RED MAPLE (*ACER RUBRUM*) RESPONSE TO PRESCRIBED BURNING ON THE WILLIAM B. BANKHEAD NATIONAL FOREST, ALABAMA

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Abstract—Prescribed burning is used as a management tool on national forests in the Southeastern United States to maintain oak (*Quercus* spp.) -dominated forest or woodland habitat. Few studies have examined response to burning at the stand, plot, and tree level. We documented red maple (*Acer rubrum*) response to dormant-season prescribed burns and the relationship with fire characteristics. At the stand level, large seedling density increased in burned stands by 930 trees per acre, significantly higher than the increase of 10 trees per acre in control stands. Prescribed burning had no effect on red maple sapling mortality, sprouting, or diameter growth. Maximum temperature did not predict red maple density changes or sprouting occurrence at the plot level. At the tree level, char height was a significant predictor of sprouting, and saplings could produce up to 97 sprouts following burning. We conclude that burning as applied in this study was not an effective tool to change species composition and stand structure in this ecosystem.

INTRODUCTION

The concern that hazardous fuel buildup and overstocked stands will increase the risk of unnatural and catastrophic wildfires has led to implementation of large-scale Federal programs to reduce fuels, which include prescribed burning (Veblen 2003). The U.S. Forest Service National Forest System (NFS) implemented prescribed burning treatments on approximately 1.3 million acres per year from 2006 to 2008 for the purposes of hazardous fuel reduction through the auspices of the Healthy Forest Initiative and the National Fire Plan (Healthy Forests and Rangelands 2009a). While much of the media and research attention related to fuels reduction has been concentrated in the Western United States, the NFS conducted 71 percent of prescribed burn acres in 2008 on lands in the Southern Region (Healthy Forests and Rangelands 2009b). National Forests in Alabama burned approximately 99,000 acres in 2008, more than the national forests in Colorado and California combined.

In addition to fuels reduction, prescribed burning is often included in NFS Land Resource and Management Plans to achieve landscape restoration goals to improve wildlife habitat, to conduct site preparation for regeneration, and to restore native species. However, adequate site-specific research examining if fuels reduction treatments can adequately achieve ecological restoration goals is lacking (Veblen 2003), particularly in the Southern United States.

For many years, researchers and natural resource managers have promoted fire as a tool that will restore the oak (*Quercus* spp.) component to upland hardwood forests (Moser and others 2006, Nyland and others 1983, Van Lear and Waldrop 1989). However, empirical evidence is often conflicting due to differences in study design among experiments, and long-term studies are rare. Results from several studies suggest that prescribed burning alone, without additional disturbances involving overstory tree harvesting, will not significantly promote oak regeneration over the short term (Blankenship and Arthur 2006, Hutchinson and others 2005, Signell and others 2005). These studies indicate prescribed burning is an inefficient tool for altering species composition in the understory; however, site-specific research needs to be conducted before broad recommendations can be made regarding the applicability of prescribed burning as a management tool to enhance the oak component in upland hardwood forests. Studies that examine large-scale vegetation responses, e.g., determining differences in vegetation response between silvicultural treatments at the stand level, are useful for determining overall effectiveness of management tools but do not help explain the mechanisms controlling the vegetation response.

A large-scale replicated study was initiated in 2005 on the William B. Bankhead National Forest (BNF) in Alabama to examine the effects of thinning and prescribed burning on fuel loading and residual oak tree health (Schweitzer and Wang, this proceedings). The overall goals of the prescribed burning treatments are to improve forest health and restore native upland hardwood forests, particularly oak, by reducing fuel loading and oak competitors in the midstory and understory. The BNF conducted the prescribed burning for this study under the auspices of their Land and Resource Management Plan (U.S. Department of Agriculture Forest Service 2003). The objective of this study was to examine if prescribed burning treatments were effective at reducing competition from a primary oak competitor, red maple (*Acer rubrum*). We examined response of red maple at the stand level, and we measured fire and tree characteristics at a smaller scale to help determine the mechanisms controlling response of this species to dormant-season prescribed burns.

METHODS

Study Area

We implemented this study within the BNF, in the Southern Cumberland Plateau Physiographic Province (Smalley 1979).

