatments was to achieve the maximum amount of mortality of *R. maximum* stems, a live stem count was the most useful monitoring technique available.

Pre-treatment stem data showed no statistical differences across treatment areas. For post-treatment analyses, pre-treatment data was used as a covariate only when the pre-treatment data showed statistical significance in the model ($p < 0.05$).

Mechanical cutting

The mechanical cutting treatment showed the most dramatic post-treatment results and consistent significance over all stem classes. When using contrast statements comparing cut v. non-cut in the RCB design, cutting showed a significant effect in the number of stems per acre for all stem classes except the four cm, 16 cm, and the 18 cm (Table 7). It is thought that the 16 and 18 cm classes failed to show significance because missing or null values may have masked the effects of the treatment (i.e., few sites had *R. maximum* stems of that size within the sampling area). Mean separations using LSMEANS in the GLM procedure of SAS showed that the cut plots always presented with more stems per acre in the two cm class than the non-cut plots. These finding are congruous both with our expectations and the findings other researchers. Severing the aboveground portion of *R. maximum* alone has been long-reported to lead to heavy basal sprouting, sometimes replacing one stem with 10 or more sprouts (Plocher and Carvell 1987, Romancier 1971, Hooper 1969).

Table 7: Stem class contrast statement analysis within a randomized complete block design

	Mean (stems ac^{-1})			
Variable	Burn	Non-burn	F-value	p
2 cm	3791.67	4470.83	0.45	0.6500
4 cm	95.83	312.50	1.88	0.1938
6 cm	133.33	204.17	1.24	0.2853
8 cm	158.33	108.33	0.16	0.6954
10 cm	112.50	91.67	0.01	0.9360
12 cm	120.83	87.50	0.62	0.5305
14 cm	62.50	33.33	1.17	0.2691
16 cm	20.83	8.33	1.36	0.2759
>18 cm	12.50	8.30	1.42	0.6186
total	4508	5325	0.35	0.5726

Variable	Herbicide	Non-herbicide	F-value	p
2 cm	1429.17	6833.33	9.65	0.0024
4 cm	137.50	270.83	0.76	0.3987
6 cm	162.50	175.00	0.09	0.7733
8 cm	150.00	116.67	0.35	0.5643
10 cm	129.17	75.00	1.86	0.1952
12 cm	141.67	66.67	1.39	0.1699
14 cm	50.00	45.83	0.02	0.8718
16 cm	25.00	4.17	2.89	0.0797
>18 cm	12.50	8.33	0.14	0.6186
total	2238	7596	8.84	0.0020

Variable	Cut	Non-cut	F-value	p
2 cm	7577.78	2063.33	9.06	0.0027
4 cm	0.00	326.67	3.02	0.1060
6 cm	0.00	270.00	18.42	0.0009
8 cm	0.00	213.33	22.02	0.0004
10 cm	0.00	163.33	15.35	0.0018
12 cm	0.00	166.67	7.25	0.0076
14 cm	0.00	76.67	7.56	0.0110
16 cm	0.00	23.33	2.33	0.0596
>18 cm	0.00	16.67	5.44	0.0687
total	7578	3320	7.58	0.0113

Our cut-only plots displayed a heavy increase in the mean number of two cm class stems, from 1,983 to 10,667 stems per acre (4,901 to 26,358 stems ha^{-1}), between pre-treatment and post-treatment data collection. This increase equates to replacing every severed stem with approximately 5.4 sprouts on the cut only plots. Sprouting observed on cut only plots was vigorous. It is unknown how vigorous the sprouts will continue to be as the increase in size and demand more nutrients from the site. In areas where downed woody slash was inordinately heavy over stumps, sprout vigor was often noticeably decreased. This observation is anecdotal but is believed to be the result of heavy shading by the woody slash.

All other classes that reported significance in the mechanical cutting contrast showed the opposite trend than that of the two cm class. The six cm, eight cm, ten cm, 12 cm, 14 cm, and total stems per acre classes had significantly less live stems per acre than the non-cut plots after treatment (Table 7). Performing the mechanical cutting treatment on *R. maximum*-dominated sites took a maximum of 50 man hours ac^{-1} and a minimum of eight man hours ac^{-1}.

Herbicide application

Herbicide application demonstrated limited effectiveness in the control of large *R. maximum*. The only stem class showing significance in the contrast statement analysis was the two cm class (Table 7). Plots that had been sprayed with herbicide had a significantly lower mean number of two cm stems per acre, 1,429 stems per acre (3,531 stems ha^{-1}) as compared with 6,833 stems per acre (16,885 stems ha^{-1}).

No other stem class displayed significance for the herbicide application contrast statement. Interestingly, the effectiveness of herbicide application in controlling smaller stems was substantial enough to mask the null effects of the same treatment on all larger stems, as the overall number of stems per acre variable showed significance in the herbicide v. non-herbicide contrast (Table 7).

Table 8: Actual herbicide usage rates for the control of *Rhododendron maximum* by herbicide and application type

Treatment	Application	Herbicide	Rate (lbs ai ac^{-1})	 (lbs ae ac^{-1})
Burn + herbicide	basal	Garlon 4	8.54	6.14
		Stalker	1.66	1.35
Herbicide + burn	basal	Garlon 4	9.53	6.85
		Stalker	1.72	1.41
Cut + herbicide	foliar	Garlon4	2.27	1.63
		Stalker	0.44	0.36
Herbicide only	basal	Garlon 4	6.90	4.96
		Stalker	1.88	1.54

It is unclear exactly why both imazapyr and triclopyr failed to cause mortality in larger *R. maximum* stems. Green (2003) reported complete control of *Rhododendron ponticum* in the UK after one application of imazapyr. One of the three replications in our experiment is an extremely moist area, perhaps more moist than a traditional *R. maximum* thicket. Care was taken to ensure that the rhododendron stems were dry enough to hold and absorb the chemical mixture, however it is possible that the stems were never dry enough to allow maximum penetration of the chemical into the cambium of the plants. It is thought that perhaps the chemical mixture and application rate (Table 8) did not allow enough active ingredient be translocated within the plant and cause mortality, and also that basal chemical application is not as effective on *R. maximum* as has been documented on both *R. maximum* and other rhododendrons in the past. (Romancier 1971, Hooper 1969).

