ANALYSIS OF TWO PRE-SHELTERWOOD PRESCRIBED FIRES IN A MESIC MIXED-OAK FOREST IN WEST VIRGINIA

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Abstract.—In 2009, a mesic mixed-oak forest in West Virginia treated with two prescribed fires (2002-2003 and 2005) to eliminate a shade-tolerant understory was characterized by 7,500 seedlings/acre ≥1.0 foot tall of oak (*Quercus* spp.), maple (*Acer* spp.), black birch (*Betula lenta*), and yellow-poplar (*Liriodendron tulipifera*) combined. Maple was the most abundant group before burning but thereafter, maple (1,192/acre), oak (1,557/acre), and yellow-poplar (1,597/acre) seedlings ≥1.0 foot were approximately equally represented. Black birch was the single most abundant species (3,337/acre). Following the prescribed fire treatments, sapling density was reduced by about 90 percent and has not recovered. Fire effects to the overstory, canopy, and subsequent understory light environment were not significant, but a shelterwood harvest in 2009-2010 reduced overstory basal area from 145 to 62 feet^2/acre and from 108 to 44 stems/acre (diameter at breast height ≥5.0 inches). A post-shelterwood prescribed fire is planned for 2013 or 2014 and will complete the experimental design of this study.

INTRODUCTION

Many mixed-oak (*Quercus* spp.) forests in the Eastern United States exhibit a trend of declining oak importance (Abrams 1992). This shift is occurring as overstory oaks are harvested or die and then are being replaced by shade-tolerant species present in lower canopy strata (Schuler 2004). In the central Appalachians, species such as red and sugar maple (*Acer rubrum* and *A. saccharum*) and black birch (*Betula lenta*) have become increasingly abundant in stem numbers and growing stock volume over the past several decades (Alderman et al. 2005, Fei and Steiner 2007, Schuler 2004). Nowacki and Abrams (2008) refer to this trend as the "mesophication" of eastern forests and attribute much of the cause to the lack of periodic fire throughout much of the 20th century.

Silvicultural guidelines that have been developed to sustain oak and reverse the mesophication trend include various herbicide applications, prescribed fire sequences, fencing options, and planting treatments and variation in the timing and degree of harvests (Brose et al. 2008, Loftis 1990, Steiner et al. 2008). In some circumstances, prescribed fire is recommended for both site preparation and release of existing oak seedlings from overtopping woody competition (Brose et al. 2008). The use of prescribed fire to release oaks from overtopping vegetation following the first removal cut of a shelterwood, referred to as the "shelterwood-burn technique" (Brose and Van Lear 1999), has been tested successfully in the Virginia Piedmont (Brose et al. 1999), but studies in the central Appalachians generally are lacking.

Our original objective was to design a study to test the shelterwood-burn technique in the mesic Allegheny Mountains of West Virginia. When this study was initiated in 2000, however, the

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understory included too few oak seedlings of competitive size relative to other woody species to conduct a shelterwood harvest. Therefore, we began by studying the effects of site preparation burning postulated to remove interfering competition and create conditions suitable for the establishment of new oak seedlings. Although these conditions have delayed the assessment of the original objective of this study (i.e., a test of the shelterwood-burn technique), it is a common situation on the landscape today, whereby small oak seedlings are present but overtopped by a dense layer of shade-tolerant woody vegetation (Nowacki and Abrams 2008).

Herein, we assess prefire and postfire conditions following two prescribed fires. In this paper, we focus on the effects on the seedling, sapling, and overstory strata. The study design included deer (*Odocoileus virginianus*)-exclosure fencing that allowed us to examine the effects of herbivory. After burning we also evaluated treatment effects on canopy characteristics to determine if levels of photosynthetic active radiation were altered relative to unburned control stands. We also include descriptive characteristics of the stand following the shelterwood harvest during the dormant season of 2009-10. Other information about this study is available pertaining to the effects of burning on acorn weevils (McCann at el. 2006), small mammals (Rowan et al. 2005), woodland salamanders (Ford et al. 2010), and the seed bank (Schuler et al. 2010).

METHODS

Site Description

Typical of the central Appalachians at low elevations to mid-elevations (< 3,000 feet), oaks dominate the overstory but are virtually absent from subcanopy strata. Moreover, dense understories of shade-tolerant species, such as striped maple (*Acer pensylvanicum*) and American beech (*Fagus grandifolia*), make it unlikely that new oak seedlings will develop into the larger individuals that will be competitive following a canopy disturbance. Furthermore, new acorns and oak seedlings are preyed upon by insects (Galford et al. 1991) and wildlife species currently abundant but formerly scarce during much of the 20th century (Horsley et al. 2003). As such, oak seedlings are ephemeral and do not persist for extended periods as in the past (Rentch et al. 2003).

Our study was conducted in the Canoe Run watershed of the Fernow Experimental Forest (39.03° N, 79.67° W) in West Virginia. The Fernow is in the Allegheny Mountains of the central Appalachian broadleaf forest (McNab and Avers 1994). The average growing season is 145 days (May to October) and the mean annual precipitation is about 56 inches, which is evenly distributed throughout the year (Pan et al. 1997). Growing season temperatures are typically moderate and growing season moisture deficits are uncommon (Leathers at al. 2000). Overstory species composition is complex and best described as mixed-mesophytic (Braun 1950) throughout much of the Fernow, but within the study area, northern red oak (*Quercus rubra*), chestnut oak (*Q. prinus*), and white oak (*Q. alba*) are the most common overstory species in descending order of importance as measured by basal area. Other common associates in the study area include red maple, sugar maple, black birch, and yellow-poplar (*Liriodendron tulipifera*).

