EFFECTS OF PRESCRIBED FIRE ON THE WOOD QUALITY AND MARKETABILITY OF FOUR HARDWOOD SPECIES IN THE CENTRAL APPALACHIAN REGION

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Abstract.—A series of research studies addressing the effect of prescribed fire on oak (*Quercus* spp.) regeneration has been ongoing on the Fernow Experimental Forest in northeastern West Virginia for 10 years. The study site is a mesic, mixed oak forest. Two prescribed fires were conducted in spring 2002 and 2005. In 2010, a shelterwood harvest was conducted. A complementary study was undertaken to evaluate the effects of the prescribed fires on the quality and marketability of the wood removed in this harvest. Seventy-four logs from the four most populous commercial species located on the study site were tracked from forest through milling. Before harvest, trained timber graders visually evaluated the residual effects of the prescribed fires on tree grade and merchantable volume. At the sawmill's log yard, pictures were taken of the logs and paint marks were placed on the log ends to indicate the side of the log most affected by the fire. During sawing, the first two boards recovered from the marked side were marked for examination. The percentage of these most "at-risk" boards showing indications of defect potentially attributable to the heat of the fire ranged from 10 percent for yellow-poplar (*Liriodendron tulipifera*) to 65 percent for red maple (*Acer rubrum*), which translates to between 2 and 16 percent of all boards sawn from these butt logs. Fire-associated defects included mineral stain, decay and incipient decay, shakes, and checks.

INTRODUCTION

The use of prescribed fire in eastern hardwood forest management has gained the acceptance of many forestry, wildlife, and ecology professionals. Resource managers use fire as a tool to develop desired regeneration, habitat, and ecological restoration outcomes and to reduce fuel buildup to lower the risk of wildfires. Numerous national forests in the U.S. Forest Service's Eastern Region have revised their planning documents to include fire as a restoration tool (Nowacki et al. 2009). In Ohio, use of prescribed fire by the state's Division of Forestry increased from less than 100 acres and three or fewer fires per year in the 1990s to an average of more than 1,000 acres and seven fires per year from 2000 through 2008 (Bowden 2009) and to an average of about 2,500 acres burned today (Ohio Department of Natural Resources 2013). The "2012 National Prescribed Fire Survey Report" (Melvin 2012) indicates that the acres to which prescribed fire has been applied in the central Appalachian region has been trending up in Pennsylvania, Virginia, Tennessee, Kentucky, and Ohio. The Monongahela National Forest in West Virginia sets annual targets for prescribed burning at about 3,000 acres. Restoration goals are being realized, but the effects on wood quality are not fully known.

Eastern hardwood tree mortality caused by fire has been evaluated in multiple studies. Factors assessed in these studies included fuel types and loadings (Brose and Van Lear 1999, Wendel and Smith 1986, Yaussy and Waldrop 2010), bark thickness (Harmon 1984, Yaussy and Waldrop 2010), tree diameter (Harmon 1984, Hutchinson et al. 2005, McCarthy and Sims 1935), season in which

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fire occurred (Brose and Van Lear 1999), fire severity (Regelbrugge and Smith 1994, Yaussy and Waldrop 2010), and tree vigor before fire exposure (Yaussy and Waldrop 2010). Fire damage severity based on degree of bole damage and crown condition also has been widely studied (Brose and Van Lear 1999, Pomp et al. 2008, Wendel and Smith 1986). The process of wound formation after fire injury has been studied by Sutherland and Smith (2000) and Smith and Sutherland (2001, 2006).

Only two studies appear in the literature related to the timber value impacts of fire. (Both studies were based on wildfire.) In a study of multiple stands in Kentucky, the average timber volume loss per acre due to wildfires was found to be 2,298 board feet and the average value loss per acre was $404 (Reeves and Stringer 2011). A study conducted in a region of southern West Virginia that has had a long history of wildfires found that net volume and dollar value per acre declined with increasing fire frequency; value decreased as much as $619 per acre, representing a 54-percent decline in stumpage value for stands subjected to six wildfires over 36 years (Wood 2010). Information about the impact of fires on hardwood timber quality, volume, and value is of interest to land owners and managers but is not well substantiated or understood across a range of timber types, landscapes, and fire conditions. Quality and value information would be useful for decisionmaking related to fire prevention efforts and prescribed fire use as well as stumpage pricing. Extending the information to include insights into the impact of fire on wood product quality, volume, and value potential would be a further step toward informing land owners and managers as well as timber buyers and producers so that decisions on timber management and procurement can be optimized.