More recent research shows that the herbicide application techniques for controlling rhododendron species are shifting away from basal application alone and toward more successful cut stump- and foliar spray-type applications (Esen and Zedaker 2004, Green 2003, Romancier 1971, Hooper 1969). Because of the success of these treatments and the relative ineffectiveness of our basal herbicide application alone treatment it is suggested that herbicides be used in conjunction with another treatment (cutting or burning) or applied as a foliar spray to young plants.

Prescribed burning

No statistical significance was found for the prescribed burning treatment across any of the *R. maximum* stem classes. These findings are consistent with past research, which indicated that prescribed burning alone was relatively ineffective in controlling *R. maximum.* Hooper (1969) documented that a hot fire was only effective for the elimination of small stems and Romancier (1971) found that burning alone caused significant basal sprouting. Our research did not show statistical evidence of basal sprouting after prescribed burning in rhododendron thickets (Table 7). It is possible that our burns did not achieve high enough intensity to incur the requisite stress on the rhododendrons to cause them to sprout. Our conclusions agree with past researchers; prescribed burning alone shows little promise in controlling or eradicating *R. maximum* after it has already established itself on a site.

Prescribed burning combination treatments

For our experiment we paired prescribed burning with two other treatments to maximize *R. maximum* mortality. Two prescribed burning and herbicide treatments were performed, in opposing sequence, along with one prescribed burning and cutting treatment. Prescribed burning in combination with herbicide application showed promise in both time sequences. Our burn and then herbicide treatment reduced the total number of stems per acre from 1383 to 1200 (3418 to 2965 stems ha^{-1}). The herbicide and then burn treatment reduced stems per acre from 2333 to 1300 (5766 to 3212 stems ha^{-1}).

Our final prescribed burning combination treatment was mechanical cutting followed by prescribed burning. This treatment was expected to be effective in controlling larger stems with the cutting treatment as well as subsequent sprouting with the burn treatment. The mechanical cutting treatment was successful, however poor fire behavior again confounded our hopes for high *R. maximum* mortality. After completing both cutting and prescribed burning, these plots showed a net non-significant increase in fuel loading. This fact explains why the mortality was not as high as expected. It was hypothesized that the large amount of downed woody fuel would elevate fire behavior and intensity on cut and burn sites, resulting in increased mortality. Such was not the case as little felled fuel was consumed and post-treatment sprouting remained heavy.

Prescription for the cut and burn plots was to fell all stems in the half-acre plots, then allow them several months to dry and cure for the following burn treatment. This window of time for curing was not achieved as two of the three replications were burned about one month after cutting. The third replication burned 5 months after cutting, but was still ineffective in consuming the freshly downed fuel. It is recommended that the window of time to allow *R. maximum* to cure be no less than one year after felling, in order to have the ability to obtain heightened fire behavior.

Mechanical cutting and herbicide

The cut and herbicide plot was our most labor-intensive treatment area, felling all stems in the plot and then treating the resultant basal sprouts with a foliar herbicide application. This treatment caused a net increase in the total number of stems per acre, from 3883 to 4300 stems ac^{-1} (9596 to 10626 ha^{-1}). Despite the increase in stems per acre, the cut and herbicide treatment showed an average of 96.3% reduction in total basal area of live *R. maximum* stems, the most effective control of *R. maximum* of all of our treatments.

The cut and herbicide treatment, like the other cut treatments, left stems in no class other than in the two cm class. The stems that remained were sprouts from the stumps and root collars of the residual *R. maximum* plants. The herbicide treatment was successful in targeting these sprouts, however was unable to completely control all sprouting. It should be noted that remaining sprouts that persisted after the foliar herbicide application were of poorer quality than those found in other cut plots and may not possess the required vigor to repopulate a site with an *R. maximum* thicket of a pre-treatment proportion.

Financial analysis

From an ecological perspective the success of vegetation control and fuel reduction treatments are simple to quantify. The simplicity of that success, however, is confounded by its own feasibility in a real-world setting. The forest systems under which *R. maximum* usually grows tend to be of lower value, or at best slow growing, causing long rotation length and delayed revenue. Managers of mountain tracts, then, who are interested in eradicating *R. maximum* from a site are interested not only in the most efficacious treatment or treatment combination but also in the most cost efficient method of *R. maximum* control. Private land managers are seeking the best treatment or treatment combination in terms of the getting the best "bang for their buck."

It is important to understand that for our financial evaluation we used only sites that were completely dominated by *R. maximum*. It is the understanding of the researchers that rhododendron clearing work is often contracted out to private contractors, who quote a price for clearing all rhododendron on a larger tract, where *R. maximum* may only cover ten or 20 percent of the area of the tract. Our per acre costs as presented, then, are known to be well outside of the acceptable realm for traditional forestry practices. I posit that the high per acre costs of clearing heavy rhododendron sites will be defrayed through the likelihood that most timber tracts are not completely dominated by the ericaceous shrub. The labor rate for all treatments used for the financial analysis, 13.78 USD hr^{-1}, was the standard rate for a government GS-04 step 1 pay grade (Leonard 2006, pers. comm.). Figure 3 is a summary of each treatment cost and the subsequent effectiveness of each treatment in controlling rhododendron, where effectiveness was measured in post-treatment basal area (ft^2)

