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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 tree regeneration and the potential for dangerous fuel conditions around suburban structures near the wildland-urban interface. In this study, treatments involving prescribed fire, mechanical cutting, and herbicide applications were applied to *R. maximum*-dominated forests in southwestern Virginia to determine what effect seven different silvicultural treatments had on (1) controlling of *R. maximum* as a forest weed; (2) fuel loading inside of a *R. maximum* thicket; and (3) treatment costs. Due primarily to less than ideal moisture conditions, a single prescribed burn was relatively ineffective in reducing overall fuel loading and causing immediate *R. maximum* mortality. However, prescribed fire reduced litter layers and caused delayed mortality on *R. maximum* stems three years following treatment. Mechanical cutting treatments were successful in reducing *R. maximum* basal area per acre and caused a drastic shift in the stem size class distribution. But cutting also resulted in heavy sprouting and increased fuel loading. When applied alone, herbicide applications were successful in controlling only the smallest diameter

class of *R. maximum* stems. Herbicide application did not reduce or increase fuel loading and was important in *R. maximum* control only when combined with other treatments. Prescribed burning 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 this study could be used over the long term to demonstrate to land managers the effects of vegetation control on rhododendron-dominated landscapes.

BACKGROUND AND PURPOSE

Great or rosebay rhododendron is widely distributed over eastern North America, from the Great Lakes to the Atlantic coast and from Alabama to Maine. It is most common in riparian areas and on moist slopes but is found on every aspect and nearly every slope position in the George Washington and Jefferson National Forest. It is intensively cultivated for its horticultural value and is a member of the largest genus of the Ericaceae family.

The increasing presence of rhododendron has been addressed by many researchers who attribute this increase to a number of possible conditions, including the exclusion of fire, the eradication of American chestnut, gaps in the overstory from partial harvest methods, and lately, loss of Eastern hemlock due to the hemlock woolly adelgid (Woods and Shanks 1959, McGee and Smith 1967, Monk et al. 1985, Philips and Murdy 1985, Clinton et al. 1994, Baker and Van Lear 1998). Vandermast et al. (2002) found that after the chestnut blight, thickets of rhododendron are more prevalent in areas where logging has taken place than in old-growth stands. Disturbance is a key to rhododendron's initial presence on a site. Gap phase dynamics in older stands has allowed rhododendron to take hold and prevent other tree regeneration from taking hold and dominating the gap. Vandermast et al. (2002) found that Eastern hemlock was the only regenerating tree species that could withstand the shade and acidic conditions present in rhododendron thickets.

Rhododendron is also being planted as an ornamental around homes in the wildland-urban interface, which causes concerns for fire managers and also creates a seed source for rhododendron to potentially spread. The presence of rhododendron is also increased in these areas by the clearing of land for roads and houses, which creates the suitable disturbance gaps necessary for rhododendron propagation. Rhododendron is a very shade-tolerant species that can thrive under a closed canopy, but for new thickets to form, an opening resulting from some sort of disturbance is necessary. Existing thickets can continue to spread in the undisturbed habitat.

During moist seasons, the shade cast by rhododendron lowers litter drying rates and, in turn, can decrease fire intensity and spread. However, during periods of drought, the low moisture content of leaves and dry litter contributes to dangerous fire behavior. A normal calm surface fire can experience tenfold increases in flame lengths upon entering rhododendron thickets (Waldrop and Brose 1999). This poses a major problem for hand crews trying to contain a surface fire that suddenly becomes a stand replacement fire, where direct attack is unsafe and unfeasible.

According to Romancier (1971), prescribed fire will often initially kill or damage the above-ground portion of rhododendron. Rhododendron will basal-sprout prolifically following the fire; however, after three or four years, the number of sprouts is reduced and top kill occurs. This is an indication of a delayed reaction to fire injury. Romancier (1971) conducted a study in which rhododendron was burned, allowed to grow for 21 months, and then chemically treated to control the new sprouts. After three years, the combination treatment controlled virtually all sprouts, while the burn-only treatment greatly reduced the number of sprouts as a result of delayed fire effects. The drawback to Romancier's (1971) findings is that 2,4,5-T is no longer legal to apply in chemical treatments.

Since Romancier's (1971) research, little work with chemical control of rhododendron has been done. Current data for the use of chemicals in controlling closely related European species (*R. ponticum* L. and *R. flavum* Don.) are available (Esen and Zedaker 2004). There have also been a few studies recently in the United States (Esen and Zedaker 1999, Esen 2002); however, no field testing of chemical treatments has been documented.

