FIRST YEAR SPROUTING AND GROWTH DYNAMICS IN RESPONSE TO PRESCRIBED FIRE IN A MESIC MIXED-OAK FOREST

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Abstract—Prescribed fire is being used more frequently as a component of regeneration treatments in accordance with silvicultural guidelines developed to sustain and increase oak reproduction. A shelterwood-burn study was initiated in response to declining oak importance in the Allegheny Mountains of West Virginia. To remove a non-oak midstory, the study site was prescribe burned twice preceding the first removal cut of a two-cut shelterwood regeneration method that occurred in 2009/2010. A third burn occurred in April 2014 to mitigate the development of non-oak species that dominated the site four years after the seed cut. First year results indicate that northern red oak (*Quercus rubra*) survived at a higher rate than red maple (*Acer rubrum*), sweet birch (*Betula lenta*), and yellow-poplar (*Liriodendron tulipifera*), and the differences were more apparent in smaller pre-burn size classes. By contrast, differences in growth rates were significant in larger pre-burn size classes, but not in smaller size classes.

INTRODUCTION

Successful oak regeneration continues to be a challenge across the mixed oak and mixed mesophytic forests of the eastern United States. As a stand matures and overstory oaks grow in size, oak basal area per acre may increase but frequently it represents a decreasing proportion of the total basal area in the stand (Moser and others 2006). The decline in oak abundance can be attributed to either there being insufficient oak regeneration, or the regeneration present was not competitive enough to be recruited into the overstory as stands develop (Loftis 2004). Despite mitigation efforts, a decline in oak abundance is occurring in stands subjected to various management techniques as well as in unmanaged stands (Schuler and Miller 1995).

Declines are not geographically universal, but have been especially severe in the Allegheny/Appalachian plateaus in the central hardwood region (Fei and others 2011). Compositional shifts are more pronounced on mesic sites where oaks are being replaced by fire-sensitive species that are thriving in the absence of fire, including those that are shade tolerant and present in the understory at the time of disturbance, as well as those that are able to more rapidly respond to the disturbance (Smith 1993). Species on mesic sites may include shade-tolerant maples (*Acer* spp.) and American beech (*Fagus grandifolia*), and fast growing species may include yellow-poplar (*Liriodendron tulipifera*) and sweet birch (*Betula lenta*) (Schuler and Gillespie 2000, Schuler 2004, Trimble 1970).

Departure from the historic fire regime has altered canopy accession pathways and shifted understory species composition, resulting in increased forest density and understory shade (Rentch and others 2003). The oak-fire hypothesis suggests that fire defined the historical disturbance regime and can be judiciously used to maintain and restore oak forests (Arthur and others 2012, Brose and others 2014). In the last 50 years, significant advancements have been made in identifying the conditions in which prescribed fire is most likely to benefit oak communities, and silvicultural guidelines have been developed accordingly (Brose and others 2008, Brose and others 2013). Synthesis has revealed that overall, fire reduces the number of small diameter stems in the midstory, promotes establishment of new oak seedlings, preferentially selects oak reproduction over its mesophytic competitors, and reduces height differences between these species (Brose and Waldrop 2014).

There is still a need for additional information regarding the impact of fire on seedling sprouting, survival, and growth in mesic forests of the central Appalachians (Schuler and others 2013). The study discussed herein is part of a more comprehensive examination of the efficacy of using prescribed fire and shelterwood harvests (Brose and others 1999) to regenerate oak on two mesic mixed-oak sites the Fernow Experimental Forest in West Virginia. Two seedbed preparation burns were conducted in 2002/2003 and 2005 to remove interfering competition, primarily the shade-tolerant

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sapling layer, and create conditions suitable for the establishment of new oak seedlings. In 2009-2010, the seed cut of the shelterwood sequence reduced overstory basal area from 33.3 to 14.2 square meters per hectare, and from 267 to 109 stems/ha (dbh >12.7 cm) (Schuler and others 2013). The objective of this study was to determine whether the competitive position of oak regeneration could be improved by greater survival and improved height relative to its competitors post-burn. First year survival rates and post-burn sprout growth dynamics are examined herein.