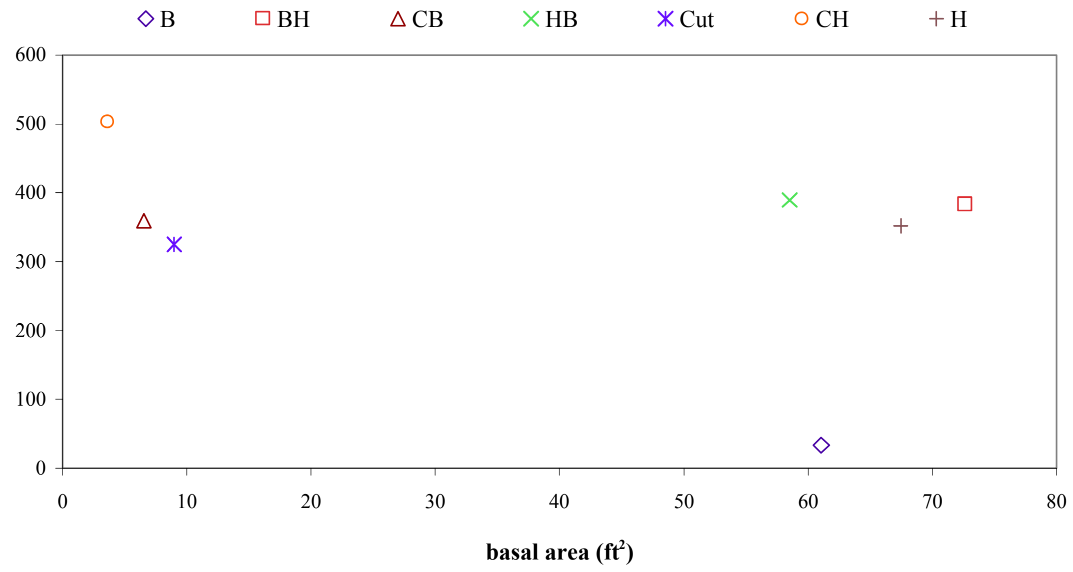

Figure 3: Treatment effectiveness (post-treatment basal area) vs. per-acre cost

Prescribed burning

The cost of prescribed burning in the southern Appalachians is highly variable. It is generally accepted, however, that burning more area at one time will drive costs down for that burn (Sutherland 2006, pers. comm.). US Forest Service personnel conducted two of our three burns on US Forest Service land. Our cost data for prescribed burning was thus obtained from US Forest Service records. Sutherland (pers. comm. 2006) reported that our replication two (1350 ac, 546 ha) burn cost 18 USD ac^{-1} on the ground, while our replication one (655 ac, 265 ha) burn cost approximately 20 USD ac^{-1}. These figures are actual implemented ground costs including labor, fuel, helicopter time, etc. Total costs for these burns were higher because of the added costs of preparation labor and equipment. The US Forest service is appropriated government funds in the amount of 34 USD ac^{-1} to carry out all prescribed burning operations. This government-appropriated rate was the cost that was used when performing our financial analysis for prescribed burning.

Mechanical cutting

For this study we used chainsaw crews of two to five laborers to perform the mechanical cutting treatments in *R. maximum* slicks. We found that the amount of time required to cut all *R. maximum* stems on an acre was widely variable and dependent on the density of rhododendron onsite. Pre-treatment stem counts ranged from 300 stems ac^{-1} to 5,950 stems ac^{-1}. Subsequently, the number of man-hours required to perform the mechanical cutting treatments ranged from eight man-hours ac^{-1} to 50 man-hours ac^{-1}. The average time to clear one acre of *R. maximum* with a chainsaw crew was 23.6 man-hours. This average time equates to a mechanical cutting cost of 325 USD ac^{-1}. The number of man-hours required to complete a mechanical cutting treatment showed a moderate relationship with *R. maximum* thicket density (stems ac^{-1}) (Figure 4).

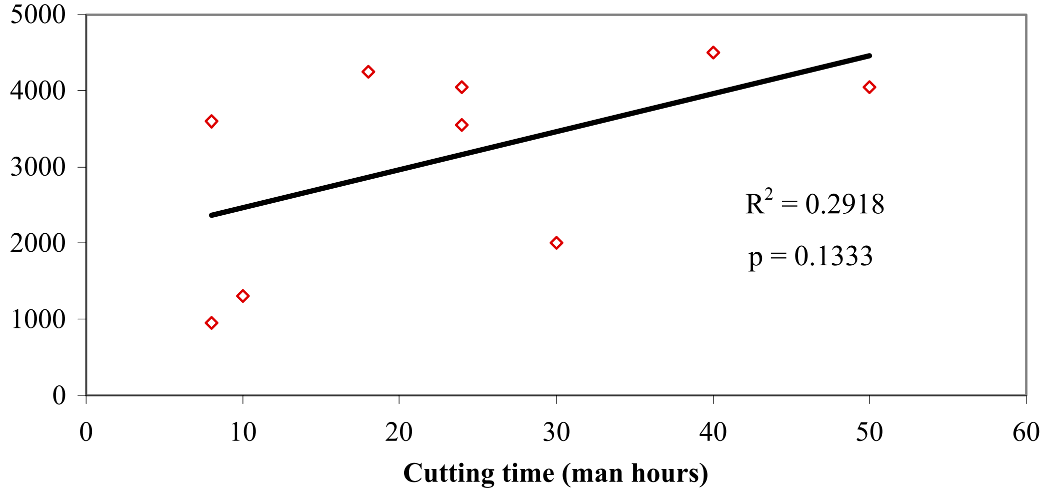

Figure 4: Number of man hours required to perform mechanical cutting treatment versus stem density in an *R. maximum* thicket in the southern Appalachians

Herbicide application

The cost of weed control through herbicide application is dependent on the application method and site characteristics, chemical cost, and chemical application rate. Different treatments and application types produced different labor costs for each treatment area. One of our treatment areas, the cut and herbicide plot, proved to be more labor-intensive than all others because of the inherent difficulty of climbing through and over rhododendron slash with a backpack sprayer. This difficulty was evident in the comparison of man-hours required to complete the work as the cut and herbicide plots took an average of 1.3 hours longer to perform than all other plots. Herbicide application labor rates were thusly dependent on each individual treatment and were calculated based on the mean number of man-hours required to treat each treatment area (Table 9).