OBJECTIVES

The preponderance of research on the effects of fire, both wildfire and prescribed fire, on hardwood species has focused on mortality rates and tree quality impacts. There is a dearth of research that extends this analysis to look at product recovery and quality impacts. This information has been sought out by the West Virginia Division of Forestry, among others. The overall objective of this study was to begin to develop information on the impact of fire on the volume and value yields of lumber of affected trees. The principal hypothesis under investigation was: There is no relationship between species and the occurrence of six types of lumber defects judged to have been caused by exposure to two prescribed fires.

An important, nonmeasurable objective of this research was to develop insight from this pilot study that will allow us to design a larger scale, longer term study on the effects of fire on lumber volume and value recovery that will be used by resource managers in making decisions about the use of prescribed fire and the value of trees that have been compromised by wildfire.

METHODS

The overstory trees from the prescribed fire and oak regeneration study conducted on the Fernow Experimental Forest in West Virginia (Schuler et al. 2013) were scheduled for removal during the dormant season of 2009-10. This was the first stage of the shelterwood removal process. The prescribed fires were conducted in the Canoe Run watershed of the Fernow Experimental Forest (39.03° N, 79.67° W). The elevation of the study site ranged from 1,920 to 2,200 feet with a western aspect and a mean slope of 39 percent. Overstory species composition of much of the Fernow is described as mixed mesophytic; this study site is dominated by northern red oak (*Quercus rubra*), chestnut oak (*Q. prinus*), and white oak (*Q. alba*) (Schuler et al. 2013). The site is a second growth forest that is about 100 years old. Two prescribed fire treatments have been applied to the site; the first was conducted in April 2002 and the second in April 2005. The maximum temperature probe readings recorded during these two burns were 576 °F in 2002 and 621 °F in 2005 and the associated rates of spread were 30 and 144 feet per minute, respectively (Schuler et al. 2013). These prescribed fires were designed to minimize damage to overstory trees and were characterized by Schuler et al. (2013: 432) as "moderate to low intensity with flame lengths less than 3 feet resulting from the combustion of leaf litter and 1-hour surface fuels."

The harvest of shelterwood trees from this site represented an opportunity to evaluate the wood quality (on a macroscale) and potential product value of hardwood trees that had been exposed to prescribed fire. Arrangements were made with the sawmill that purchased the timber to allow us to track the breakdown of about 80 logs at the sawmill. The sample size of this study was dictated by the need to limit our interference with the operations of the cooperating sawmill. The 80-tree sample size was split among 4 species to provide a broader look at the wood quality impacts of prescribed fire on commercial species of the region in anticipation of a more comprehensive future study.

Sample Selection and Quality Assessment in the Woods

Based on comprehensive data sets maintained for the fire and oak regeneration study, four commercial tree species that were prevalent among the larger shelterwood stems (>13 inches diameter at breast height [d.b.h.]) on the study site were selected for this study: red maple (*Acer rubrum*), red oak, white oak, and yellow-poplar (*Liriodendron tulipifera*). Sample trees for this study were selected from within and proximal to the established plots of the fire and oak regeneration study (Schuler et al. 2013). Trees in these plots have been measured about every 3 years since the study was established in 2000. Data loggers positioned in each plot during the prescribed fires provided information on temperature intensity and rate of fire spread. Trees having a d.b.h. of ≥13 inches (i.e., large enough to meet Hardwood Tree Grade 2 minimum d.b.h. requirement) in each of the four target species that were scheduled for harvest were included in this study.

Sample selection was conducted by timber technicians at the Fernow who are experienced in species identification, measurement, and tree grading. The criteria for selection were: (1) trees only of the four target species (target of 20 trees per species), (2) trees from among those marked for removal in the upcoming harvest, and (3) live stems only. Inclusion in the sample did not depend on the type or amount of fire scarring evident (if any) on the tree bole. After the sample was selected based on the three listed criteria, the following data were collected for each tree:

- Species
- Type of fire scar (none, black bark, bark sloughing, cat face, butt scar)
- Length of fire scar from base of tree
- Circumference of fire scar around tree at widest point
- Scar location relative to slope (uphill or uphill and side-hill)
- Tree d.b.h.
- Tree grade
- Amount of deduction, if any, due to burn scar

Figure 1.—Red maple logs from Fernow Experimental Forest, West Virginia, at sawmill log yard with paint and arrows designating the face on each log that was affected by fires and a log identifier (X32, X1, X11) for use in tracking the lumber sawn from each study log.