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Average annual precipitation is approximately 57 inches per year, average annual temperature is 60 °F, and elevation averages 870 feet. Soils are Typic Hapludults, consisting of moderately deep, well-drained soils that are weathered from sandstone with a thin strata of siltstone or shale. Stands are on gently sloping to moderately steep side slopes and ridgetops with slopes ranging from zero to 30 percent.

Stands are 15- to 45-year-old loblolly pine (*Pinus taeda*) plantations that have not been entered for harvesting since establishment and have not been burned during the last 10 years. Basal area averages approximately 100 square feet per acre consisting of 75 percent pine and 25 percent hardwood (Schweitzer and Wang, this proceedings). The BNF's Land and Resource Management Plan (U.S. Department of Agriculture Forest Service 2003) details a proposed action for restoring existing pine plantations to oak-dominated forests using treatments that include thinning and prescribed burning.

Data Collection and Experimental Design

This study was conducted within a larger silvicultural research study (Schweitzer and Wang, this proceedings). The original study was designed as a two-factor, randomized, complete block with sampling to examine vegetation response to different silvicultural treatments. Experimental units were 20- to 30-acre forest stands. Treatments included three levels of thinning (no thinning control, residual basal area of 50 square feet per acre, and residual basal area of 75 square feet per acre); three levels of prescribed burn treatments (no burning control, infrequent burn every 8 to 10 years, and frequent burn every 3 to 5 years); and all combinations of burning and thinning treatments. The resulting overall study constitutes nine treatments, each replicated four times, and blocked by year of implementation (block 1 implemented in 2006; blocks 2 and 3 implemented in 2007; block 4 implemented in 2008).

For the purposes of this study, we only examined prescribed burn and control treatments, and we did not examine treatments that involved thinning. The first implementation of the two prescribed burn treatments was conducted during the same year within each of the four blocks; therefore, we had eight replications of the prescribed burn treatment and four replications of the control treatment.

Prescribed burns were conducted between December 20 and March 4 using a combination of flanking, backing, and strip-head fires with hand ignition. Fire behavior was recorded by ocular estimation by BNF personnel during prescribed burns, flame lengths were estimated to average 1.2 feet (range 0.6 to 1.8 feet), and rate of spread was estimated to average 1.4 chains per hour (range 1.1 to 2.0 chains per hour) across the eight prescribed burns. Fires were characterized by BNF personnel as cool burns with low risk of escaping across fire line boundaries. Objectives of burning included fuels reduction, enhancement of wildlife habitat, and enhancement of hardwood natural regeneration (U.S. Department of Agriculture Forest Service 2003).

Five measurement plots consisting of two concentrically nested circular plots were systematically arranged within each stand relatively equidistant to each other. We used a 0.025-acre plot to record large saplings (1.5 to 5.5 inches d.b.h.), and we tallied understory tree regeneration on a 0.01-acre plot by enumerating vegetation into three size classes—small seedlings (<1 foot height), large seedlings (≥1 foot, <4 feet height), and small saplings (≥4 feet height, <1.5 inch d.b.h.). We measured and recorded vegetation in plots prior to and just after each treatment implementation.

To more accurately determine the mechanisms controlling red maple response to fire, we documented fire characteristics within stands. We installed fire-monitoring devices at each of the five vegetation plots within the frequent burn regime treatment units (stands to be burned every 3 to 5 years). We could not measure fire behavior in the infrequent burn regime treatments due to lack of resources. In block 1, maximum fire temperature was measured using aluminum tags painted with five levels of temperature-sensitive paints (Tempil®) that melt at 175, 200, 300, 400, and 575 °F. We positioned aluminum tags horizontally on an aluminum pin flag 10 inches above the ground so that each of the five paints had equal opportunity to melt during the prescribed burn. One tag was placed at plot center, and 4 tags were placed 12 feet in each cardinal direction from plot center, resulting in 25 tags per burn unit in block 1. Temperature-sensitive paints are a relatively inexpensive and efficient method for monitoring fire behavior when resources for research monitoring are low. For blocks 2, 3 and 4, additional resources became available and we used type-K thermocouple probes attached to HOBO dataloggers to record fire behavior data. The probe tips record temperature, and they were placed in an upward position 10 inches above the ground. A 6-foot cable extending from the probe to the datalogger was buried in a 3-inch trench of mineral soil. Prior to transportation to the field, the datalogger was covered in an antistatic bag to prevent a buildup of static electricity (Iverson and others 2004). In the field, the datalogger was placed inside a PVC casing and buried in a 6-inch hole. We installed dataloggers and probes on the morning of the burns, and we programmed them to record temperature every 2 seconds. Care was taken to minimize disturbance to fuels around the probe tip, and the litter layer was repositioned over the trench of the buried cable. We positioned three probes 12 feet from plot center in the north, east, and west cardinal direction. We recorded a plot as burned if one of the paint tags or one of the dataloggers obtained a minimum temperature of at least 175 °F or 90 °F, respectively. If none of the paint tags or dataloggers reached this minimum temperature, we labeled the plot as unburned.