Table 9: Herbicide application labor costs by treatment area and application type on *Rhododendron maximum*-dominated sites

Treatment	Application	Treatment time (man hrs)	Labor cost (USD ac^{-1})
Burn + herbicide	basal	3.3	89.57[a]
Herbicide + burn	basal	2.8	78.09
Cut + herbicide	foliar	4.4	121.72
Herbicide only	basal	3.3	91.87

[a] Labor cost determination = Treatment time X $13.78/hr (GS-04 step 1)

Chemical cost is another important factor in determining the total cost of an herbicide operation. Our experiment used triclopyr as Garlon 4 and imazapyr as Stalker. When comparing chemical cost only, Stalker was most expensive at 2.70 USD $fl.oz^{-1}$, while Garlon 4 was 0.74 USD $fl.oz^{-1}$. Our vegetable oil carrier used in basal application was approximately 0.05 USD $fl.oz^{-1}$. The Stalker, applied basally at a nine percent solution was also more expensive per gallon of mixture at 37 USD gal^{-1}. Garlon 4 mixed at a 20 percent solution was 24.23 USD gal^{-1}. Foliar application rates were five percent for Garlon 4 and two and one half percent for Stalker. These rates equated to a foliar mixture cost of 4.74 USD gal^{-1} and 8.63 USD gal^{-1}, respectively. The combined costs for the each treatment type and chemical type are presented as "Herbicide cost" in Table 10.

Table 10: Summary of treatment costs by treatment area for prescribed burning, mechanical cutting, and herbicide application

Treatment	Burning cost[a] (USD ac^{-1})	Cutting cost[b] (USD ac^{-1})	Herbicide type	Herbicide cost[c] (USD ac^{-1})	Total cost (USD ac^{-1})
Burn only	34	-	-	-	34
Burn + herbicide	34	-	Garlon 4	300	334
			Stalker	398	432
Cut + burn	34	325	-	-	359
Herbicide + burn	34	-	Garlon 4	312	346
			Stalker	399	433
Cut only	-	325	-	-	325
Cut + herbicide	-	325	Garlon 4	165	490
			Stalker	191	516
Herbicide only	-	-	Garlon 4	261	261
			Stalker	442	442

[a] based on federal funds appropriated for prescribed burning (Sutherland 2006, pers. comm.)

[b] based on average labor time and a GS-04 step 1 wage rate of 13.78 USD hr^{-1}

[c] determined through the addition of chemical cost and average labor cost

Conclusions

The effects of our individual and combination treatments were widely variable and revealed differing trends in forest fire fuel management and woody competition control. It was discovered that the individual treatments alone were mostly ineffective in meeting our objectives and thus require subsequent treatments to fulfill these objectives. As there are many possible goals in the eradication of *R. maximum*, the optimum treatment or treatment combination for the landowner or land manager will depend solely on the objectives for the subject property.

The most drastic treatment effects on fuel loading were observed in all of the mechanical cutting plots. It only makes sense that severing all *R. maximum* stems on a plot will increase fuel loading and the possibility of wildfire. Mechanical cutting alone was also found to increase the number of stems on a site, potentially causing more complete domination of the understory by *R. maximum* than before treatment. Mechanical cutting alone seemed to cause more harm than good but may be an effective beginning to an aggressive sprout and fuel management procedure. If a rigorous prescribed burning program is implemented after mechanical cutting of *R. maximum*, the freshly downed fuel will eventually break down and burn. The time limitation of this study disallowed any long-term fuel loading monitoring, so these effects were not realized on our treatment areas.

It remains unclear how the aboveground biomass of sprouting *R. maximum* stems will effect the live fuel and wildfire potential on a site, however it is presumed that successive prescribed burns in cutover sites will reduce the vigor of sprouting *R. maximum* stems and eventually favor early-successional grasses and forbs. Mechanical cutting followed by prescribed burning, as all combination treatments, is an expensive endeavor but can be spread over several years to help offset steep costs.

Basal application of herbicides alone for the control of *R. maximum* was ineffective in this study. The application of herbicide alone is also expensive and not recommended without using it in combination with another treatment. The two time-series combinations of basal herbicide application and prescribed burning, however, showed the two smallest values of both the two-cm and total stems per acre *R. maximum*.

The two-cm class is a good indicator of future viability and expansion of a rhododendron slick, and appeared to have been well controlled through the combination of prescribed burning and herbicides. Importance of the sequence of the herbicide and burn treatments was not detected while it seemed very important that the initial stress on the plants from the first treatment be high, in order to obtain any mortality from the second treatment. It is the recommendation of the researchers, however, that a hot fire be used first to pre-weaken and dry the *R. maximum* stems, causing them to be more receptive of the following basal herbicide application. Again basal herbicide application in a rhododendron thicket was costly, but may be the best option in *R. maximum* control when combined with prescribed burning.

It is known that natural fires historically burned to the edges of rhododendron thickets, causing them to remain small, in and adjacent to wetter habitat. Due to fire suppression these thickets have expanded and caused large, contiguous areas that are completely dominated by not only the ericaceous shrub, but also the increased moisture and decreased air circulation inherent under the dense shade of *R. maximum*. As forest managers now look to eliminate these *R. maximum* slicks, it is unclear whether the re-introduction of the lacking natural fire component will show success in altering these communities to a pre-suppression state.