Treatment areas for our study encompass approximately 77 acres in two separate locations approximately 0.15 miles apart. Site elevations range from about 2,000 to 2,500 feet above sea level. Site index is about 70 for northern red oak (Schnur 1937) throughout the study area. Sites with these

Table 1.—Weather and fire behavior characteristics for prescribed burns on the Fernow Experimental Forest, West Virginia

Date	Air† (°F)	RH† (%)	ROS‡ (ft/min)	PT‡ (°F)	WS‡ (mi/h)	Days since rain
4/12/2002	73 - 72	38 - 39	30 (13)	576 (307)	3 (2)	3
4/4/2003	70 - 63	41 - 64	49 (49)	484 (190)	6 (1)	5
4/11/2005	70 - 72	13 - 12	144 (272)	621 (252)	5 (1)	3
4/15/2005	57 - 55	21 - 23	39 (30)	615 (151)	9 (1)	7

† Air temperature (Air) and relative humidity (RH) given for start and finish times of prescribed fires.

‡ Rate of spread (ROS), maximum probe temperature (PT), and wind speed (WS) are means with standard deviations in parentheses.

values are considered good quality for timber production but are less productive than coves or side slopes with a more favorable aspect (Barrett 1995). The study area comprises a broad ridgetop and mostly west-facing side slopes. Soils are Calvin channery silt loam with a minor inclusion of a Gilpin channery silt loam. Calvin soils are well drained, moderately permeable, and strongly acid to very strongly acid. Natural fertility is moderate to moderately low. Gilpin soils are very strongly acid to extremely acid, are moderately permeable, and have moderately low fertility (Losche and Beverage 1967).

Experimental Design and Data Collection

Initial inventories revealed that a dense layer of shade-tolerant understory vegetation was present and would likely inhibit any positive response from the targeted oak seedlings following the first stage of shelterwood harvest. Therefore, we began our study by treating the majority of the study area with two prescribed fires just before the start of the growing seasons in 2002 and 2003, and 2005. The first prescribed fire in spring 2002 was interrupted due to unfavorable weather conditions, resulting in burning only a portion of the study area. The remainder of the study area not burned in 2002 was burned in 2003. In 2005, a second prescribed fire was conducted that resulted in more uniform effects throughout the study area. Fire behavior mostly was moderate to low intensity with flame lengths less than 3 feet resulting from the combustion of leaf litter and 1-hour surface fuels (Table 1). Strip head fires were used to manage fire intensity. Our objective was to minimize injuries to overstory trees and eliminate the shade-tolerant understory. More information on the fire and weather data can be found in Schuler et al. (2010).

We used a three-tier sampling scheme to measure the treatment response of seedling, sapling, and overstory strata through time. We monitored overstory response to treatments in twenty-four 0.5-acre growth plots. All but four of these plots were in the forest matrix treated with the two prescribed fires. We erected deer exclosure fencing in 2000 on half of the overstory growth plots in the forest matrix treated with prescribed fires. The unburned reference plots, primarily established for a concomitant herpetofauna (Ford et al. 2010) study allowed us to compare burned versus unburned portions of the stand. However, there were no fenced plots in the unburned portions of the study area, thereby preventing us from examining the interaction of no fire combined with deer exclosure fencing.

Within each overstory plot, we permanently tagged all stems 5.0 inches and larger in diameter at breast height (d.b.h.) following Lamson and Rosier (1984). All stems were identified by species, status (alive or dead), and d.b.h., and we noted stem characteristics such as fire damage. We defined the sapling size class as all woody stems 1.0 to <5.0 inches d.b.h.; all stems within this size range were permanently tagged and monitored by using the same measures as for overstory trees. We monitored saplings on ten 0.01-acre plots systematically distributed within each overstory plot for a total of 240 sapling-size plots throughout the study area.

We defined the seedling size-class as all woody stems less than 1.0 inch in d.b.h. and tallied seedlings by height class on twenty 0.001-acre plots systematically distributed within each overstory plot for a total of 480 plots. We defined height classes as all stems less than 6, 6 to <12, 12 to <36, 36 to <60, and ≥60 inches in total height but <1.0 inch in diameter. When we collected the data, we recorded seedlings and sprouts separately. However, the vast majority of all stems in this size category were true seedlings and we have combined both forms of regeneration for this analysis and refer to them as seedlings. In this paper, we conducted analyses based on all seedlings and those ≥12 inches in total height. For all three strata, we conducted pre-treatment inventories in 2000 and post-prescribed fire measurements in summer 2006 and 2009. Following the first removal cut of the shelterwood harvest during the dormant season of 2009-10, we collected overstory measurements again in 2010.

To assess the amount of solar radiation penetrating the canopy, we used a Nikon E8400 digital camera (Nikon Corp., Tokyo, Japan) coupled with a Nikon FC-E9 fisheye lens held within a self-leveling mount to take hemispherical canopy images at each plot. One image from the center of the plot at each time period was used for analysis. All images were oriented to magnetic north and taken at heights of about 4 feet, which was above the extant herbaceous layer. We took canopy imagery between August 15 and September 12 in 2007 and 2010. No images were taken before the prescribed burns; therefore, our analysis was limited to comparing twice-burned stands (n=20) to portions of the study area that have not been treated with prescribed fire (n=4).