Specific Project Objectives (Purpose):

1. Measure the response of rhododendron-dominated sites to prescribed burns, cutting, herbicide application, and their combinations, for fuel loading, rhododendron survival, and immediate treatment installation costs.
2. Document short-term (3-yr) and predict long-term efficacy of fuel treatments and costs over time for different treatments by measuring rhododendron recovery and fuel build-up.
3. Predict differences in fire behavior and annual cost of fuel management as a result of differences in fuel treatment.

STUDY DESCRIPTION AND LOCATION

A replicated experiment (four replicates) installed in pre-planned prescribed burns on the Fishburn Forest owned by Virginia Tech and the Jefferson National Forest in southwestern Virginia was measured for treatment effects on fuel reduction, rhododendron mortality and regrowth, tree seedling regeneration, and treatment costs. The treatments consisted of:

1. Prescribed fire
2. Prescribed fire followed by herbicides
3. Cutting
4. Cutting followed by fire
5. Cutting followed by herbicides
6. Herbicide
7. Herbicide followed by fire
8. Control

One-half-acre treatment areas were delineated within prescribed burns. Cutting treatments consisted of chainsaw or brushsaw severing of all rhododendron stems within 6 in of the ground surface. Herbicide and herbicide followed by fire treatments consisted of basal applications of triclopyr or imazapyr in methylated seed oil on each plot. Cutting and burning treatments followed by herbicides utilized foliar applications of triclopyr or imazapyr in emulsions to all resprouting rhododendron. All herbicide plots were randomly split in half for the application of imazapyr or triclopyr on different halves. Analyses of variance and mean separation by LSD were used to compare treatment effectiveness for fuel loading and costs.

Objective 1

Two diagonal fuel transects were permanently established in each treatment plot to assess fuel coverage, height, and loading (Brown et al. 1982). Fuel transects were inventoried before and immediately after treatment by Virginia Tech students and staff. Live rhododendron stem counts, heights, and basal area were taken during the fuel inventory by measuring all stems in a 10-ft-wide band centered on the transect lines. Times for cutting and herbicide applications were measured on each plot, and chemical use was monitored for cost determinations.

Objective 2

Rhododendron height, stem counts, and basal area growth and fuel measurements on the permanent transects were conducted annually to estimate recovery rates. Fuel coverage, live fuel loads, and dead fuel loading were projected forward.

Objective 3

Fuel measurements and projections from Objectives 1 and 2 will be used in the NEWMDL subroutine of BEHAVE to develop custom fuel models. Each specific treatment and time combination fuel model will then be compared using the SITE module of BEHAVE. Annualized costs to prevent fire behaviors exceeding those subject to direct control by hand crews will be estimated for each treatment by determining the time to a retreatment trigger of 4-ft flame lengths and 100 BTU/ft/s fireline intensity.

More detail on the methods and materials used for this project can be found in the M.S. theses of Christopher Pearce and Charles Harrell, which can be accessed through the Virginia Tech Library, Electronic Thesis and Dissertation System: http://scholar.lib.vt.edu/theses/etd-search.html.

KEY FINDINGS AND DISCUSSION

Fire Weather and Behavior

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

Replication 4 was burned on April 17, 2008, with the help of the Virginia Tech Wildland Fire Crew. Weather for this burn was favorable, with a temperature ranging from 62-70°F, a relative humidity of around 23%, and wind coming from the WNW at 2 to 5 mph with gusts up to 7 mph. Due to a 4 p.m. burning ban, ignition could not take place until later in the day; however, despite the late burning time the prescribed fire was deemed successful. A backing fire was set along the NE and SW facing ridges, which burned down the slope 100 ft within the fireline. Once a proper buffer was established from the backing fire, three fire crew members established a head fire originating from the creek drainage in order to ignite the *R. maximum* thickets along the northern slope. This resulted in the desired fire behavior, with flames from burning *R. maximum* thickets reaching up to 15 ft. Over 90% of the ground area in the burn plots was affected by fire. Flames outside of *R. maximum* thickets in the open overstory ranged from 2 to 4 ft, with greater flame lengths occurring in isolated patches of concentrated fuel. The litter layer was over 50% consumed, with the duff layer remaining largely intact. No overstory mortality was observed from this prescribed fire.

Table 1. Prescribed burn site characteristics, weather, and fire behavior for replications.

