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Seed Bank Response to Prescribed Fire in the Central Appalachians

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Abstract

We compared pre- and post-treatment seed bank characteristics of woody species after two prescribed fires in a mesic mixed-oak forest in the central Appalachians. Nineteen woody species were identified from soil samples. Mean species richness and diversity declined but evenness did not. The seed bank was dominated by black birch (*Betula lenta*), yellow-poplar (*Liriodendron tulipifera*), blackberry (*Rubus* spp.), grapevine (*Vitis* spp.), and Hercules club (*Aralia spinosa*) before burning. Following burning, the median density of seed bank propagules declined by 45 percent (247.6 to 138.1 m^{-2}). Black birch, yellow-poplar, and grapevine declined by 69, 56, and 40 percent, respectively. The results illustrate the importance of the seed bank as a robust source of non-oak regeneration in this forest type and of the potential effect of fire in altering it. Oak restoration efforts that do not account for this significant source of regeneration in mesic mixed-oak forests likely will be unsuccessful.

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Cover Photo

Conditions in the study area in June 2005 following the second prescribed fire on the Fernow Experimental Forest (April 2005). Note the absence of understory trees and the relatively sparse forest floor. The large wound in the tree at right is unrelated to the prescribed fire. Photo by Thomas M. Schuler, U.S. Forest Service.

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INTRODUCTION

Successful regeneration of oak (*Quercus* spp.) is widely recognized as a serious problem throughout the hardwood regions of the Eastern and Central United States (Abrams 2000). Both managed and unmanaged forests show declining oak abundance as overstory oaks experience natural mortality or are harvested (Schuler 2004). Other woody species such as red maple (*Acer rubrum*) have become increasingly abundant over the past several decades in number of stems and growing-stock volume (Alderman and others 2005, Fei and Steiner 2007). Nowacki and Abrams (2008) referred to the widespread replacement of oaks with more mesic species as the "mesophication" of forests in the Eastern United States.

To counter the mesophication of oak forests, silvicultural guidelines using the shelterwood method have been developed to increase the size of existing oak seedlings, as large oak seedlings are more competitive with other vegetative competitors following canopy reductions (Loftis 1990, Brose and others 1999, 2008). Treatments are commonly needed to reduce non-oak competition and increase oak seedling size before significant canopy reductions. Loftis (1990) proposed a preharvest herbicide application to remove understory and midcanopy trees. More recently, prescribed fire has been recommended to reduce non-oak competition and improve the competitiveness of oak seedlings (Abrams 1992, Brose and Van Lear 1998, Hutchinson and others 2005). Factors related to fire effectiveness include site characteristics, frequency and intensity, insects, and native and nonnative invasive species (Brose and others 2006, Glasgow and Matlack 2007).

Enhancing oak competitiveness through prescribed burning is more likely on sites with xeric characteristics (Thomas-Van Gundy and others 2007). In part, mesic sites dry more slowly and develop less flammable forest litter (non-oak species), which makes it difficult to conduct a successful prescribed fire (Nowacki and Abrams 2008). There might be significant additional resistance to oak restoration efforts on mesic sites due to the extant seed bank. Seed banks are an important aspect of site characteristics that can play a critical role in the regeneration process, but the effect of prescribed fire on seed bank dynamics has only recently been explored.

In the relatively xeric Ozark Mountains of Arkansas, Schuler and Liechty (2008) found a low abundance of seed bank propagules in a mixed-oak forest, both woody and herbaceous, before and after prescribed burning. However, in more mesic conditions, seed banks can store substantial quantities of viable seed of both shrub and arboreal species (Wendel 1987, Adams and others 2004), illustrating the capacity of the seed bank to store non-oak propagules and interfere with oak restoration. Little is known about the extent to which prescribed fire alters seed bank characteristics in the central Appalachians and thus its effectiveness in promoting oak regeneration.