We then conducted canopy analysis by using the WinsCANOPY system version 2006b (Regent Instruments Inc., Quebec, QC). Latitude and longitude were specified for each image and true north adjusted from magnetic north by using the local magnetic declination during analysis. Interactive masks were used to block any ground surface captured in the image due to slope characteristics. We defined the growing season for canopy analysis as May 1 to September 30. WinsCANOPY estimates numerous canopy parameters based on calculated solar tracks for specific locations and canopy characteristics. We report the under-canopy direct site factor (DSF), which is the ratio of the average daily direct radiation received under the canopy and the average daily direct radiation received over the canopy for the growing season expressed as a percentage. Because photosynthetic active radiation (PAR) is a constant percentage of total radiation, we used DSF as a surrogate for the amount of PAR penetrating the forest canopy to the height of the lens. We also report openness, which is the fraction of the total number of pixels classified as open sky, adjusted for the lens, in the canopy above the lens.

Data Analysis

We used repeated measures modeling with restricted maximum likelihood via SAS PROC MIXED (SAS Institute 2004) to evaluate treatment effects through time for seedling density by species (for all seedlings and seedlings >1.0 foot tall, hereafter referred to as larger seedlings), saplings, and overstory measures. We used a completely randomized design with year, fence, and plot as fixed effects. Both stem density (stems/acre) and basal area (feet^2/acre) were used as response factors for the sapling and overstory strata, whereas only stem density was evaluated for seedlings. The average characteristics for both seedlings and saplings served as the experimental unit for these strata in this paper. In other words, the average of 20 seedling plots and 10 sapling plots on one overstory plot at a point in time compose one experimental unit for each variable of interest.

During preliminary analyses, we included site (ridgetop versus sideslope) as an explanatory factor. Although some differences were found, meaningful ecological results related to the objectives of this study were not identified. Therefore, we present the results independent of any potential effects related to landscape position. We adjusted the denominator degrees of freedom by using the Kenward-Rogers method. In repeated measures analysis, the appropriate specification of the error covariance structure is an important part of the model-building process. After testing several covariance structures, we used the unstructured error covariance model because it generally produced the smallest Akaike information criterion values, resulted in significant p-values from the null model likelihood ratio test in all cases ($\alpha = 0.05$), and was appropriate for unequally spaced repeated measures.

Significant values from the null model likelihood ratio test indicate the unstructured covariance matrix was a better fit than the ordinary least squares null model. Because we were specifically interested in fire effects through time, we excluded the unburned plots from our repeated measures analysis, which allowed us to examine year of observation as the explanatory variable for fire effects rather than evaluating more complex two-way and three-way interactions necessary if we included the control plots. Moreover, although we could not examine the interaction of no fires with fencing present, we include the control plots (i.e., no fire with no fencing) in the graphical presentation of our results for comparison purposes. We used the Tukey-Kramer mean separation test ($\alpha = 0.05$) to examine for individual differences in treatment levels and to interpret interactions between factors, when needed.

RESULTS

Seedlings

Repeated measures analysis indicated that year was a significant predictor of total oak seedling density ($p < 0.001$). Oak seedling density was greatest in 2006 after two prescribed fires as indicated by mean separation results, totaling almost 10,000 seedlings/acre (Fig. 1). Neither fencing ($p = 0.6794$) nor the year*fence interaction ($p = 0.9970$) was a significant predictor of oak seedlings. When we considered just oak seedlings >1.0 foot in total height, again year was the only significant factor in the repeated measures model ($p = 0.0045$). However, it was not until 2009 that the number of larger oak seedlings increased significantly as indicated by the Tukey-Kramer results. Before burning, there were only about 50 larger oak seedlings/acre and this level remained relatively unchanged in 2006 after burning, but by 2009 the density increased to more than 1,500 stems/acre. Northern red oak was the most abundant of the three oak species present. There were almost no larger oak seedlings in the unburned control plots at any time in the last decade (Fig. 1).

As expected, there was an abundance of maple seedlings throughout our sampling intervals, but prescribed fire did alter population levels ($p = 0.0031$). Maple seedling density was greatest before burning in 2001, decreased by about two-thirds in 2006 following the burn treatments,