Variable	**Replication 1 (Brush Mountain, JNF)**	**Replication 2 (Huff Hollow, JNF)**	**Replication 3 (Fishburn Forest)**	**Replication 4 (Fishburn Forest)**
Date	4/19/05	4/17/05	2/10/06	4/17/08
Temperature (^{o}F)	62-75	62-68	42-46	62-70
Relative humidity (%)	35	26	29	23
Ignition technique	Helicopter ping-pong ball	Drip torch	Drip Torch	Drip Torch
Slope position	Headslope	Footslope/adjacent to creek	Footslope/adjacent to creek	Headslope
Burn size (ac)	630	100	32	27
Predicted fuel moisture (%) (1-hr/10-hr/100-hr)	9/10/11	9/10/11	9/10/11	12/13/14
Expected flame length (ft) *	2.7	2.6	2.7	2.3
Actual flame length (ft)	4-8	0.5 - 1.5	0.5 – 1.5	2 – 13
Fireline intensity (Btu/ft/s) *	49	46	47	43

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

Table 2. Visual estimation of percentage of ground area burned for each burned treatment plot**.**

Treatment	R1 (Brush Mountain, JNF)	R2 (Huff Hollow, JNF)	R3 (Fishburn Forest)	R4 (Fishburn Forest)	Treatment Mean
	-- % --				
Burn only	95	85	90	95	91
Burn + herbicide	90	70	80	95	83
Cut + burn	95	80	90	90	89
Herbicide + burn	95	80	85	95	89
Replication mean	94 **a**	79 **c**	86 **b**	94 **a**	88

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

R. maximum **Stem Mortality (Objective 1)**

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

Table 3. Pre-treatment average stems per acre in treatment plots for various *R. maximum* stem diameters.

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

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

Prescribed Burning

Treatments involving prescribed burning had significantly fewer pre-treatment total stems per acre than non-burned treatments. To account for this discrepancy, the burned and non-burned treatments were analyzed for the percent change in total stems that occurred from pre-treatment to post-treatment, year 2, and year 3 sampling periods (Table 4). Both burned and non-burned treatments experienced similar percent increases in stems per acre during post-treatment and a similar decrease during year 2. Burned treatments in year 3 experienced a significantly greater percent decrease in *R. maximum* stems from pre-treatment levels compared to non-burned treatments.

Table 4. Percent change in total number of stems from pre-treatment levels for burned and non-burned treatments throughout the duration of the project. The contrast statement analysis is within a randomized complete block design at the $\alpha = 0.05$ level.

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

Stems per acre for the burn-only treatment increased during post-treatment, while basal area decreased (Fig. 1). The increase in the total number of stems per acre during post-treatment sampling was due to *R. maximum* stump sprouting. The average number of 0.5-in diameter stems increased from 3,225 stems per acre pre-treatment to 5,405 stems per acre post-treatment. During year 3, both total stems per acre and basal area dropped below pre-treatment levels.

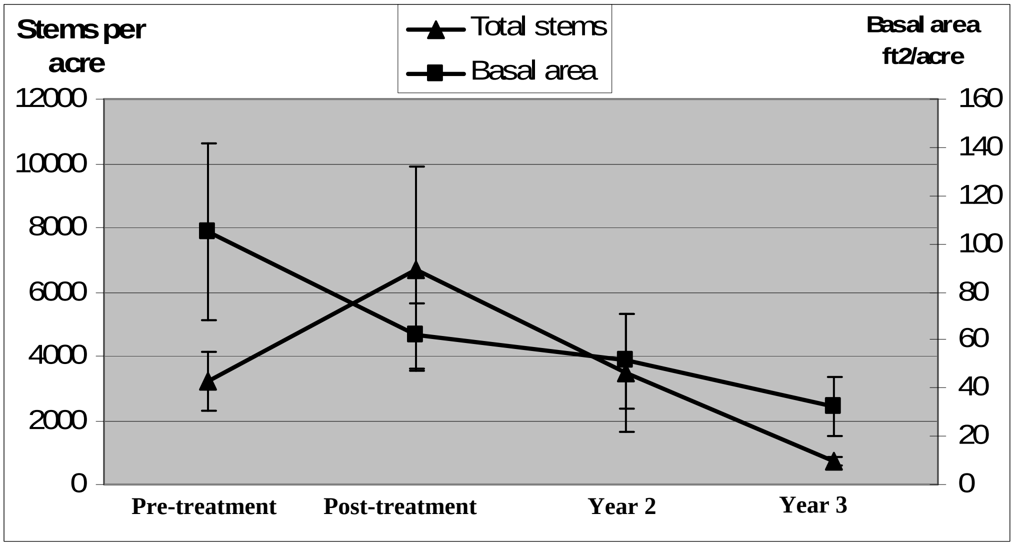

Figure 1. Average number of total stems per acre and basal area for the burn-only treatments.