Butt logs from the sample trees were marked with paint and flagged. After harvest, the logs from each tree were again marked with paint and the tree number was marked on the end of each log for tracking purposes at the sawmill. The study sample was segregated at the log landing and hauled to the mill, where it was again segregated from the other logs in the log yard.

Sawmill Study Methods

At the sawmill, in advance of the tracking study, sample logs were spread out in the log yard and the face of each log with the most significant evidence of fire was designated by marks painted on the log ends (Fig. 1). Different colors of paint were used for each species to help with tracking during breakdown in the sawmill. In addition, a log scaler at the cooperating sawmill graded and scaled each of the study logs and provided that information to us so that we could evaluate the value loss associated with the fire-caused cull deductions noted by the timber technicians during sample selection.

For the tracking study in the sawmill, all logs of a given species were processed before the logs of another species were brought into the sawmill. As each log was sawn, the marks on the ends of the logs were used to identify the first two boards sawn from the fire-affected face. These two boards were marked and renumbered and the orientation of the marks was applied so that we could be certain which end of each board was from the butt end of the study log. In the sawmill, 19 red maple, 21 red oak, 16 white oak, and 23 yellow-poplar were sawn as part of this study.

Between communicating with the forklift operator and the lumber marks placed on the sample boards of interest, most of our marked boards were successfully separated for us into unique stacks in the lumber yard to enable us to inspect lumber quality. For 67 of the sample trees, both boards were successfully tracked and evaluated for quality. For seven of the sample trees, only one of the two boards sawn from underneath the fire-affected surface was available for evaluation. Board samples from six sample trees were not successfully segregated, so they could not be recovered and evaluated. In the end, board samples (1 or 2 boards) from 17 red maple trees, 20 red oak trees, 16 white oak trees, and 21 yellow-poplar trees were evaluated for defect potentially caused directly or indirectly by the prescribed fire.

Lumber evaluation at the sawmill was designed only to identify defects occurring on the first two boards removed below the bark on the face of the butt log that was most affected by the heat of the prescribed fire. Defects identified were those that could have been caused by the heat generated by the fire. Thus, defects such as knots and double pith were not documented; but decay, mineral stain, shakes, and checks were recorded. When the defects of interest were located within the bottom 6 feet of the board, they were captured in the tally. A stain or decay defect that was located farther up the board without associated defect area at the bottom of the board, was not included.

Data Coding and Analysis

Butt log quality effects evaluated in the woods that were judged to be associated with the prescribed fire were coded as 0 (no effect) or 1 (grade- or scale-reducing effect). We used a generalized linear model via PROC GENMOD (SAS 9.3, SAS Institute Inc. 2011) with tree species as a fixed effect. We used the binomial distribution and the logit link function. After running the model, we had unstable maximum likelihood estimates because yellow-poplar yielded a "perfect" model (i.e., no variation in the response outcome because none of the yellow-poplar tree boles had grade or scale reductions). We deleted this species and reran the analysis. Statistical differences in the three remaining species were evaluated by least means squares. The test was conducted with a significance level of $\alpha = 0.05$. Pivot table analysis and simple calculations were used to further examine log defects by species and the value loss associated with these defects.

Lumber quality observations tallied at the sawmill were evaluated by using a generalized liner model via PROC GENMOD (SAS Institute Inc. 2011). Using expert opinion, we ordered the six outcomes from least to most detrimental to lumber quality. The lumber quality rating scores were coded as follows: 1 - clear, 2 - mineral stain, 3 - checks, 4 - ingrown bark, 5 - decay, and 6 - shake. The fixed effect in the model was species. Because of the inherent ordering we used a multinomial distribution model with a cumulative logit link function (Allison 1999). To evaluate statistical differences in species we used least squares means.