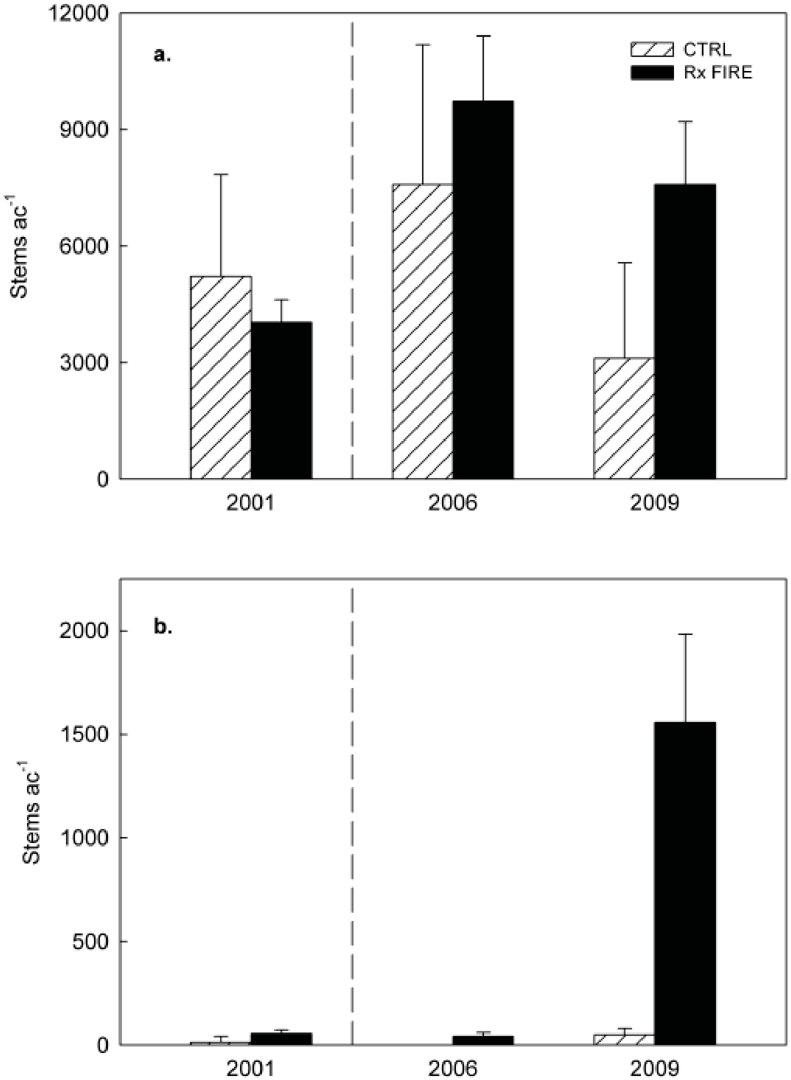

Figure 1.—Mean oak (includes northern red, chestnut, and white oak) seedling density (with standard error) through time for study areas on the Fernow Experimental Forest, West Virginia, subjected to two prescribed fires (n=20) and reference areas not treated with fire (n=4). a. Oak seedlings of all sizes; b. oak seedlings ≥12 inches tall. Dashed vertical line represents preconditions and post-conditions related to prescribed fires.

and recovered in 2009 (Fig. 2). The Tukey-Kramer results identified 2006 as unique, indicating the fire effects were short-lived. There was some evidence that the interaction of year and fencing ($p = 0.0502$) was contributing to the results as well. Most noteworthy observations occurred in 2009, when we found an average of 14,435 maple seedlings/acre in the unfenced plots and 6,990 seedlings/acre in the fenced plots. In 2001 and 2006 there were no meaningful deviations among fenced and unfenced results. There was no evidence that the interaction between year of observation and fencing carried over into larger maple seedlings ($p = 0.2488$), either. Larger maple seedling density differed only by year ($p = 0.0277$), with the preburn density significantly higher than the 2006 and 2009 observations (Fig. 2), suggesting the number of larger maple seedlings had yet to recover to preburn levels.

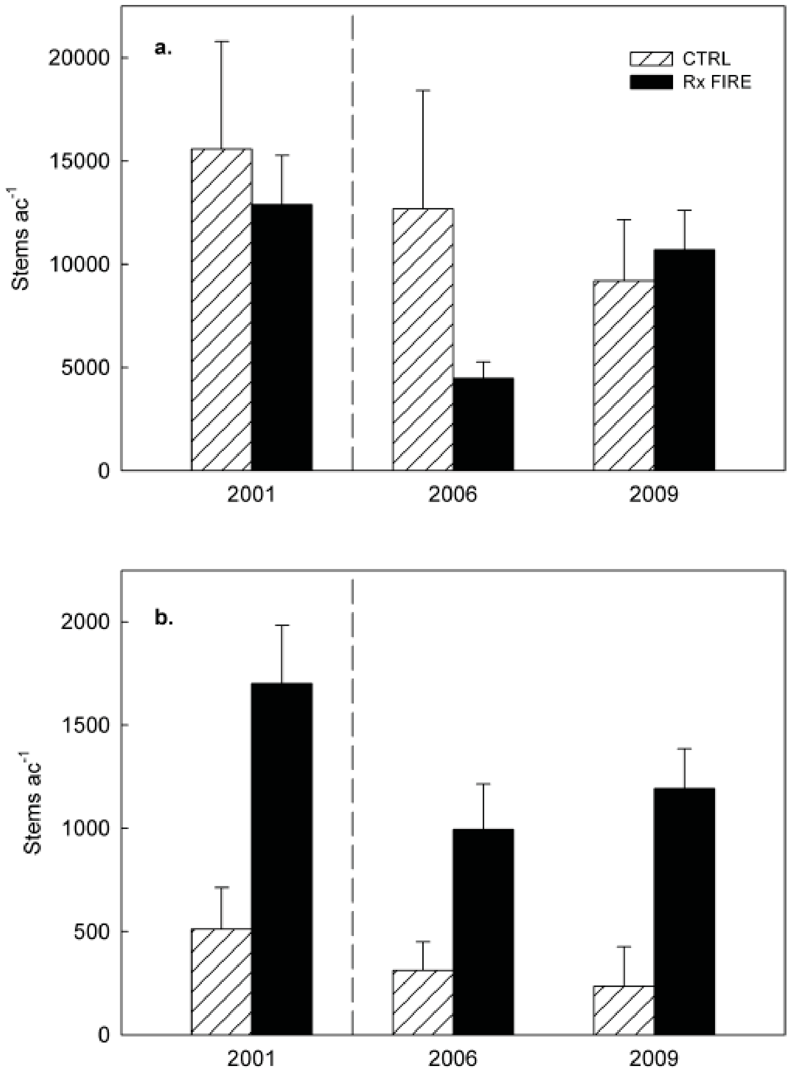

Figure 2.—Mean maple (includes striped, sugar, and red maple) seedling density (with standard error) through time for study areas on the Fernow Experimental Forest, West Virginia, subjected to two prescribed fires (n= 20) and reference areas not treated with fire (n=4). a. Maple seedlings of all sizes; b. maple seedlings ≥12 inches tall. Dashed vertical line represents preconditions and post-conditions related to prescribed fires.