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

Herbicide Application

Applications of impazapyr and triclopyr showed limited effectiveness in eliminating *R. maximum* stems with diameters larger than 0.5 in. Control of 0.5-in diameter *R. maximum* stems was so substantial that it resulted in significantly fewer total *R. maximum* stems per acre when compared to non-herbicide applications post-treatment and 2 years following treatment (Table 5). Total stems per acre in herbicide treatments continued to decline.

Two different herbicides, Garlon (triclopyr) and Stalker (imazapyr), were applied on the two halves of the treatment. Esen and Zedaker (2004) found that foliar-applied imazapyr had significantly greater *R. maximum* basal area control and sprout suppression than foliar-applied triclopyr when applied to *R. ponticum* and *R. flavum*. Personal observations note that neither herbicide alone was adequate as a basal application to control *R. maximum* stems with diameters greater than 0.5 in. It is likely that other herbicide treatment methods such as hack and squirt (herbicide injected after a wound is placed in the stem), stump spraying after a stem has been cut, or foliar sprays could be more successful in treating larger-diameter *R. maximum* stems. *R. maximum* stems with diameters of 0.5 in were significantly fewer in herbicide plots than in non-herbicide plots. This shows that herbicide treatments can be a very viable option in combination with other treatments such as mechanical cutting or burning that could potentially control larger diameter *R. maximum* stems, but would result in substantial sprouting.

Table 5. Total stems per acre for herbicide vs. non-herbicide treatments. The contrast statement analysis is within a randomized complete block design at the α = 0.05 level.

	n	**Herbicide**	**Non-Herbicide**	**F-Value**	**P**
		-- average total stems per acre --			
Pre-treatment	32	3122	3369	0.54	0.46
Post-treatment	32	2188	6734	14.53	0.00
Year 2	24	1988	4021	7.03	0.01
Year 3	24	1713	2508	1.23	0.28

Mechanical Cutting

Mechanical cutting treatments were much more successful in eliminating larger diameter classes of *R. maximum* stems in comparison with the other silvicultural treatments. This was expected, because mechanical cutting treatments effectively sever the main stem of *R. maximum* plants. Following mechanical cutting, substantial basal sprouting occurs. Cutting the stems of *R. maximum* can result in 10 or more sprouts per severed stem (Romancier 1971). This was clearly shown in this research project. Mechanical cutting treatments had significantly more 0.5-in diameter stems per acre than non-cutting treatments, resulting in greater total stems per acre for all three years of sampling (Table 6).

Table 6. Total stems per acre for cutting vs. non-cutting treatments. The contrast statement analysis is within a randomized complete block design at the α = 0.05 level.

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

All three mechanical cutting treatments were successful in controlling *R. maximum* stems except for the 0.5-in stem diameter class. The number of *R. maximum* basal sprouts following mechanical cutting treatments could be an indicator of the future composition of *R. maximum* thickets. Each of the three mechanical cutting treatments showed differences in the amount of *R. maximum* basal sprouting that occurred over time (Fig. 2).

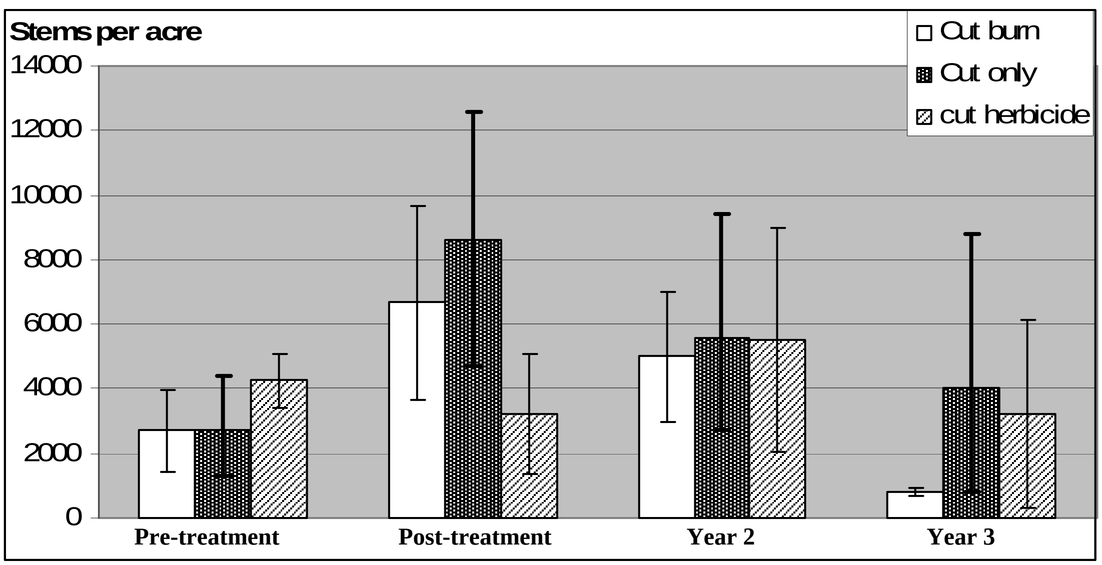

Figure 2. Number of 0.5-in diameter stems per acre for mechanical cutting treatments over the duration of the research project.