In this study we compared seed bank characteristics before and after prescribed burning in a mesic mixed-oak forest in West Virginia. Unlike studies that have assessed the seed bank indirectly by reporting the number of new seedlings following burning (Hutchinson and others 2005), we sampled the forest floor before and after burning to gain a better understanding of the effects of fire on the seed bank itself. We report the number of propagules, species, and diversity characteristics before and after two prescribed fires. This research is part of a larger, ongoing study designed to determine the feasibility of using prescribed fire in conjunction with shelterwood harvesting in the central Appalachians to facilitate the sustainability of mixed-oak forests.

METHODS

Site Description

The study was conducted in the Canoe Run watershed of the Fernow Experimental Forest (39.03º N, 79.67º W) in east-central West Virginia. The Fernow is in the Allegheny Mountains of the Central Appalachian Broadleaf Forest (McNab and Avers 1994). The mean growing season is 145 days (May to October); mean annual precipitation is about 1,430 mm and is distributed evenly throughout the year (Pan and others 1997). Temperatures during the growing season usually are moderate and moisture deficits during the growing season are uncommon (Leathers and others 2000). Species composition in the forest overstory is complex

Figure 1.—Samples of forest floor on greenhouse benches allowed identification and counts of tree and shrub species.

throughout much of the Fernow and best described as mixed-mesophytic (Braun 1950). However, within this smaller 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 are red maple, sugar maple (*A. saccharum*), black birch (*Betula lenta*), and yellow-poplar (*Liriodendron tulipifera*). Treatment areas encompass approximately 31 ha and site elevations range from about 600 to 770 m asl. Site index is about 70 for northern red oak (Schnur 1937) throughout the study area.

Experimental Design and Data Analysis

As part of a larger and ongoing study, we monitored the response of the seed bank on twenty 0.202-ha rectangular permanent growth plots treated with prescribed fire. Within each growth plot we sampled the forest floor and the upper horizon of the soil at randomly located distances along a transect running across each growth plot during March of 2000 (before prescribed fire) and in March 2007 (after two prescribed fires). We followed the methodology of Wendel (1987). We collected four samples per transect plot in 2000 and three samples per plot in 2007. Samples of the forest floor were cut with a shovel to a depth of 10 cm around the inside of a wooden template (30 by 30 cm). The samples were placed in wooden trays with a mesh hardware cloth bottom and lined with paper. We labeled samples as to location and plot and then placed flats on greenhouse benches randomly (Fig. 1); the flats were watered as needed. Seeds that germinated and or root stocks that sprouted were allowed to grow until summer to allow identification and counts of tree and shrub species in each tray. Nothing else was done to stimulate germination nor did we attempt to census herbaceous vegetation that was present.

We calculated Shannon-Weiner's diversity index (H') (Whittaker 1972), Pielou's (1969) evenness index (J'), and species richness based on species presence and density for each experimental unit through time (Magurran 1988); often seed bank data are not distributed normally (Hyatt 1999) and most species in our sample did not exhibit normality. As a result, we used the Wilcoxon signed-rank test to test for differences in species abundance before and after prescribed burning. The null hypothesis is that the median difference between the pair of observations is zero. We used a paired t-test

Table 1.—Weather and fire behavior characteristics for prescribed burns on the Fernow Experimental Forest, West Virginia. Air temperature (Air) and relative humidity (RH) given for start and finish times of fires; rate of spread (ROS), maximum probe temperature (PT), and wind speed (WS) are means with standard deviations in parentheses

Date	Air	RH	ROS	PT	WS	No. days since rain
	°C	*Percent*	*m/min*	*°C*	*km/hr*	
4/12/2002	23 - 22	38 - 39	9 (4)	302 (153)	4 (3)	3
4/4/2003	21 - 17	41 - 64	15 (15)	251 (88)	9 (2)	5
4/11/2005	21 - 22	13 - 12	44 (83)	327 (122)	8 (2)	3
4/15/2005	14 - 13	21 - 23	12 (9)	324 (66)	14 (2)	7

to examine changes in diversity measures related to fire treatments through time after determining that patterns of normality and homogeneity of variance had been met. The level of statistical significance for all tests was alpha = 0.05. It should be noted that the samples before and after prescribed fire do not account for changes that might have occurred in the absence of fire.