The responses of black birch and yellow-poplar to prescribed fire were similar. Total birch (p = 0.0012) and yellow-poplar (p = 0.0010) seedlings varied by year in the repeated measures analysis and increased almost tenfold in 2006 after burning (Figs. 3 and 4). By 2009, total seedling densities for both species were beginning to decline, but densities of larger seedlings increased. It appears that many smaller birch and yellow-poplar seedlings were surviving and growing into larger seedlings in the understory environment. For larger seedlings alone, year of observation was the only significant model term for both birch (p = 0.0012) and yellow-poplar (p = 0.0101), but the increase was not significant until 2009 for either species according to the mean separation tests (Figs. 3 and 4).

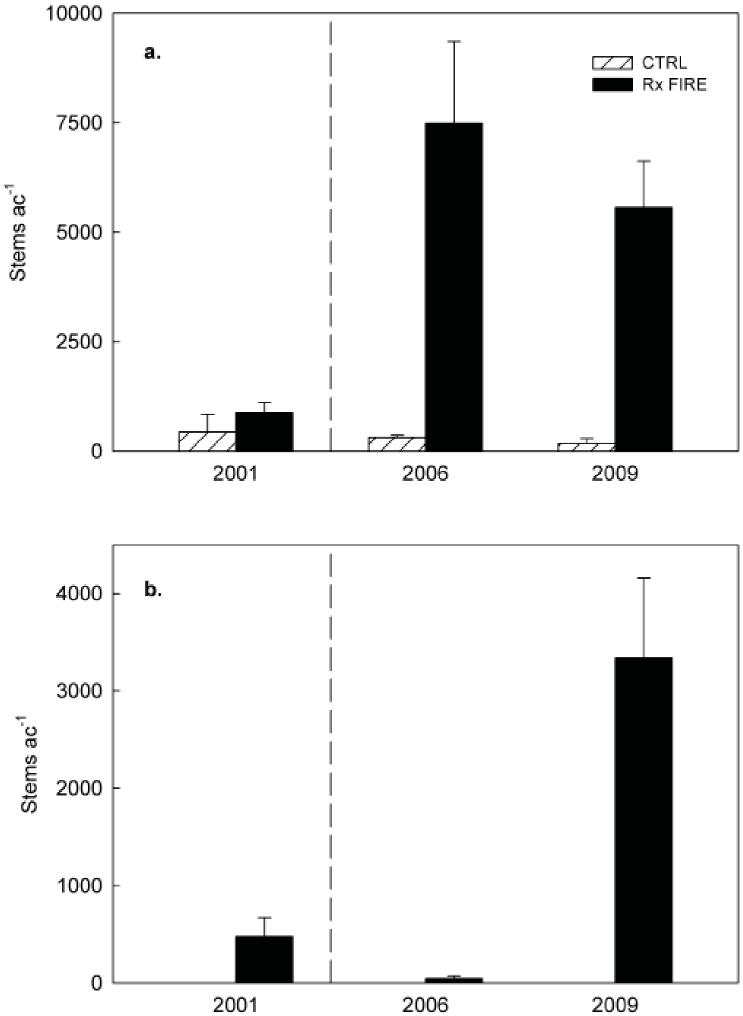

Figure 3.—Mean black birch seedling density (with standard error) through time for study areas on the Fernow Experimental Forest, West Virginia, subjected to two prescribed fires (n=20) and reference areas not treated with fire (n=4). a. Black birch seedlings of all sizes; b. black birch seedlings ≥12 inches tall. Dashed vertical line represents preconditions and post-conditions related to prescribed fires.

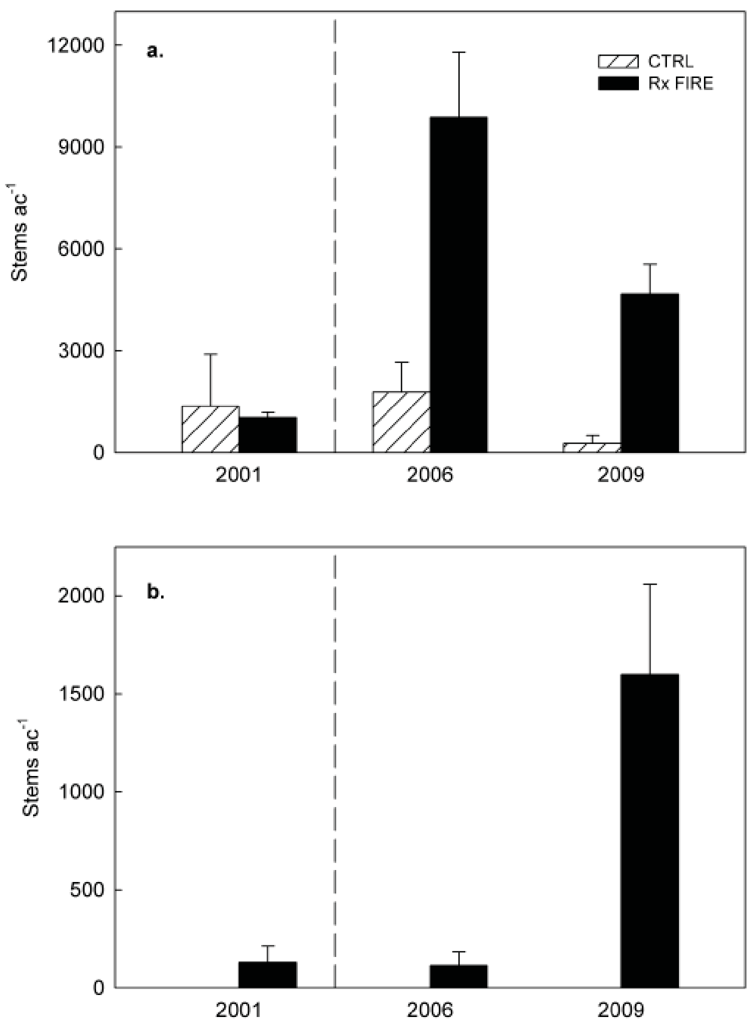

Figure 4.—Mean yellow-poplar seedling density (with standard error) through time for study areas on the Fernow Experimental Forest, West Virginia, subjected to two prescribed fires (n=20) and reference areas not treated with fire (n=4). a. Yellow-poplar seedlings of all sizes; b. yellow-poplar seedlings ≥12 inches tall. Dashed vertical line represents preconditions and post-conditions related to prescribed fires.