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

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

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

Fuel Loading (Objective 2)

Pre-treatment Data

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

Pre-treatment litter levels were found to be high on our sites (Table 7). Stottlemeyer et al. (2006) reported an average of 1.7 tons per acre of litter on xeric to mesic sites in the Chauga ridges region of the southern Appalachians. Loucks (2008) reported an average of 3.1 tons per acre of litter on oak-hickory forests in eastern Kentucky. This discrepancy could be due to our sites having been specifically chosen to have a high *R. maximum* dominance. Many who have done research on *R. maximum* have noted that fuel loading under thickets includes a thick litter layer that is slow to decompose (Plocher and Carvell 1987, Clinton and Vose 1996, Monk et al. 1985).

Table 7. Mean pre-treatment tons per acre of fuel load components on all treatment types.

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

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

Prescribed Burning

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

Prescribed burning did have an effect on the amount of litter consumed. The randomized complete block design contrast analysis showed that post-treatment tons per acre of litter were significantly less in burning treatments compared to non-burning treatments (Table 8). Two and three years following prescribed burning treatments, litter levels rose, resulting in non-significant p values. Despite this increase, the average amount of litter for treatments involving prescribed burning was 1.83 tons less per acre during year 3 than pre-treatment. One of the main goals of many prescribed fires is to reduce the fuel load in order to prevent larger, hazardous fires from occurring, and reducing litter contributes to this goal.

Table 8. Average tons per acre of litter for burned vs. non-burned treatments. The contrast statement analysis is within a randomized complete block design at the $\alpha = 0.05$ level.

	n	**Burned**	**Non-Burned**	**F-Value**	**P**
		---- average tons/acre ----			
Pre-treatment	32	5.30	4.60	0.65	.429
Post-treatment	32	2.59	3.59	8.78	.007
Year 2	24	3.70	4.15	3.89	.068
Year 3	24	3.47	3.98	1.11	.310

Mechanical Cutting

The mechanical cutting treatments had the most significant effects on 1-, 10-, and 100-hr fuel loading on the forest floor. Mechanical cutting treatments had significantly greater tons per acre of fuels than non-cutting treatments post-treatment, 2 years, and 3 years following treatment (Table 9). This was expected, since the stems were left undisturbed on the forest floor after being cut.

Table 9. Average tons per acre of 1-, 10-, and 100-hr fuel loading for cut vs. non-cut treatments. The contrast statement analysis is within a randomized complete block design at the α = 0.05 level.

Fuel Class	Cut	Non-Cut	F-Value	P
	-- average tons/acre --			
Post-Treatment (n = 32)				
1-hr	0.54	0.27	11.17	0.00
10-hr	1.46	0.59	20.72	0.00
100-hr	5.83	1.88	19.56	0.00
Year 2 (n = 24)				
1-hr	0.48	0.21	30.66	< .0001
10-hr	1.79	0.70	13.67	0.00
100-hr	8.65	1.92	29.96	< .0001
Year 3 (n = 24)				
1-hr	0.41	0.24	12.57	0.00
10-hr	2.28	0.79	6.29	0.02
100-hr	10.18	2.02	17.77	0.00

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

Herbicide Applications

Treatments involving herbicide applications had no significant impact on fuel loading. Herbicide applications did not achieve the *R. maximum* stem mortality desired; therefore, fuel loads were not affected. Furthermore, rhododendron stem mortality and subsequent additions to the dead fuel load were still occurring three years after treatment initiation. This ongoing process, after only three years, makes it impossible to predict long-term fuel loads at this point in time. Much longer-term assessments must be made to accomplish this su-objective.

Financial Analysis (Objective 3)

From an ecological perspective, the success of vegetation control and fuel reduction treatments is 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-effective method of *R. maximum* control. Private land managers are seeking the best treatment or treatment combination in terms of 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 our understanding 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 10 or 20 percent of the area of the tract. Our per-acre costs as presented, then, are known to be well outside the acceptable realm for traditional forestry practices. We 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 its subsequent effectiveness in controlling rhododendron, where effectiveness was measured in post-treatment basal area (ft^2).