Prescribed burning alone, in this study, showed virtually no success in altering the plant dynamics on an *R. maximum*-dominated site after one burn. It is thought that successive annual or biennial prescribed burning through rhododendron slicks may cause increased air circulation, and subsequent drying may allow for increased fire behavior resulting in increased *R. maximum* mortality. More research is needed on the effectiveness of repeated prescribed burns on the vegetation and fuel dynamics in an *R. maximum* thicket. Prescribed burning is very cost-efficient, however, and may be a feasible option even if multiple prescribed burns are required to successfully control rhododendron.

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Appendix A - Site Characteristics

Table 11: Plot characteristics for Brush Mountain, Huff Hollow, and Fishburn Forest. Plot identification: R (replication), H (herbicide), B (burned), and C (cut).

Plot	Sample Date		Slope (%)	Aspect
	Pre-treatment	Post-treatment		
R1B	3/29/05	10/18/05	25	1
R1BH	3/30/05	10/18/05	40	344
R1CB	4/1/05	8/9/06	50	345
R1HB	3/30/05	10/18/05	20	333
R1Cut	7/22/05	8/9/06	5	340
R1CH	7/20/05	8/9/06	7	340
R1H	5/30/06	8/23/06	6	331
R1Control	6/6/06	8/9/06	40	332
R2B	3/19/05	10/10/05	15	310
R2BH	3/19/05	7/24/06	15	333
R2CB	3/19/05	10/10/05	20	306
R2HB	3/19/05	10/10/05	20	338
R2Cut	5/23/05	10/21/05	35	330
R2CH	6/20/05	7/24/06	23	332
R2H	5/23/05	10/21/05	26	320
R2Control	6/21/05	7/24/06	28	325
R3B	9/1/05	7/11/06	35	21
R3BH	9/1/05	8/22/06	25	304
R3CB	8/25/05	7/11/06	38	3
R3HB	9/13/05	8/22/06	8	322
R3Cut	4/4/06	7/11/06	45	10
R3CH	4/4/06	8/23/06	55	355
R3H	4/11/06	8/22/06	35	309
R3Control	4/11/06	8/23/06	30	309

Appendix B – Maps

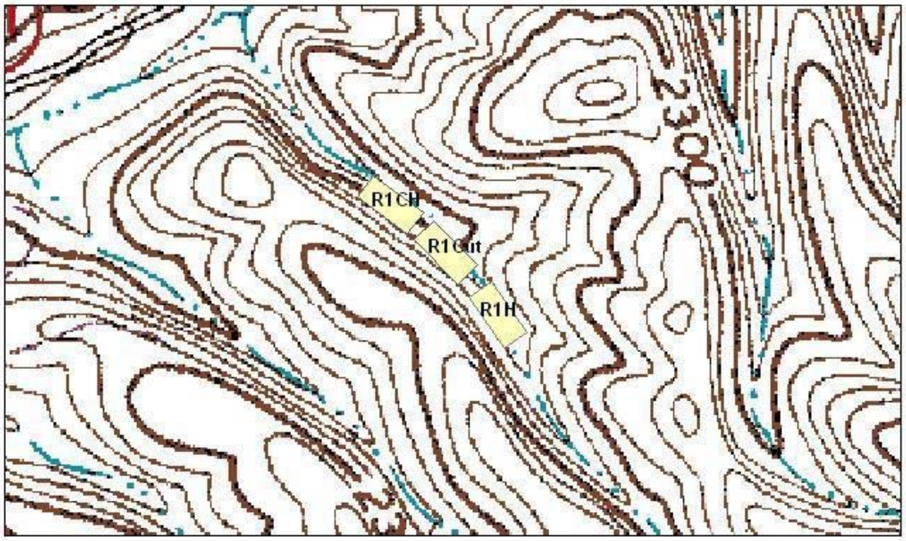
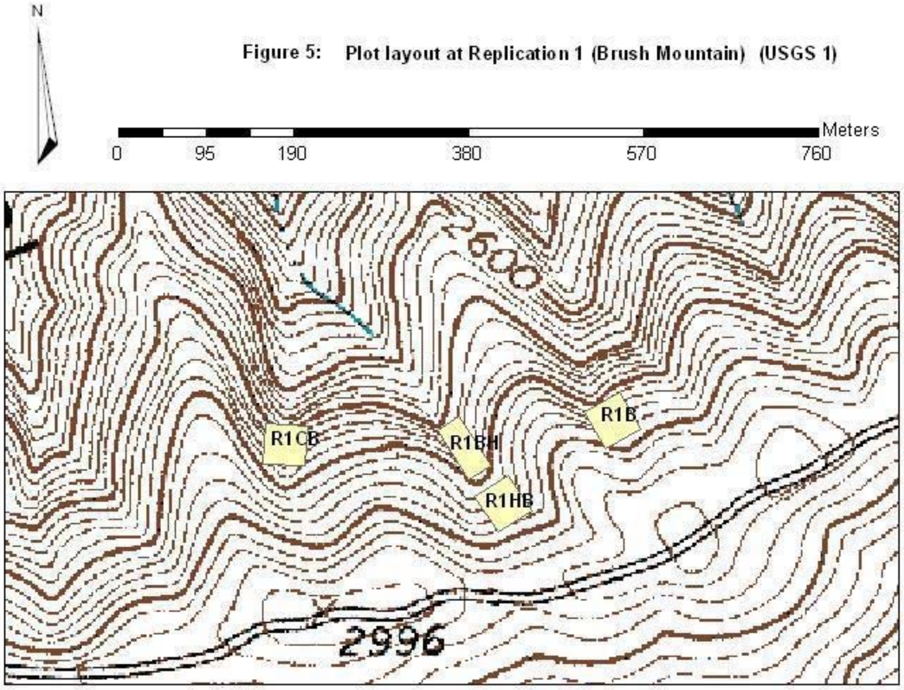


Figure 5: Plot layout at Replication 1 (Brush Mountain) (USGS 1)