By 2009, areas treated with prescribed fire were supporting dense seedling populations totaling more than 7,500 seedlings/acre ≥1.0 foot in total height of oak, maple, birch, and yellow-poplar combined. Maple was the most abundant genera before burning, but after burning by 2009, maple (1,192/acre), oak (1,557/acre), and yellow-poplar (1,597/acre) seedlings ≥1.0 foot were approximately equally represented and birch was the most abundant species (3,337/acre). With respect to seedlings of this size (≥1.0 foot tall) and the burning treatments, oak, yellow-poplar, and birch all increased in density in response to prescribed fire treatments, whereas maple declined. Fencing had no meaningful effects on woody seedling population levels.

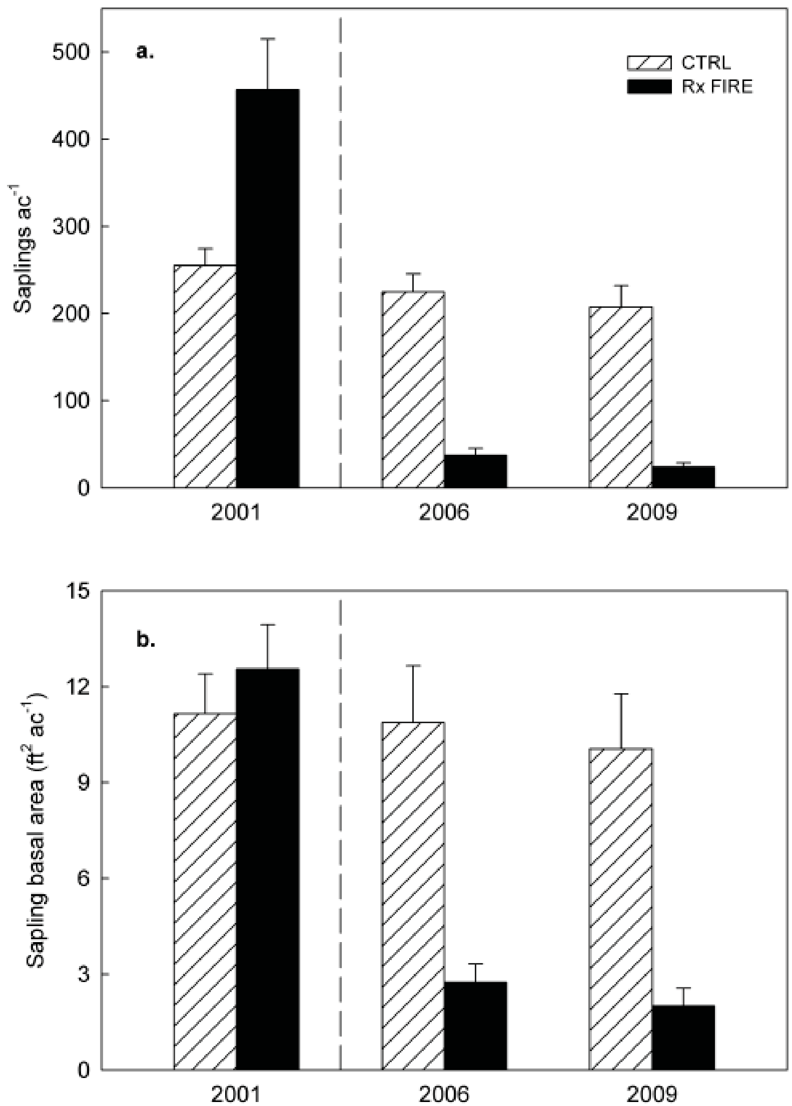

Figure 5.—Mean sapling-size tree abundance (with standard error) before (2000) and after (2006, 2009) two prescribed fires in terms of stem density (a) and basal area (b) on the Fernow Experimental Forest, West Virginia. Dashed vertical line represents preconditions and post-conditions related to prescribed fires.

Saplings

Before burning, the sapling layer was dominated by striped maple, American beech, and sugar and red maple in descending order of importance, and virtually no oaks were present. Following burning, species composition changes in the sapling layer were modest, but structural changes were well defined. Year of observation was a significant predictor of both sapling density ($p < 0.0001$) and basal area ($p < 0.0001$). After the prescribed fire treatments, sapling density was reduced by about 90 percent and basal area was reduced by almost 80 percent in 2006; both measures of sapling abundance continued to decline through 2009 (Fig. 5). Mean separation tests identified all three observation years as unique, suggesting the treatment effects from the prescribed burning were not fully realized in 2006. Sapling density and basal area in the control plots remained largely unchanged from 2000 to 2009 (Fig. 5).