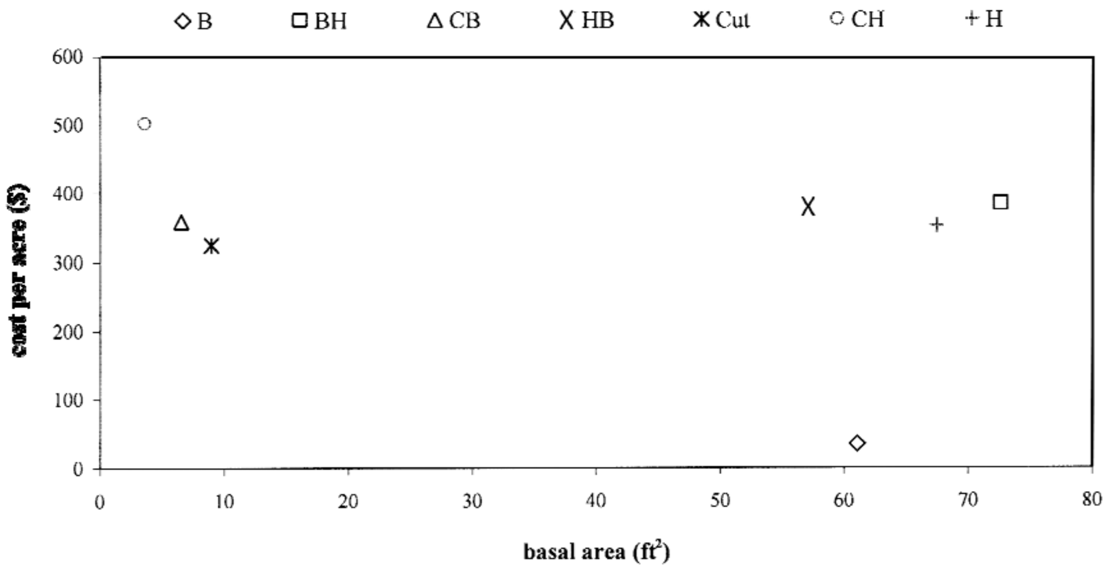

Figure 3. Treatment effectiveness (post-treatment basal area) vs. per-acre cost.

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.). USDA Forest Service personnel conducted two of our three burns on Forest Service land. Our cost data for prescribed burning were thus obtained from Forest Service records. Sutherland (pers. comm. 2006) reported that our replication 2 burn (1350 ac, 546 ha) cost 18 USD ac^{-1} on the ground, while our replication 1 burn (655 ac, 265 ha) cost approximately 20 USD ac^{-1}. These figures are actual implemented ground costs, including labor, fuel, helicopter time, and other costs. Total costs for these burns were higher because of the added costs of preparation labor and equipment. The Forest service is allocated government funds in the amount of 34 USD ac^{-1} to carry out all prescribed burning operations. This government-appropriated rate 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.

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 8 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 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}) (Fig. 4).

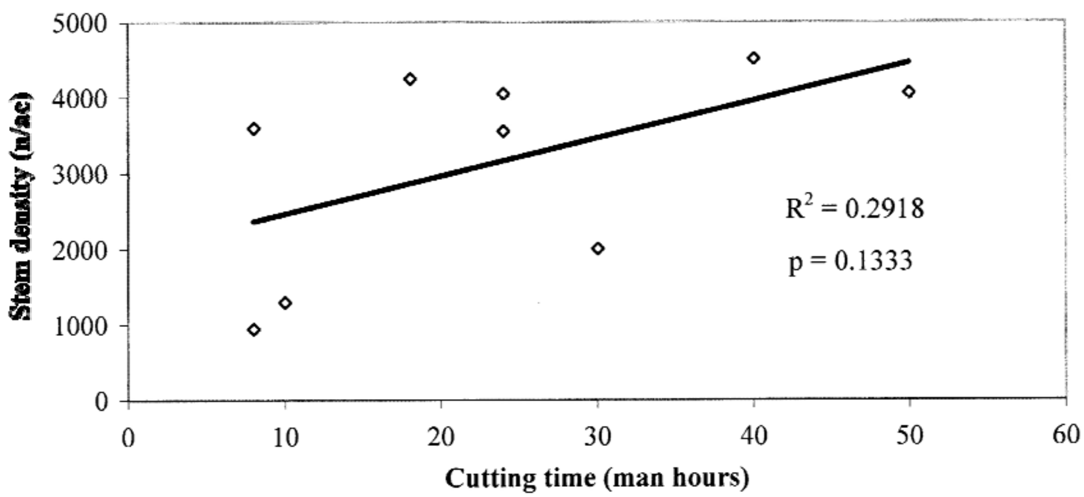

Figure 4. Number of man-hours required to perform mechanical cutting treatment versus stem density in an *R. maximum* thicket in the southern Appalachians.