RESULTS AND DISCUSSION

Tree Quality

Of the 79 trees marked for inclusion in this study, all but 9 trees had visible signs of bark alterations due to the prescribed fires. However, only 10 trees were judged to have suffered tree grade or scale volume reductions. Of the 10 trees that showed a substantial fire effect, 7 were red maple stems (Table 1). Of the 23 yellow-poplar stems measured for the study, none showed visual evidence of grade or scale volume-reducing defects that could have been caused by the prescribed fires (Table 1).

The 10 trees with defects that affected the tree grade and led to a scale deduction each had a large cat face at the bottom of the butt log on the uphill face of the tree (Fig. 2). Four of these trees suffered cull (volume) deductions of 10 percent, four contained cull amounts of 20 percent, and two had cull deductions of 30 percent. None of the other types of defects (black bark, bark sloughing, small cat face, butt scar) were judged to be more than superficial in terms of their effects on the quality of the underlying wood. A log value loss associated with the cull deduction was calculated for each butt log based on the log value assigned by the scaler at the sawmill. The percentage-based log value loss for all

Table 1.—Visual quality assessment of trees selected for study of effects of prescribed fire on wood quality and value, by species, West Virginia

Grade- or scale-reducing defect present?	Evidence of fire	Red maple	Red oak	White oak	Yellow-poplar	Total
No		12	19	15	23	69
	None	4	1	1	3	9
	Black bark	3	17	10	17	47
	Bark sloughing	1	0	2	3	6
	Cat face, small	1	1	1	0	3
	Cat face, large	3	0	0	0	3
	Butt scar	0	0	1	0	1
Yes		7	2	1	0	10
	Cat face, large	7	2	1	0	10
Total		19	21	16	23	79

butt logs in the sample was 0.023 percent for red maple, 0.010 percent for red oak, 0.002 percent for white oak, and 0.000 percent for yellow-poplar.

Based on the statistical results, red maple is more prone than white oak to suffer tree grade- or scale-reducing damage from prescribed fire of low to moderate intensity ($P > 0.039$). Differences in tree grade and scale damage amounts caused by fire for red oak and white oak were not significant. Red oak and red maple tree damage results did not differ, but with a P-value of 0.055, this outcome is not absolute. Yellow-poplar was not included in the model because, with no samples of this species indicating damage, its inclusion made the model unstable. The lower occurrence of damage in yellow-poplar than in white oak shows that yellow-poplar is less prone to fire-caused tree grade and scale defects than white oak or red maple. Therefore, the null hypothesis is rejected as there appears to be a relationship between species and the occurrence of tree grade- or scale-reducing defects.

The occurrence of more fire-related defects in the red maple stems than in the white oak and yellow-poplar stems is an expected outcome. Fire simulations performed by Hengst and Dawson (1994) substantiate the belief that thicker barked species are less vulnerable to damage from certain types of fire as the bark provides cambial protection. The maximum cambial temperatures in thick-barked species are lower and the time to maximum temperature is longer; thus, a fire that spreads more quickly will inflict less damage on thicker barked species (Hengst and Dawson 1994). The average ratio of d.b.h. inside bark to d.b.h. outside bark for the four species included in this study are 0.942 for red maple, 0.921 for red oak, 0.929 for white oak, and 0.896 for yellow-poplar (Martin 1981). These ratios show that yellow-poplar has the thickest bark and red maple the thinnest bark of the species studied.

Lumber Quality

Although 79 trees were evaluated for grade and defect in the field, lumber from only 74 of these trees was evaluated after sawing due to tracking problems noted under Methods. Aligned with the log quality results, the percentage of yellow-poplar boards found to be clear of fire-related defects was higher than for the other species and the percentage for red maple was the lowest among the four

Figure 2.—Large cat face on uphill side of red maple tree that was exposed to two prescribed fires 5 and 8 years before this picture was taken (Fernow Experimental Forest, West Virginia).

species (Table 2). Also, except for red oak, the second board removed from beneath the fire-affected face of the log was clear of targeted defects (decay, incipient decay, mineral stain, checks, shake, and ingrown bark) more frequently than the first board (Table 2). Targeted defect occurrence rates shown in Table 2 indicate that mineral stain was found more frequently in red maple whereas checks and shake were found more frequently in red and white oak, known to be check-prone species.