We examined response to fire at the tree-level scale by recording maximum fire temperature and red maple responses for 42 red maple saplings (1.5 to 5.4 in d.b.h.) in the block 4 frequent burn regime unit. We placed two aluminum tags painted with temperature sensitive paint (as described above) just above the litter layer on opposite sides of the base of each tree. Prior to the burns, we measured d.b.h. and tallied number of sprouts (>1 foot in height, <1.5 inch d.b.h.) for each red maple sapling. We also recorded volume (height, width, and depth to nearest 0.1 inch) of existing cambium wounds on the tree. The day following the burns, we measured maximum height of the charred surface, i.e., char height, on each red maple sapling to the nearest 0.1 foot and recorded the minimum temperate recorded from the paint tags. A tree was labeled as unburned if none of the levels of temperature-sensitive paints on the two tags melted. In late May following the prescribed burn, we documented tree mortality, and if the tree was alive, we documented dieback to the main stem and counted number of sprouts.

Data Analysis

We used the statistical program, SAS (SAS Institute Inc. 2000), to conduct all statistical analyses, and we chose an error level of 0.05 to indicate significance in all tests. We examined fire effects at the stand level by using PROC MIXED to conduct an analysis of variance (ANOVA) (table 1). The ANOVA was conducted on pretreatment measurements to determine differences between burn and control treatments in density of red maple regeneration in each size class prior to treatment implementation. We then conducted the ANOVA to determine if there were differences among burn and control treatments in stem density changes following treatment implementation. Stem density change was calculated as the difference in number of stems from before to after treatment implementation. For the ANOVA, we included data from all vegetation plots in the burn treatments, whether they were recorded as burned or unburned, because we wanted to determine overall effect of management practices currently used by the BNF on the density of red maple at the stand level. Normality and equality of variance assumptions for residuals were checked and dependent variables were transformed when needed.

We examined the mechanisms controlling red maple response to fire by measuring fire behavior at the plot and tree level in all of the frequent burn regime treatment units. We conducted a linear regression (PROC REG) to determine if mean maximum fire temperature recorded in the plot could be used to predict red maple density changes of regeneration (<1.5 inches d.b.h.), mortality of red maple large saplings (1.5 to 5.5 inches d.b.h.), and occurrence of large sapling sprouting. We removed plots that were recorded as unburned from the linear regression analysis because it is impossible to determine the relationship between vegetation response to fire characteristics if no burning occurred on the plot itself. Temperatures recorded in block 1 using temperature-sensitive paints were adjusted to be comparable with the temperatures recording using probes in blocks 2 through 4. We adjusted the temperature by multiplying by 0.815 and adding 49.5 °F (Iverson and others 2004). This adjustment is necessary because temperature-sensitive paints record lower temperatures than probes.

We examined fire effects at the tree level by conducting a multiple linear regression using data from the 42 large saplings tallied in block 4. The regression was conducted using a stepwise elimination with mean maximum fire temperature, char height, wound volume, and d.b.h. as independent variables and differences in number of sprouts before and following prescribed fire as the dependent variable. Logistic regression (PROC LOGISTIC) was used to determine if mean maximum fire temperature, char height, wound volume, and d.b.h. could be used to explain the probability of sapling mortality and occurrence of crown dieback. For the multiple regression and logistic regression analysis, we removed trees that were labeled as unburned, as described above.