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. 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 plot treatments took an average of 1.3 hours longer to perform than all other treatments. Herbicide application labor rates were thus dependent on each individual treatment and were calculated based on the mean number of man-hours required to treat each plot (Table 10).

Table 10. Herbicide application labor costs by treatment area and application type on *Rhododendron maximum*-dominated sites.

Treatment	**Application Type**	**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 more expensive at 2.70 USD $fl.oz^{-1}$, while Garlon 4 cost 0.74 USD $fl.oz^{-1}$. The vegetable oil carrier used in basal application was approximately 0.05 USD $fl.oz^{-1}$. Stalker, applied basally as a 9% solution, was also more expensive per gallon of mixture at 37 USD gal^{-1}. Garlon 4, mixed at a 20% solution, cost 24.23 USD gal^{-1}. Foliar application rates were 5% for Garlon 4 and 2.5% for Stalker. These rates equated to foliar mixture costs of 4.74 USD gal^{-1} and 8.63 USD gal^{-1}, respectively. The combined costs for each treatment type and chemical type are presented as herbicide cost in Table 11.

Table 11. Summary of treatment costs by treatment area for prescribed burning, mechanical cutting, and herbicide application.

Treatment	Burning Cost[a]	Cutting Cost[b]	Herbicide Type	Herbicide Cost[c]	Total Cost
	------- (USD ac^{-1}) --------			--------- (USD ac^{-1}) ---------	
Burn only	34	---	---	---	34
Burn + herbicide	34	---	Garlon 4	300	334
			Stalker	399	433
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

Fire Behavior (Objective 3)

Fire behavior scenarios were run using BEHAVE 4.0, using custom fuel models, for the different rhododendron removal treatments using a likely spring fire weather, fuel moisture, and slope conditions common in the George Washington and Jefferson National Forest (Table 12). Only under the herbicide-only treatment (under nominal conditions) did the flame lengths approach the 4.0-ft (100BTU/Ft/Sec Intensity) trigger point for limiting direct suppression using hand crews. Even under extreme weather, moisture, and slope conditions, none of the initial fuel loads resulted in flame lengths over 6.0 feet. These model projections seem dubious, since full involvement of the 10- to 20-ft tall rhododendron canopy and resultant 20- to 40-ft flame lengths have been observed by the authors and confirmed by many others, under these prevailing moisture and weather conditions. This suggests that BEHAVE does not model the understory shrub layer fire intensity with regard to rhododendron canopies nearly as well as expected for other southern or western brush fuel models. Again, it is difficult or impossible to predict future fire behavior under the conditions of ever-increasing fuel loads at year 3. Post-treatment year 3 fuel loads for cut treatments exceed 10 tons per acre for the 100-hr fuels and 2 tons per acre for the 10-hr fuels, while the 1-hr fuels remained largely unchanged (to slightly lower) compared to the pre-treatment levels. In an attempt to attain proximal BEHAVE predictions of observed fire behavior in rhododendron canopies under extreme conditions, we assumed that all of the litter layer would be consumed as 1-hr fuel, used the highest 10-hr fuel loading observed (2.25 tons/ac) and the highest 100-hr fuel loads observed (10 tons/ac in the cutting treatments) in our three-year post-treatment data. This resulted in 10-ft flame lengths and 35 chain/hr rates of spread, matching observed behaviors in the George Washington-Jefferson NF, but certainly not the extreme of observed behaviors. Therefore, these predicted fire behavior anomalies, and the fact that the fuel loading was still changing dramatically at the end of the experiments, made it impossible to compute the annualized costs to prevent fire behaviors exceeding those subject to direct control by hand crews.