The lumber quality differences among species were significant with yellow-poplar lumber possessing fewer of the most damaging fire-associated defects (ingrown bark, decay, shake) than the other three species. In evaluating the lumber quality summary data, this relationship between species and defect occurrence stands out (Table 2).

These trees were harvested fairly quickly after the prescribed fires were conducted (7-8 years after the first fire and only 5 years after the second fire); thus, the full impact of the prescribed fire on butt log/tree value and lumber yield and value could not be appraised fully. At most, decay occurring as a result of burn injuries will be found in the outer couple of boards, which will tend to be narrower boards than would be the case if the decay were found further into the wood. As seen in Table 2, some of the defect was “incipient decay,” an early stage of wood decay that may further proliferate and worsen with time, depending on the ability of the tree to compartmentalize the injury. As this was just the first step in the shelterwood removal process, some injured trees are expected to remain in the stand for another 15 years or more while other steps in the prescription are implemented. Time plus an additional prescribed fire could result in substantially more loss in wood volume than documented here.

Table 2.—Number and percentage of clear boards and targeted defects on boards sawn from the log section located under the face of the log most affected by prescribed fires for four species, West Virginia

	Number and percentage of boards free of targeted defects		Targeted defects					
Species and board position	Clear	Percent clear	Mineral stain	Checks	Decay and incipient decay	Shake	Ingrown bark	Total number of boards surveyed
Red maple								
1st board	5	33	6	0	3	1	0	15
2nd board	6	37	7	0	2	1	0	16
Red oak								
1st board	9	47	3	3	1	3	0	19
2nd board	9	45	2	5	2	2	0	20
White oak								
1st board	9	47	1	3	2	1	1	17
2nd board	8	57	2	2	1	0	1	14
Yellow-poplar								
1st board	18	90	2	0	0	0	0	20
2nd board	20	95	1	0	0	0	0	21

Lessons Learned for Future Research

Several elements of this preliminary study, which was planned and conducted over a short timeframe to take advantage of the impending harvest of trees that had been exposed to prescribed fires (Schuler et al. 2013), will inform a more comprehensive, designed study for which planning has begun. Besides the obvious problems of logs and boards beings lost at the sawmill, experimental design adjustments are needed. A control sample of matched trees from a nearby, unburned stand with similar stand attributes will allow for a more meaningful analysis of the impacts of prescribed fire on volume and value yield. The checks and shakes seen in the oak species in this study may or may not have been related to the fire; the control sample would help make that determination. Another sample selection factor to be implemented in future research is the selection of equal-size samples of trees from different fire-affected stands having different slopes. Another factor of interest that may help explain vulnerability of a stem to fire damage is stem d.b.h., so sample selection will include at least two distinct d.b.h. classes (e.g., 12-17 inches and 22-27 inches). Evaluating the effects of prescribed fire on wood quality and value after a greater period of time has passed will add value to the information obtained from a more expansive study.

At the sawmill, the study must capture the thickness of the slab removed as the first boards are sawn so that the depth-below-bark of the boards is known. The most important change needed in the sawmill portion of the study is the allocation of more time to lumber measurements so that specific defect sizes and recovery impacts can be captured.

CONCLUSIONS

Loss in log value associated with two prescribed fires of low to medium intensity can appear minimal upon visual inspection of stems 5 years or more after the burn was conducted. In this case, value loss of <0.25 percent was suffered overall from cull caused by decay that resulted from injury from the heat of the fire. Red maple was the most prone to fire damage among the species evaluated here. Yellow-poplar had the lowest risk of injury because of its thick bark, which insulates the wood from temperature extremes. The outer two boards sawn from the side of logs that are most directly exposed to the heat of the fires develop mineral stain and some level of decay about 65 percent of the time in red maple, about 7 percent of the time in yellow-poplar, and at an intermediate rate in red and white oak. Lumber value loss is to be expected after prescribed fires, and the occurrence rate is greater than would be expected based solely on the visual inspection of the butt logs in the woods. A much more expansive and controlled study design is required to be able to determine value loss rate ranges for different physical and market conditions. As the oak regeneration process may require 15 to 20 years or longer from the time of the first prescribed fire to the final shelterwood harvest, the effects of fire intensity and duration of time until harvest on value impacts need to be elucidated.

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