METHODS

Study Area

The Fernow Experimental Forest is in the Allegheny Mountains section of the Central Appalachian Broadleaf Forest and is characterized by high, sharp ridges, low mountains, and narrow valleys (McNab and Avers 1994). Elevation of the study area is from 613 to 774 m. Annual precipitation is distributed evenly throughout the year and averages 148 cm, of which about 14 percent is snow. Mean annual temperature is approximately 9 °C. The growing season is about 149 frost-free days from May to October (Adams and others 2012).

Soils in the study area are Calvin channery silt loam, which is derived from acidic sandstone and shale, is well drained, moderately permeable, strongly acid to very strongly acid, and natural fertility is moderate to moderately low, with a minor inclusion of Gilpin channery silt loam, which is moderately permeable, very strongly acid to extremely acid, and has moderately low fertility (Schuler and others 2013).

Characteristic species on the Fernow include upland oaks, with northern red oak being most abundant, but also include chestnut (*Q. montana*), white (*Q. alba*), scarlet (*Q. coccinea*), and black oak (*Q. velutina*), yellow-poplar, black cherry (*Prunus serotina*), maples (*Acer* spp.), sweet birch, American beech (*Fagus grandifolia*), hickories (*Carya* spp.), basswood (*Tilia americana*), blackgum (*Nyssa sylvatica*), sassafras (*Sassafras albidum*), and white ash (*Fraxinus americana*). The natural conifer component consists of Eastern hemlock (*Tsuga canadensis*) and scattered red spruce (*Picea rubens*) (Madarish and others 2002). The study area could more specifically be described as mesic mixed-oak. Oak overstory species, represented in decreasing order of basal area, include northern red, chestnut, and white oak, and common associates include red maple, sugar maple (*A. saccharum*), sweet birch, and yellow-poplar (Schuler and others 2013). The study area site index is 21 m (age 50) for northern red oak and is characterized as a good site (Schnur 1937). Prescribe burn treatment areas encompass 13.8 ha between two locations 0.24 km apart.

Experimental Design and Data Collection

Seedling response plots were established in 10 overstory plots measuring 0.2 ha that were treated with prescribed fire. Five of the overstory plots were fenced and five were unfenced, facilitating the examination of deer herbivory effects. Five seedling response plots systematically distributed at the corners and middle of the overstory plots resulted in 50 total seedling response plots. Plot radius was extended outward to a distance necessary to measure sufficient sample seedlings, resulting in variable plot sizes from about 3.5 to 4.6 m. To more rigorously examine the individual response of reproduction, we tagged and measured three to four stems each of red maple, northern red oak, sweet birch, and yellow-poplar, with the intent of selecting stems so that the range of seedling diameters were as equally represented as possible.

Pre-burn seedling response plot measurements included species, stem height, ground line diameter, and presence of competition. The arboreal or non-arboreal species of the largest individual in a vertical cone with an angle extending 45 degrees above the terminal bud of the tagged seedling was determined to be the "worst aggressor" competition. Post-burn seedling data collected at the end of the 2014 growing season included stem impact class (kill, topkill and sprout, no topkill), number of sprout stems per rootstock, dominant sprout diameter, height to the highest live bud, and if browsed, the number of sprout stems browsed per rootstalk.

Unlike complete or random sampling, this sampling methodology was uniquely designed to capture an equal representation of diameters, the variable of interest, and inferences about diameter distribution or densities cannot be made from this sample on the population. Experimental design in the larger existing study captures those data.

Prescribed Fire Treatment

The dormant season prescribed fire was conducted on April 18, 2014. Except for a few larger yellow-poplar and sweet birch seedlings just starting to exhibit signs, leaf expansion had not yet begun. Ignition operations on the lower burn unit started at approximately 12:55 and total elapsed firing time was about 2 hours. Ignition operations in the upper burn unit were started at 16:00 the same day and total elapsed firing time was estimated to be 1 hour. During the burn window, temperature ranged from 19.5 to 22.0 °C, humidity ranged from 22 to 28 percent, and wind speed ranged from 0 to 13.7 km/hr. Temperature measurements during the fire were recorded by Hobo Type K data loggers connected to 25 cm long probes with thermocouples placed on a square grid at the corners and center of the overstory plots, collocated at 48 of 50 seedling survival plots. The maximum temperature in the lower burn unit was 498.8 °C, the average maximum temperature was 171.0 °C, and the average duration >50 °C was 6.1 minutes. The maximum temperature in the upper burn unit was 498.8 °C, the average maximum temperature was 232.3 °C, and the average duration >50 °C was 6.4 minutes.