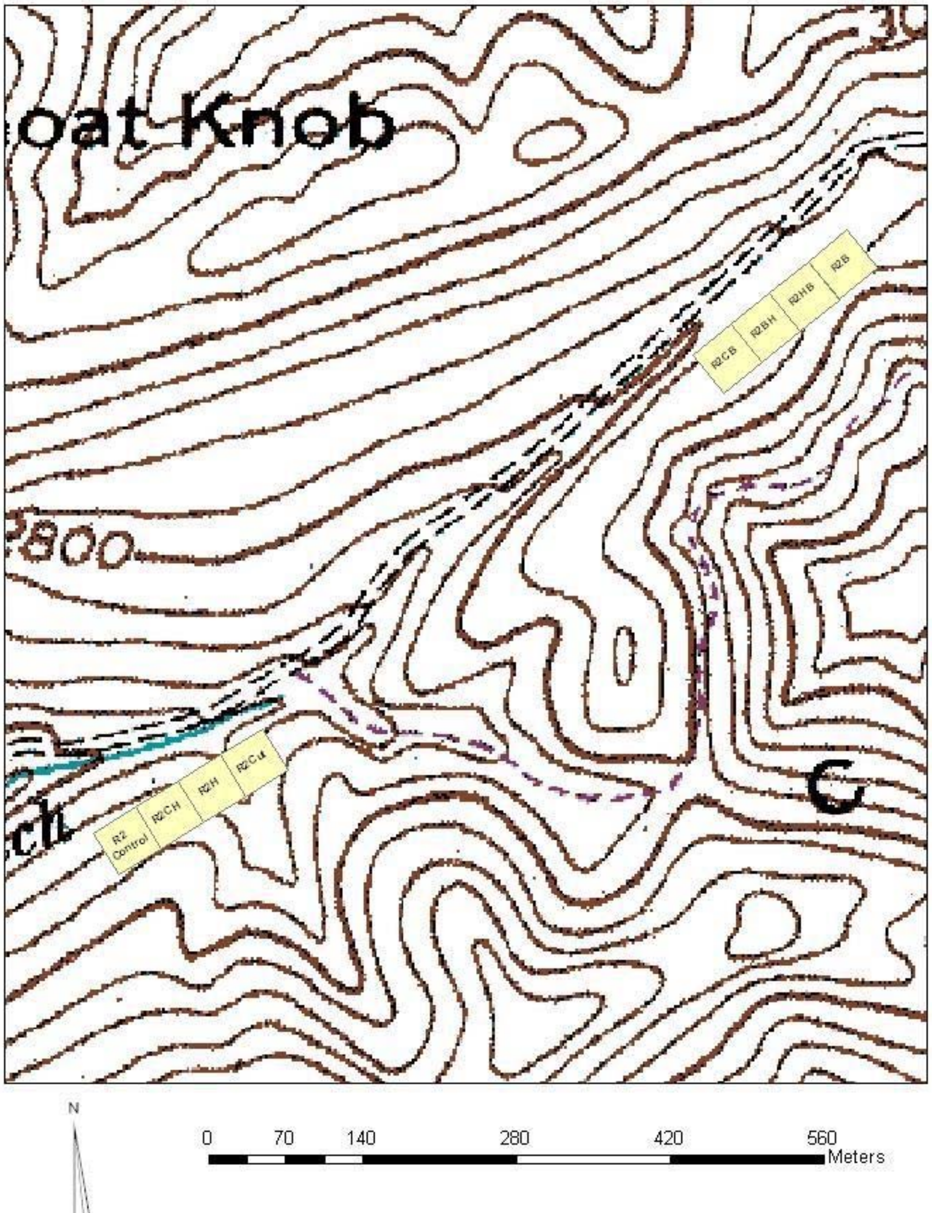


Figure 6: Plot Layout at Replication 2 (Huff Hollow) (USGS 2)