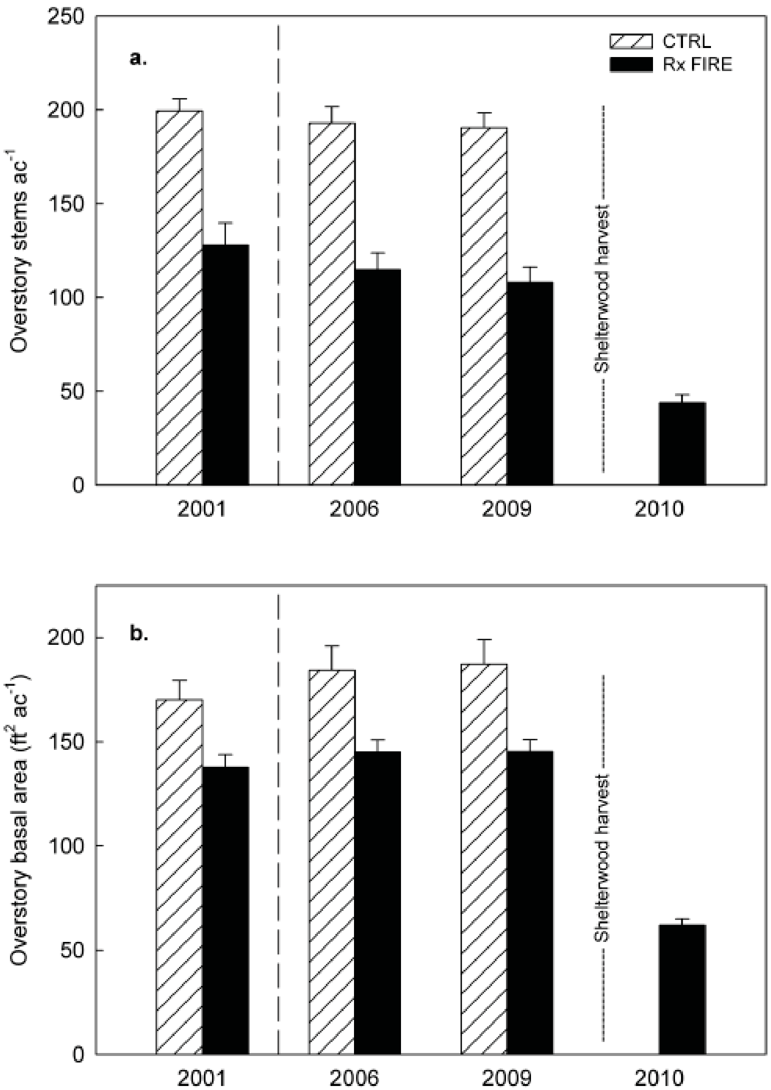

Figure 6.—Mean overstory tree abundance (with standard error) before (2000) and after (2006, 2009) two prescribed fires, and after the shelterwood harvest (2009-10) in terms of stem density (a) and basal area (b) on the Fernow Experimental Forest, West Virginia. Data for the unharvested reference areas not collected in 2010. Dashed vertical line represents preconditions and post-conditions related to prescribed fires.

Tracking individual stems allowed us to attribute the cause of stem death, which in the vast majority of the cases was fire effects, based on evidence of scorching and bark slough. Although not quantified, species composition of the seedling layer was not dominated by sprouts from dead sapling-size stems. Once again, fencing alone was not a significant predictor of either sapling density ($p = 0.9348$) or basal area ($p = 0.6318$), nor was the interaction between fencing and year of observation for either density ($p = 0.2383$) or basal area ($p = 0.7203$).

Overstory

Relative to burning, structural changes in the overstory were quite limited. Tree density declined through time ($p = 0.0034$) and each year was unique according to the mean separation tests, but without meaningful structural changes (Fig. 6). Year was also a significant explanatory factor of basal area ($p = 0.0009$), but unlike tree density, the level of basal area increased slightly from the preburn level in 2000 to the postburn measurements in 2006 and 2009. The percentage of overstory oak based on stem density increased slightly from 39.1 to 42.6 percent from 2000 to 2006. This increase occurred because the density of oaks remained constant whereas the absolute density of other species declined slightly. Fire-related mortality primarily affected the smaller subcanopy trees. American beech, sugar maple, and red maple were the species most commonly associated with fire-related mortality. In 2009 prior to the shelterwood harvest, overstory basal area averaged 145 feet^2/acre with 108 stems/acre (d.b.h. ≥5.0 inches); in 2010 after the first shelterwood harvest, overstory basal area averaged 62 feet^2/acre with about 44 stems/acre. Post-shelterwood residual stand basal area in 2010 varied from 56.1 to 68.1 feet^2/acre.

Canopy

Openness differed slightly between the burned and unburned portions of the study in 2007 during the first year of hemispherical canopy imagery ($p = 0.0261$). Mean openness was 8.9 and 7.2 percent for the burned and unburned portions of the study area, respectively. Maximum openness was 10.8 percent for the burned plots and 7.8 percent for the controls. Lacking a pretreatment canopy measurement, we cannot definitively attribute these differences to the prescribed fire treatments. Mean DSF, used as a surrogate for PAR, was 17.8 and 12.0 percent for burned and unburned plots, respectively in 2007, but there was little evidence to support real differences ($p = 0.1327$). Following the shelterwood harvest in 2010, mean DSF increased to 56.3 percent and openness increased to 36.7 percent, whereas these measures remained relatively constant in the untreated reference plots.

DISCUSSION

There were noteworthy vegetation dynamics in the study area related to prescribed burning and the shelterwood harvest. With the prescribed fire treatments, the silvicultural objective was to reduce interfering competition, primarily the shade-tolerant sapling layer, and this objective was largely successful. After two prescribed fires, sapling density was reduced by 90 percent in a forest where the understory stratum was a dominant feature. The postfire structural conditions were more open in appearance and atypical of mesic forest conditions found today in the central Appalachians (Fig. 7). Given the slow growth rate of understory maples and birches in fully stocked stands (Lorimer 1981) and the absence of any sapling recovery 4 years after the last prescribed fire in this study, we speculate that dense understories may not have had time to develop if pre-20th-century fire return intervals of about a decade characterized the disturbance regime as estimated in some locations of Kentucky, Ohio, Maryland, and West Virginia (McEwan et al. 2007, Schuler and McClain 2003, Shumway et al. 2001, Sutherland 1997).