Data Analysis

Seedlings were divided by species into six pre-burn height classes for analysis. Chi-square analysis was used to test whether the number of stems surviving in each size class was evenly distributed between species. Analysis of variance (ANOVA) was used on the response variables post-burn height and diameter, with the Tukey-Kramer mean separation test to examine differences between species. All comparisons were evaluated at alpha equal to 0.05.

RESULTS

The 692 stems tagged within the 50 seedling response plots in the burn units were distributed as follows: 53 red maple, 236 red oak, 208 sweet birch, and 194 yellow-poplar. Of these seedlings, 520 had one or more aggressors. Arboreal aggressors were more common than non-arboreal aggressors. Worst aggressor was distributed by species as follows: 42 percent sweet birch, 24 percent blackberry (*Rubus* spp.), 10 percent greenbrier (*Smilax* spp.), 5 percent beech, 4 percent striped maple (*Acer pensylvanicum*), 4 percent red maple stump sprouts, and 3 percent yellow-poplar stump sprouts. Various other species represented the remaining 8 percent.

Survival

Of the 692 total stems tagged in the burn units, 691 were used in the data analysis. One seedling survived the fire without being topkilled and was excluded. Overall, red maple and yellow-poplar survival was low, with 40 and 48 percent, respectively. Sweet birch survival was moderate with 67 percent, and red oak survival was high with 87 percent. By pre-burn height class, there was a significant difference in survival between species only in the three smallest size classes. Oak survival was consistently high in all size classes (table 1).

Growth

ANOVA results indicated that there was no significant difference in post-burn average diameter between species in the smallest two and largest two pre-burn height classes. Post-burn average diameters differed between species in the middle two pre-burn height classes. Yellow-poplar diameter was significantly larger in both middle size classes (table 2). Similarly, ANOVA results indicated that there was no significant difference in post-burn average height between species in the smallest two and largest two pre-burn height classes. Post-burn mean heights differed between species in the middle two pre-burn height classes. Yellow-poplar height was significantly taller in both middle size classes (table 3).

DISCUSSION

The two previous seedbed preparation burns in earlier stages of this study were effective in reducing the maple component of the stand. Prior to the initial burning in 2002/2003 and 2005, maple had been most abundant, but after burning twice, maple, oak, and yellow-poplar were approximately equally represented; however, following the seed cut sweet birch became the most abundant (Schuler and others 2013). The reduction in red maple precluded finding an adequate sample size of red maple seedlings, particularly in the larger diameters, to tag for the study. Thus, it is hard to make any meaningful conclusions about red maple, especially at larger diameters and heights. The increased abundance of sweet birch was reflected in the "worst aggressor" assessment, representing 42 percent. Although there was not an overall shortage of sweet birch stems, very few were located that represented smaller diameters, illustrating their rapid growth.

Brose and others (2006) review of species sensitivity levels to fire was generally consistent with the results

Table 1—Average survival following the first growing season post-burn

		Pre-burn Height Class					
Species	Overall	0-60 cm	61-120 cm	121-180 cm	181-240 cm	241-300 cm	300+ cm
RM	40	24	61	100	—	—	—
RO	87	81	90	85	100	100	—
SB	67	33	24	63	73	78	83
YP	48	23	47	64	62	60	100
P-value	<0.001	<0.001	<0.001	0.032	0.077	0.754	1

Table 2—Average basal diameter in mm (±1 SE) following the first growing season post-burn.