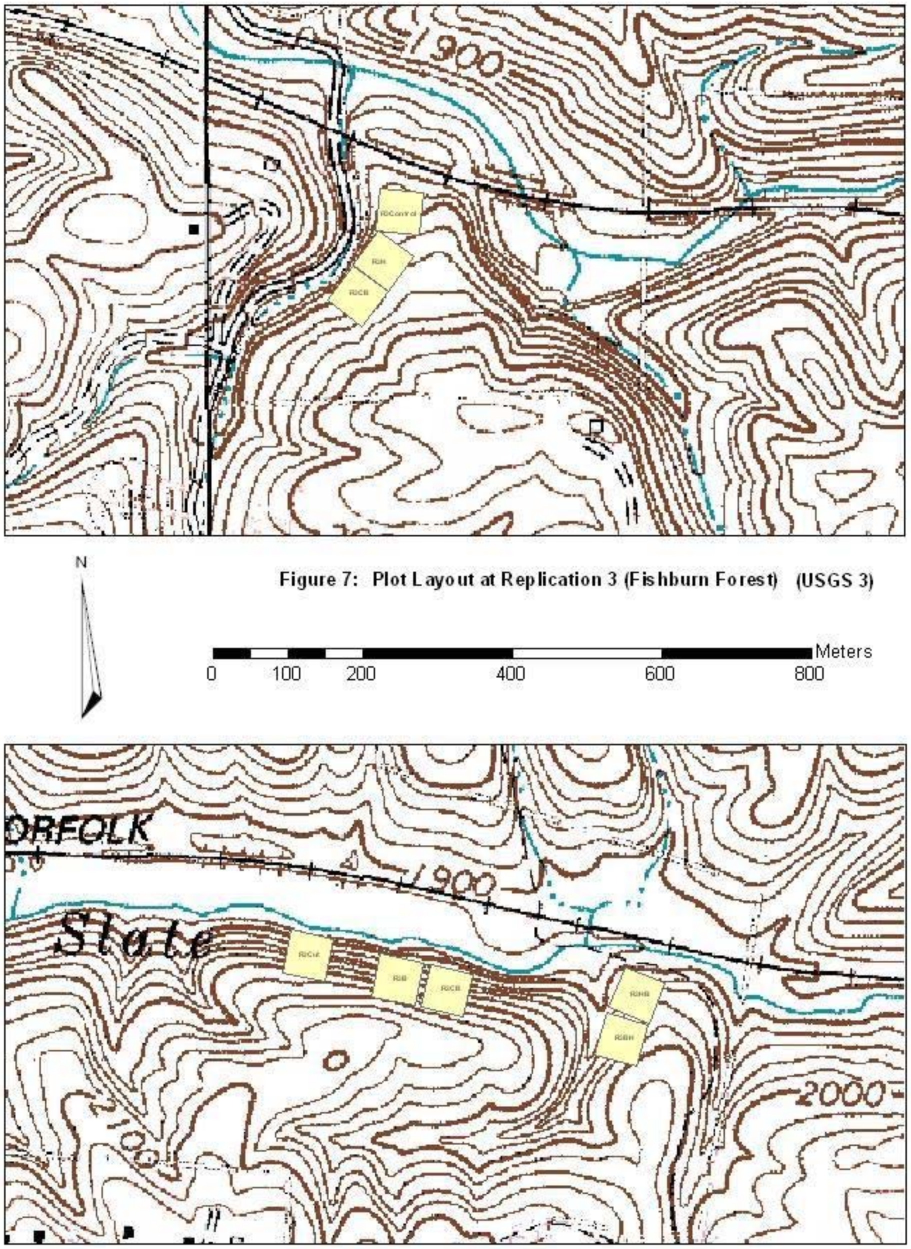


Figure 7: Plot Layout at Replication 3 (Fishburn Forest) (USGS 3)

Appendix C – Analyses

Table 12: ANOVA for testing the 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	0.0002	0.0002	0.01	0.9471
split plot	2	0.2098	0.1049	2.28	0.1646
bs*sp interaction	2	0.0418	0.0209	0.45	0.6504

Table 13: ANOVA for testing the 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	0.0168	0.0168	0.29	0.6462
split plot	2	1.0192	0.5096	4.26	0.0549
bs*sp interaction	2	0.0691	0.0346	0.29	0.7564

Table 14: ANOVA for testing the 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	27.6025	27.6025	8.39	0.1014
split plot	2	121.4173	60.7086	5.52	0.0312
bs*sp interaction	2	15.7372	7.8686	0.72	0.5180

Table 15: ANOVA for testing the interaction of burn status and split plot on sound 1000-hr fuel loading (N = 18)

Source	df	Type III SS	Mean Square	F value	p
burn status	1	71.8601	71.8601	1.81	0.3111
split plot	2	24.6731	12.3366	0.41	0.6774
bs*sp interaction	2	71.6096	35.8048	1.19	0.3535

Table 16: ANCOVA for testing the interaction of burn status and split plot on rotten 1000-hr fuel loading (N = 18). Pre-treatment data was used as a covariate.

Source	df	Type III SS	Mean Square	F value	p
burn status	1	24.5327	24.5327	3.55	0.2002
split plot	2	3.2209	1.6104	0.22	0.8092
bs*sp interaction	2	18.8067	9.4033	1.27	0.3374

Table 17: ANOVA for testing the 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	5.7664	5.7664	5.06	0.1534
split plot	2	4.9931	2.4965	5.44	0.0322
bs*sp interaction	2	0.2812	0.1406	0.31	0.7444

Table 18: ANOVA for testing the interaction of burn status and split plot on duff fuel loading (N = 18)

Source	df	Type III SS	Mean Square	F value	p
burn status	1	5.0785	5.0785	1.23	0.3826
split plot	2	12.5775	6.2887	0.53	0.6095
bs*sp interaction	2	0.5747	0.2874	0.02	0.9763

Table 19: ANCOVA for testing the 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	1.5617	1.5617	0.02	0.9068
split plot	2	154.9341	77.4670	1.57	0.2731
bs*sp interaction	2	4.6542	2.3271	0.05	0.9542

Table 20: ANOVA for testing the interaction of burn status and split plot on the number of two-cm class rhododendron stems per acre (N = 18)

Source	df	Type III SS	Mean Square	F value	p
burn status	1	866805.6	866805.6	4.68	0.1761
split plot	2	224830277.8	112415138.9	6.53	0.0209
bs*sp interaction	2	48463611.1	24231805.6	1.41	0.2996

Table 21: ANCOVA for testing the interaction of burn status and split plot on the number of four-cm class rhododendron stems per acre (N = 18)

Source	df	Type III SS	Mean Square	F value	p
burn status	1	72802.36	72802.36	1.58	0.3359
split plot	2	83314.51	41657.25	1.00	0.4138
bs*sp interaction	2	243084.53	121542.26	2.93	0.1191

Table 22: ANOVA for testing the interaction of burn status and split plot on the number of six-cm class rhododendron stems per acre (N = 18)

Source	df	Type III SS	Mean Square	F value	p
burn status	1	142222.22	142222.22	23.81	0.0395
split plot	2	370000.00	185000.00	9.31	0.0081
bs*sp interaction	2	154444.44	77222.22	3.89	0.0661

Table 23: ANOVA for testing the interaction of burn status and split plot on the number of eight-cm class rhododendron stems per acre (N = 18)

Source	df	Type III SS	Mean Square	F value	p
burn status	1	3472.22	3472.22	0.51	0.5492
split plot	2	170277.78	85138.89	8.76	0.0097
bs*sp interaction	2	26944.44	13472.22	1.39	0.3043

Table 24: ANOVA for testing the interaction of burn status and split plot on the number of ten-cm class rhododendron stems per acre (N = 18)

Source	df	Type III SS	Mean Square	F value	p
burn status	1	138.89	138.89	0.01	0.9426
split plot	2	138611.11	69305.56	5.98	0.0258
bs*sp interaction	2	25277.78	12638.89	1.09	0.3814