Table 12. Fire scenario statistics for different treatments (pre-treatment) assuming fuel moistures of 6, 7, and 8% for 1,hr, 10, and 100hr fuels, respectively, 60% live herbaceous and 90% live woody, 30% slopes and 6 mph mid-flame wind speed (nominal); 4.5, 5.5. 6.5% (1hr, 10hr,100hr), 60% slope, 10 mph mid-flame (extreme)

	Fuel Loading (T/ac)					**Fire Behavior (nominal/extreme)**	
Treatment	**Litter**	**1-hr**	**10-hr**	**100-hr**	**Live Woody Load**	**ROS (ch/hr)**	**Flame Length (ft)**
Burn only	5.1	0.44	0.93	2.06	1.0	8/24	3.1/5.5
Herbicide + burn	8.2	0.38	1.16	1.70	0.2	10/28	2.6/4.4
Cut + burn	6.3	0.34	0.83	1.49	0.2	10/25	2.4/3.9
Burn + herbicide	3.7	0.26	0.84	2.42	0.2	8/23	2.4/4.1
Control	5.4	0.30	0.61	1.22	1.0	8/27	2.7/5.1
Herbicide only	4.6	0.45	0.65	0.85	1.0	12/36	3.5/6.0
Cut only	6.0	0.35	0.56	1.17	0.2	12/26	2.4/3.6
Cut + herbicide	2.8	0.38	0.47	2.24	0.2	10/29	2.5/4.3

MANAGEMENT IMPLICATIONS

Silvicultural treatments for controlling *R. maximum* thickets (slicks) had variable results, with many possible outcomes that may serve as guides for management strategies. Finding the most effective approach to control *R. maximum* is increasingly important as it continues to establish itself as the dominant cover in moist southern Appalachian forests. The USDA Forest Service's partial cutting/harvesting regimes, the lack of fire and herbicide use as site preparation tools, and the USDI Park Service's lack of prescribed burning and other active management strategies in the region exacerbates this problem.

Mechanical cutting had the most significant effect on eliminating larger diameter *R. maximum* stems; however, substantial sprouting occurred. Mechanical cutting followed by either prescribed fire or foliar herbicide application was successful in reducing stump sprouting. The most obvious negative aspect of the mechanical cutting treatment was an immediate increase in fuel loading on the forest floor. It was hoped that mechanical cutting followed by prescribed burning would reduce the amount of fuel loading on the forest floor; however, the experimental burns performed lacked the fire intensity to consume much of these downed fuels.

R. maximum stems exhibited delayed mortality in plots where prescribed burning was used as a single treatment. A lack of fire intensity with two of the prescribed burns probably resulted in this particular treatment not reaching its full potential. Personal observations noted that where *R. maximum* thickets did experience intense fire behavior on the outside edges of the thickets and in when it was growing in single clumps, fire-caused mortality of larger stems was more evident. Multiple prescribed fires could be successful for reducing *R. maximum* thickets by reducing this outside edge effect as well as drying out the fuels underneath thickets for increased fire behavior.

Basal applications of herbicides alone were unsuccessful in reducing *R. maximum* stems with diameters greater than 0.5 in. More research is needed to determine which methods of herbicide applications can correctly deter *R. maximum* growth and establishment. A disadvantage of herbicide application is that it is difficult to maneuver through *R. maximum* thickets with an herbicide applicator. Cost analysis research has shown that herbicide application can be up to 13 times more expensive than prescribed burning alone. Foliar herbicide application to treat stump sprouts following mechanical cutting was found to be very successful and would be a logical choice for deterring future *R. maximum* growth when used with other treatments that result in high stump sprouting.

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 affect the live fuel and wildfire potential; however, it is presumed that successive prescribed burns in cutover or sprayed sites will reduce the vigor of sprouting *R. maximum* stems and eventually favor early-successional grasses and forbs.

The 2-cm diameter class of stems 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. We recommend that a hot fire be used first to weaken and dry the *R. maximum* stems, causing them to be more receptive to the following basal herbicide application. Again, basal herbicide application in a rhododendron thicket is costly, but may be the best option in *R. maximum* control when combined with prescribed burning.

It was overly ambitious, and perhaps naïve on the part of both the principal investigators and the proposal reviewers of this project, to assume that long-term projections of fuel loading, fire behavior, and fuels treatment costs might be calculated. The increased fuel loading and resprouting, and the continued larger stem mortality that occurs even five years after the initial treatments, preclude long-term projections.

FUTURE WORK

More time is needed to reflect the true responses of the rhododendron slicks to these treatments and the impacts on fuel loading. Perhaps these experimental plots will remain intact for a decade or more, which might be sufficient to allow projections into the next forest planning cycle.

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 into 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 reintroduction of the lacking natural fire component will show success in returning these communities to a pre-suppression state.

DELIVERABLES

This project was projected to result in the production of two annual and one final report, two or more journal articles, and two presentations at the JFSP annual meetings. The two annual reports were produced and submitted. This is the final report promised. Two MS theses were also produced (none were promised). Two reports at JFSP Annual meetings were also promised, however, after the project was initiated, the JFSP stopped having annual meetings to which PIs were invited/requested to present. Two journal articles were anticipated, these are still being written by the graduate students.

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