	Pre-burn Height Class					
Species	0-60 cm	61-120 cm	121-180 cm	181-240 cm	241-300 cm	300+ cm
RM	3.7 (0.66)	4.5 (0.72)	5.3ab (1.91)	—	—	—
RO	4.4 (0.26)	5.9 (0.25)	8.0b (0.39)	9.7b (0.71)	9.1 (2.10)	—
SB	2.0 (0.84)	4.4 (1.20)	5.0a (0.55)	4.3a (0.37)	5.1 (0.50)	5.9 (0.44)
YP	4.4 (0.59)	6.4 (0.41)	9.9c (0.51)	12.9c (0.53)	5.2 (1.72)	8.6 (1.93)
P-value	0.058	0.09	<0.001	<0.001	0.202	0.193

* Means followed by different letters are significantly different within that height class (alpha=0.05)

Table 3—Average total height in cm (±1 SE) following the first growing season post-burn.

	Pre-burn Height Class					
Species	0-60 cm	61-120 cm	121-180 cm	181-240 cm	241-300 cm	300+ cm
RM	35.3 (6.9)	50.0 (8.5)	70.5b (21.1)	—	—	—
RO	29.0 (2.7)	50.3 (2.8)	75.4b (4.4)	104.9b (10.2)	81.5 (25.6)	—
SB	17.0 (8.8)	63.0 (14.2)	70.4b (5.8)	59.4c (5.4)	75.1 (6.1)	94.3 (6.1)
YP	33.8 (6.2)	60.0 (4.9)	93.0a (5.6)	136.0a (7.6)	54.0 (20.9)	87.5 (26.4)
P-value	0.362	0.321	0.033	<0.001	0.602	0.803

* Means followed by different letters are significantly different within that height class (alpha=0.05)

presented here. Northern red oak is considered resistant to fire, which was confirmed by its overall 87 percent survival rate. As a seedling, yellow-poplar is considered very sensitive to fire, which was confirmed in this study by an overall 48 percent survival rate. Sweet birch is considered fire-sensitive, which is somewhat supported by a 67 percent survival rate. Red maple is considered to be fire-sensitive to intermediate, depending on fire intensity, seasonality, and seedling size (Brose and others 2006, Ward and Brose 2004). Only 53 red maples in the desired size classes were located and most of them were less than 12.7 mm and 61 cm tall. About 40 percent of the red maple survived, illustrating their sensitivity at small sizes. Unfortunately, the small stature and size of the sample discourages making conclusions about larger red maple seedlings based on these results.

Greater differences in mortality among species are often reported in the small seedling sizes (Brose and Van Lear 1998, 2004). This is especially apparent when comparing oak to red maple, sweet birch, and yellow-poplar in the pre-burn height classes up to 120 cm. The probability of survival for oak is reported to increase with increasing diameter (Dey and Hartman 2005, Spetich 2013); however, for the range of seedling sizes examined in this study, probability of survival only slightly increased with size.

A small stem may be a seedling or a seedling sprout that has experienced one or more episodes of dieback and sprouting (Johnson and others 2009). Thus, stem size is not always indicative of age or root system size and consequently, does not always reflect the capacity to sprout, especially when growing on highly disturbed sites. Part of the reason that even small oaks were able to consistently sprout in this study was likely due to a higher root:shoot ratio that developed as seedlings survived two seedbed prep burns, as well as a harvest.

In addition to survival rates increasing with stem height for sweet birch and yellow-poplar, post-burn height growth increases with pre-burn stem height, illustrating that the capacity to control oak competitors may be reduced as the duration between the seed cut and the release burn increases. Although 67 percent of sweet birch survived, it did not recover its dominant pre-burn stature. While only 48 percent of yellow-poplar seedlings survived, survivor height growth was rapid. Reducing the height discrepancy between yellow-poplar, sweet birch, and oak is important in the short-term and, even if only temporarily, allows increased oak height growth and root development (Ward and Brose 2004). Ultimately, reducing the density of those competitors is also necessary.

These results indicate that red oak appears to exhibit a consistent ability to survive regardless of diameter, but it is questionable that the smaller diameter oaks will produce a sprout that will grow fast enough to compete successfully with other species, particularly yellow-poplar survivors, and become at least codominant in the stand. Although referring to post-harvest sprouting, not post-burn sprouting, Sander (1971) speculated that stems of oak advance reproduction should be >12.7 mm in diameter before it will produce a new sprout that will grow fast enough to compete successfully. Although oak seedlings with root collar diameters > 6.4 mm will likely sprout, it is recommended not to burn until oaks are approximately 12 mm in diameter and 30.5 cm tall (Brose and others 2014, Spetich 2013). Moreover, oaks with root collar diameters >19.1 mm, with sufficient light levels, are capable of relatively rapid, sustained height growth (Brose and others 2014). When assessing advanced regeneration in anticipation of a cut, "competitive oak" seedlings taller than 91.4 cm with root collar diameters greater than 19.1 mm are highly likely to be at least codominant at crown closure following overstory harvest (Brose and others 2008).