Table 1—Analysis of variance used to determine differences in changes in density pre- and posttreatment between prescribed burn and control treatment units

Source	Effect	Degrees of freedom	Error term
Treatment	Fixed	1	Block*treatment
Block	Random	3	
Block*treatment	Random	3	
Plot (block*treatment)	Random	9	

RESULTS

The prescribed burns in the frequent burn regime treatment units were relatively similar in mean maximum temperature across blocks but were highly variable within stands. The overall mean of fire temperature was 181 °F (table 2), but plots ranged in mean maximum temperature from 98 °F to 308 °F across all blocks. Block 1 in the frequent burn regime treatment units had the most consistent burn pattern with all plots burning (n = 5), and this block had higher maximum fire temperatures than all other blocks. Block 2 had the lowest

Table 2—Fire mean maximum temperature, associated number of plots (*n*), standard error, and associated range for each block and across blocks. Fire temperature was recorded using temperature-sensitive paints in block 1 and was recorded using thermocouple probes attached to dataloggers in blocks 2, 3, and 4.

Block	*n*	Mean maximum temperature (°F)	Standard error	Range (°F)
1[a]	5	269	12	240–308
2	2	110	12	98–121
3	4	188	21	130–228
4	4	157	5	143–164
Overall	4	181	34	109–269

[a] Temperature values for block 1 have been adjusted as described in the methods.

recorded temperatures and the fewest number of plots that burned (n = 2).

We did not detect any pretreatment differences in red maple density between control and prescribed burn treatments for any size class ($P > 0.70$). Prior to treatment implementation, stands had an average of 1,840, 380, 280, and 208 stems per acre of small seedlings, large seedlings, small saplings, and large saplings, respectively. Small seedling density changes following treatment implementation did not differ between control and burn treatment ($P = 0.91$). Large seedlings increased 930 trees per acre after prescribed burning and increased 10 trees per acre in the control treatment (fig. 1), and the difference between treatments was significant ($P = 0.04$). Prescribed burn units had a reduction of small saplings by 120 trees per acre following treatment implementation, while the control treatments had an increase of 95 small saplings per acre; however, the difference between treatments was not statistically significant ($P = 0.11$). Large sapling density changes were not different between treatments ($P = 0.23$).

Maximum fire temperature was not a good predictor of variation in density changes for red maple regeneration in any size class ($R^2 < 0.22$, $P > 0.28$), and it did not explain variation in large sapling mortality and sprouting occurrence ($R^2 = 0.06$ and 0.0005, respectively; $P = 0.41$ and 0.94, respectively). Char height was selected as the only significant variable that explained variation in number of new sprouts from saplings after prescribed burning ($R^2 = 0.24$, $P = 0.01$). The model predicts that number of new sprouts following burning was positively related to char height (inches).

$$\hat{y} = -7.3 + 20.2b \tag{1}$$

Of the 42 saplings that we tallied, 20 percent had crown dieback and 43 percent produced new sprouts following the burn. Average number of new sprouts following prescribed burning was 10 per tree, but could be as high as 97. Using logistic regression, sapling d.b.h., wound volume, char height, and maximum fire temperature around the base of the tree could not be used to explain the probability of sapling mortality ($P > 0.45$) or occurrence of crown dieback ($P > 0.34$).

DISCUSSION

Fire is an ecological process that has helped maintain oak-dominated forests of the Eastern United States for millennia (Delcourt and Delcourt 1997, Van Lear and Waldrop 1989). Determining the effects of fire on species composition and stand structure through empirical research is difficult due to the variable nature of ecosystem function and processes, and the difficulty in replicating fire as a testable treatment effect. Our research indicates that the first application of dormant-season prescribed burning was highly variable in intensity, as measured from fire temperature, and did not have the desired effect of decreasing red maple density to favor recruitment of hard-mast species like oak. Prescribed burn units showed an increase of 930 trees per acre in the abundance of red maple large seedlings, likely due to basal sprouting following