Table 25: ANOVA for testing the interaction of burn status and split plot on the number of twelve-cm class rhododendron stems per acre (N = 18)

Source	df	Type III SS	Mean Square	F value	p
burn status	1	0.00	0.00	0.00	1.0000
split plot	2	143333.33	71666.67	5.93	0.0263
bs*sp interaction	2	0.00	0.00	0.00	1.0000

Table 26: ANOVA for testing the interaction of burn status and split plot on the number of fourteen-cm class rhododendron stems per acre (N = 18)

Source	df	Type III SS	Mean Square	F value	p
burn status	1	555.56	555.56	0.08	0.8075
split plot	2	25833.33	12916.67	4.04	0.0612
bs*sp interaction	2	13611.11	6805.56	2.13	0.1812

Table 27: ANOVA for testing the interaction of burn status and split plot on the number of sixteen-cm class rhododendron stems per acre (N = 18)

Source	df	Type III SS	Mean Square	F value	p
burn status	1	555.56	555.56	4.00	0.1835
split plot	2	5833.33	2916.67	2.62	0.1329
bs*sp interaction	2	3611.11	1805.56	1.62	0.2557

Table 28: ANCOVA for testing the interaction of burn status and split plot on the number of >eighteen-cm class rhododendron stems per acre (N = 18)

Source	df	Type III SS	Mean Square	F value	p
burn status	1	0.00	0.00	0.00	1.0000
split plot	2	1111.11	555.56	1.14	0.3660
bs*sp interaction	2	0.00	0.00	0.00	1.0000

Table 29: ANOVA for testing the interaction of burn status and split plot on the total number of rhododendron stems per acre (N = 18)

Source	df	Type III SS	Mean Square	F value	p
burn status	1	35555.60	35555.60	0.00	0.9534
split plot	2	171750277.80	85875138.90	5.14	0.0367
bs*sp interaction	2	33193611.10	16596805.60	0.99	0.4120

Appendix D – Timeline of events

Date	Event
2005	
January	
12	Begin site search
February	
9-12	Install replication 1 (Brush Mountain) burn plots
25	Install replication 2 (Huff Hollow) all plots
March	
19	Sample all burn plots at Rep 2
26-30	Sample all burn plots at Rep 1
25	Perform cutting treatment on Rep 2 cut + burn plot
31	Perform cutting treatment on Rep 1 cut + burn plot
April	
1	Perform cutting treatment on Rep 1 cut + burn
14	Perform herbicide treatment on Rep 1 herbicide + burn plot
16	Perform herbicide treatment on Rep 2 herbicide + burn plot
17	Burned Rep 2
19	Burned Rep 1
May	
23	Sample non-burn plots at Rep 2
June	
1	Working plan first submission
13	Begin cutting treatment on Rep 2 cut plot
14	Working plan final submission
20	Finish cutting treatment on Rep 2 cut plot
20	Sample non-burn plots at Rep 2
21	Perform cutting treatment at Rep 2 cut + herbicide plot
20-24	Install replication 1 non-burn plots
20-24	Install replication 3 (Fishburn Forest) all plots
July	
6-8	Field Work
19	Perform herbicide treatment on Rep 2 herbicide only plot
August	
11	Perform cutting treatment on Rep 1 cut and Rep 1 cut + herbicide plot
September	
1	Sample Rep 3 burn plots pre-treatment
15	Perform cutting treatment on Rep 3 cut + burn plot
October	
18	Sample Rep 1 burn plots post treatment (-R1CB)
21	Sample Rep 2 non-burn plots post-treatment (-R2CH)

2006

February		
	11	Burn Rep 3
April		
	4	Sample Rep 3 non-burn plots pre-treatment
	11	Sample Rep 3 non-burn plots pre-treatment
	19	Perform cutting treatment on Rep 3 cut + herbicide plot
	28	Perform cutting treatment on Rep 3 cut only plot
May		
	8	Perform herbicide treatment on Rep 2 burn + herbicide and cut + herbicide plots
	12	Perform herbicide treatment on Rep 3 burn + herbicide and herbicide only plots
	30	Install and sample Rep 1 herbicide replacement
	31	Perform herbicide treatment on Rep 1 herbicide replacement
July		
	6	Perform Herbicide at Rep 3 cut + herbicide
	11	Sample at Rep 3 post-treatment
	24	Sample at Rep 2 post-treatment – Rep 2 complete
August		
	23	Sample at Rep 1 post-treatment – Rep 1 complete
	23	Sample at Rep 3 post-treatment – Rep 3 complete

Appendix E – GPS coordinates

Table 30: GPS coordinates and altitude for the southwestern corner of each treatment area. Coordinates are UTM Zone 17 N, NAD 83

Plot	Latitude	Longitude	Altitude (m)
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

Vita

Charles Wesley Harrell, III was born on June 14, 1982 in Gainesville, FL to Wesley and Carol Harrell. His family moved to Muncie, IN for 3 years then to Marietta, GA, where Chuck went to high school. It was through a job at a local farmer's market during high school when Chuck discovered his affinity for the outdoors and his desire to pursue a career in forestry. In the fall of 2000, Chuck left Georgia for Clemson University, where he studied forest resources management. During the summers he worked at YoungLife camps and for the U.S.D.A. Forest Service on the National Fire and Fire Surrogate study. With a Bachelor of Science in forest resources management, Chuck became a third generation graduate of Clemson University in May of 2004, following his father and grandfather, Charles Wesley Harrell, Jr., and Charles Wesley Harrell, Sr. Eager to pursue further understanding of fire ecology, Chuck accepted a graduate research assistant position at Virginia Tech in the fall of 2004. In the summer of 2007, Chuck successfully completed all degree requirements for a Master of Science in Forest Biology, and so graduated from Virginia Tech. In January 2007, Chuck Harrell began a district forester position with Resource Management Service, LLC in Marion, SC.