Despite the encouraging understory structural changes brought about by prescribed burning, our results also illustrated that current seed bank characteristics may pose a major impediment to achieving oak regeneration or restoration goals. Seedling densities of birch and yellow-poplar increased dramatically after burning and earlier work has shown that these two species were the most abundant arboreal species stored in the seed bank before prescribed burning (Schuler et al. 2010). The results reported here suggest that the fires stimulated the germination of these species and many are now successfully developing in the understory. It is a primary objective of this study to understand if the postharvest prescribed fire yet to be implemented will be a sufficient deterrent of black birch and yellow-poplar dominance in the understory and favor oak as it did in the Virginia Piedmont (Brose and Van Lear 1998). We anticipate conducting the additional springtime prescribed

Figure 7.—Plot 4 in early spring 2002 before burning (A) and late summer 2006 after two prescribed fires in 2002 and 2005 (B) on the Fernow Experimental Forest, West Virginia. Note the absence of the dense sapling layer in 2006 and the high level of overstory stocking at both timess.

fire, most likely in April, in either 2013 or 2014, which is when we project the oak stems present in the study area will begin to be overtopped by faster-growing stems of other species.

As we look to the future for the full implementation of this study, we are encouraged by the greater abundance of oak seedlings in the areas treated with prescribed fire. Following the second prescribed fire, there was an unquantified but qualitatively abundant oak mast year in fall 2005. Oak seedlings consequently increased throughout the study area in 2006 and the persistence by 2009 was greater in the areas treated with fire. The dramatic increase in oak seedlings in 2006 coupled with the virtual elimination of the sapling layer met the conditions we stipulated to halt prescribed fire treatments, at least temporarily. As noted by Brose et al. (2008), the application of prescribed fire is recommended only during certain stages of stand development and use of prescribed fire in some situations may lead to lower oak survival (Alexander et al. 2008).

By 2009, the density of oak seedlings ≥1.0 foot in total height was about 30 times greater in the burned areas than in the unburned control plots or in the burn areas before the application of fire. This result suggests the conditions following two prescribed fires favored not only the persistence, but also the growth, of oak seedlings. Miller et al. (2004) demonstrated that removing the shade-tolerant understory in mesic mixed-oak forests will lead to improved root and shoot development in oak seedlings, as well as greater levels of survival. The prescribed fires also enhanced the competitive stature of oak in relation to maple. In 2001, maple seedlings (≥1.0 foot tall) outnumbered oak seedlings 30 to 1; by 2009 after two prescribed fires, the ratio was nearly equal but favored oak (Figs. 1 and 2).

Because oak and yellow-poplar were about equal in abundance in 2009 (for both small and larger seedlings), the competitive interaction in the coming years will hinge, in part, on the response of both species to the next prescribed fire as yellow-poplar seedlings are likely to outgrow all other species following a major canopy disturbance in the absence of fire (Brashers et al. 2004). Even though yellow-poplar is one of the fastest growing species, about 80 percent of the yellow-poplar seedlings were killed by a prescribed fire in Virginia (Brose and Van Lear 1998). Abundant black birch seedlings also pose a significant hurdle for oak regeneration in our study. Birch was the single most abundant arboreal species in the understory in 2009 and may exclude other species if left unchecked (Schuler and Miller 1995), but also may be vulnerable to mortality in the next prescribed fire. For example, in Connecticut, 76 percent of all regenerating birch stems were killed by a single prescribed fire following a clearcut harvest (Ward and Brose 2004).

In 2006, postfire stocking reductions in the sapling layer did not meaningfully alter the understory light environment. This finding supports other research that one or more prescribed fires did not increase the amount of irradiance reaching the understory (Alexander et al. 2008, Hutchinson et al. 2005). However, herbicide reductions of understory stems up to 7 inches in d.b.h did increase PAR from about 2 to 8 percent, which elicited a significant growth response in extant northern red oak seedlings (Miller et al. 2004). Northern red oak and yellow-poplar achieve maximum rates of photosynthesis at about 30 percent of PAR (Holmgren 2000, Phares 1971), well above light levels we estimated in the 2006 understory. However, after the first stage of the shelterwood harvest in 2009-10, light levels increased to more than 50 percent of DSF, a direct correlate of PAR. Therefore, neither species should be limited by irradiance levels, at least initially, in the coming years.

After more than a decade of work, including fence building and maintenance, two prescribed fires, annual data collection of some variables, and the first stage of the shelterwood harvest, we are on the verge of achieving the conditions we were striving for to test the shelterwood-burn technique for releasing established oak seedlings from faster-growing competitors. The post-shelterwood fire will complete the experimental treatments of this study. The response to that treatment will be evaluated over the following decade, illustrating that the oak regeneration process, as well as studies to understand it, require commitment and substantial time. Until then, the results reported here should be viewed as preliminary because the full experimental design of this study as conceived and planned has yet to be fully implemented. The reader is reminded year was a surrogate for fire in our model and we cannot be certain the effects we report as significant are due to fire alone, even though the unburned control plots exhibited little change through time. As we progress into the next stage of this research, the effects of fire, time, fencing, and landscape position will be fully evaluated. Until then, these preliminary results add to our understanding of oak ecology and 21st-century forest management.

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