Following several years of monitoring, delayed mortality differences between species have been observed (Yaussy and Waldrop 2010), which suggests that the percent of surviving seedlings may decline at different rates. In addition to delayed mortality differences by species, delayed mortality can also differ on a size gradient (Sander 1972). The small oak stems < 60 cm showed a strong ability to survive the burn, but their persistence over the next several years will indicate if their survival was just a short-term phenomenon. Furthermore, height growth is frequently not linear during the first years following treatment, and even a relatively light residual overstory reduces growth of all reproduction (Sander 1972). By design, shade from the residual overstory trees will likely slow growth rates or induce mortality to a greater degree for more light-demanding species. It appears that oak responded positively to the burn, but a successful regeneration will in part hinge on how well sweet birch and yellow-poplar seedlings recover and if significant numbers of new germinants become established.

In earlier stages of this study, the influence of the seedbed preparation burns was apparent in the correlation between the post-fire conditions and enhanced red oak establishment. The timing of the 2005 burn before an abundant acorn crop was ideal, and density in 2006 was almost 4,047 oak seedling/ha of all sizes. Before the two seedbed prep burns there were about 20 larger oak seedlings/ha, but by 2009 the density of large oak seedlings was over 607 stems/ha. In contrast, there were almost no larger oak seedlings in the unburned control plots in the previous 10 years (Schuler and others 2013). Although fire helps improve the seedbed to facilitate successful oak germination and seedling establishment, it can also create favorable conditions for other species to germinate which may translate to an overall unchanged relative abundance of oak (Brose and others 2013). Reports of increased post-burn yellow-poplar seedling abundance are not uncommon, and sweet birch has also been particularly problematic (Barnes and Van Lear 1998, Shearin and others 1972, Schuler and others 2010). Following the two seedbed prep burns in 2002/2003 and 2005, sweet birch and yellow-poplar seedlings increased tenfold by 2006 (Schuler and others 2013). The seedbank was sampled prior to and after the fire in 2005 and sweet birch and yellow-poplar were 2 of 5 species comprising 76 percent of the post-burn seedbed (Schuler and others 2010). Enough seedlings survived or germinated following those burns and grew sufficiently for sweet birch to represent 42 percent of the "worst aggressor" population in 2014. Hence, fire can have unintended, although not unexpected, problematic effects. This challenge is not unique to disturbances following fire; yellow-poplar and sweet birch seedlings can have the highest importance of tallest stems and express canopy dominance in the high-light environment of young stands following clearcutting (Brashears and others 2004, Sander and Clark 1971). Stemming from prodigious seed production, seedbank accumulation, and rapid early height growth, controlling these species proves to be a significant management challenge faced on mesic sites.

First year results are a tentative assessment, but are important to incorporate in our understanding of oak ecology, stand development, and prescribed burning guidelines for regeneration of mixed-oak forests. Delayed mortality and growth rate dynamics may change in coming years, and more definitive conclusions can eventually be made about how the shelterwood-burn sequence affected the competitive position of oak. Brose (2010) presented promising results in a follow-up to an early shelterwood-burn study (Brose and Van Lear 1998) that show the increased density of oak stems and decreased red maple and yellow-poplar stems found 2 years post-fire, persisted after 11 years. Additionally, the number of dominant oak increased with fire intensity, while the number of red maple and yellow-poplar dominant stems decreased (Brose 2010). Monitoring stand development in coming years will help contribute to knowledge about effects of the shelterwood-burn method in mesic mixed-oak stands on good sites (SI 21 m) in the central Appalachian Mountains. With the ability to predict outcomes of seedbed preparation and release burns more reliably, developing silvicultural treatments will be easier to navigate.

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