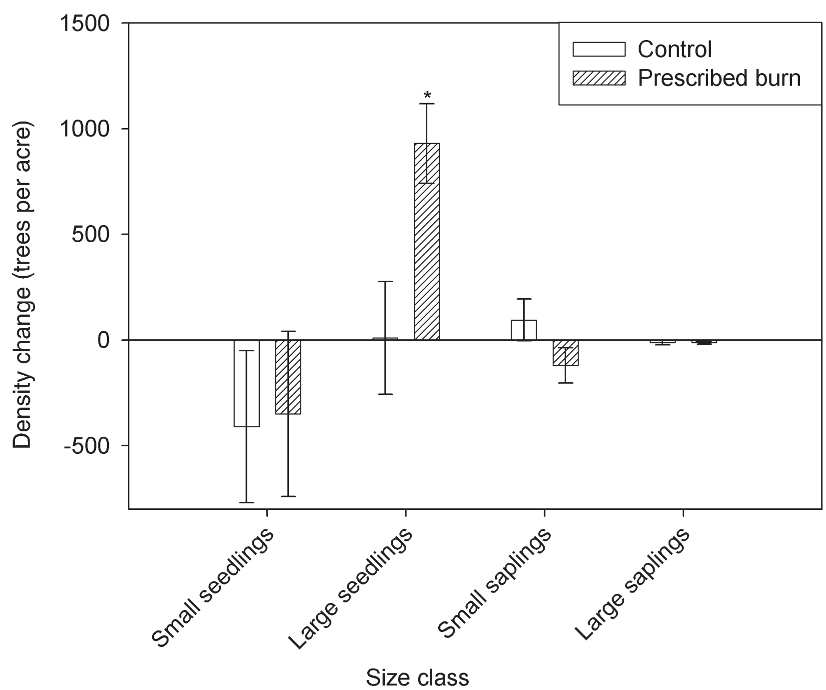

Figure 1—Stem density changes in red maple (*Acer rubrum*) seedlings and saplings following control and prescribed burn treatments. Error bars represent standard error of the mean. Asterisk indicates significant differences between control and prescribed burn treatments for respective size class.

topkill of the main stem. This increase in stem density of large seedlings represents an important biological change that may affect the recruitment of advanced oak regeneration (Lorimer and others 1994). While small saplings did decrease by 120 trees per acre in prescribed burn units, the difference between burn and control units in stem density changes was not statistically different. The reduction in small saplings in burn units may be significant to managers, however, as this represented a 46-percent density decrease from pretreatment levels.

We predict that additional prescribed burn treatments alone will not reduce red maple density of large seedlings in the short term. Blankenship and Arthur (2006) found that three prescribed burns increased the density of red maple stems in a similar size class to the large seedling size class in this study. Decreases in red maple seedling densities due to fire will probably be temporary as sprouts mature and new seedlings establish after the disturbance (Hutchinson and others 2005, Waldrop and others 2008).

Examination of smaller scale mechanisms that might affect red maple response was difficult due to the variable nature of the fire and response of red maple at the plot and tree level. The use of maximum fire temperature measured from temperature-sensitive paints placed at the base of maple saplings was not useful for predicting individual tree response to prescribed burning. If we repeat this study, we will measure temperature at positions farther up the bole of the tree to increase correlations between tree response and fire temperature. Char height was the only variable that was a significant predictor of tree response to fire, and this variable was correlated positively to number of sprouts produced following a prescribed burn. Char height has been shown to be a good indicator of mortality in boreal species (Hely and others 2003) and in slash pine (*Pinus elliottii*) (Menges and Deyrup 2001), but has not been adequately tested for red maple.

CONCLUSIONS

At a stand-level scale, prescribed burning did not have a significant effect on reducing red maple density. In fact, density of large seedlings significantly increased compared to the control treatment. Small sapling density decreased by 46 percent in burn treatments. Although this reduction was not statistically different than the control, it may hold some value for management practitioners in these ecosystems. Without additional treatment, however, basal sprouts from these topkilled small saplings will eventually contribute to overall recruitment of red maple into the midstory. The failure of correlation between vegetation response and fire temperature at the plot and tree level was due to the high variability in fire behavior and in the spatial patchiness of the burns. We predict that repeated burning alone will not be an effective tool to reduce the abundance of red maple due to the ability of this species to sprout prolifically following topkill of the main stem.

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