Prescribed Fire: Treatments and Characteristics

The study area was treated with two prescribed fires just before the growing seasons in 2002 and 2003 and again in 2005. Because the first prescribed fire in April 2002 was interrupted due to poor weather, we were able to burn only one-half of the site. The remaining portion was burned the following spring (2003). We conducted a second prescribed fire in April 2005 so that the entire study site has been burned twice. We used the strip-head fire technique; ignition was by hand-held drip torches. We wanted to generate flame lengths of about 1 m with a rate of spread (ROS) of about 1 to 3 m per minute based on BEHAVE (v. 3.0.2) predictions using Fuel Model 9. Meteorological data at the time of the fires were obtained from a U.S. Environmental Protection Agency weather station (PAR107) located about 4.5 km north of the study area.

We monitored fire behavior at 10 locations for each prescribed burn. We used Hobo Type K data loggers connected to stainless steel probes 25 cm long with an isolated thermocouple at the tip (Onset Computer Corp.).[1] This methodology is similar to that used by Iverson and others (2004). Temperatures were recorded every 2 seconds by the probe and data logger and were recorded at five points at each instrumented growth plot during the fires. We set temperature probes at each corner on a square grid (9.1 by 9.1 m) and one in the center of the grid. Because the data loggers had synchronized clocks, we were able to calculate the fire's rate of spread at each plot location using the elapsed time between the rapid initial fire-induced elevated temperatures (> 32 °C) logged by adjacent data loggers. We have not attempted to correlate fire effects with fire characteristics at the plot level because not all plots were instrumented with temperature probes, and probe grids were not sized consistently with our seed bank measurements. However, we do report general characteristics of fire behavior for each fire for comparison with similar studies as recommended by Brose and others (2006).

Differences in factors such as air temperature, relative humidity, and wind speed (Table 1) contributed to variability in fire behavior. We observed mostly moderate or less intense fire behavior during all of our burns (i.e., flame lengths less than 1 m stemming from the combustion of leaf litter and 1-hour surface fuels). Actual fire spread rates were greater than those predicted by modeling but were similar to those reported in Ohio (Iverson and others 2004).

[1]The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

Table 2.—Median density of seed bank propagules of most abundant species before and after two prescribed fires in a mesic mixed-oak forest in West Virginia (minor species not listed individually but included in total)

	Number of propagules m^{-2}		
Species	Pre-burn	Post-burn	P[a]
Betula lenta	47.1	14.4	<0.01
Rubus spp.	45.7	53.8	0.82
Liriodendron tulipifera	44.4	19.7	<0.01
Vitis spp.	24.2	14.4	0.04
Aralia spinosa	12.1	3.6	0.18
Sassafras albidum	5.4	0	<0.01
Acer rubrum	4.0	0	0.08
Robinia pseudoacacia	0	3.6	<0.01
Total	247.6	138.1	< 0.01

[a]Wilcoxon signed-rank test

RESULTS

The seed bank was dominated by black birch, yellow-poplar, blackberry (*Rubus* spp.), grapevine (*Vitis* spp.), and Hercules club (*Aralia spinosa*). These five species comprised 70 and 76 percent of seed bank propagules before and after prescribed burning, respectively. Nonetheless, following prescribed burning, the median density of seeds and other vegetative propagules in the seed bank was reduced significantly by 44 percent (Table 2), according to the Wilcoxon signed-rank test results. Birch, yellow-poplar, and grapevine abundance declined significantly by 69, 56, and 40 percent, respectively (Table 2). Conversely, we found no evidence that blackberry abundance was affected by prescribed burning as afterward it became the most abundant species due to the decreased abundance of other species. Only black locust (*Robinia pseudoacacia*) exhibited significantly greater abundance after burning than before; however, it remained a relatively minor species, accounting for slightly more than 2 percent of the overall sample in 2007.

We identified 19 woody species from the soil samples. Mean species richness declined significantly from 8.35 to 6.60 after burning ($P < 0.001$) based on results of the paired t-test. H' also declined after burning, from 1.676 to 1.421 ($P = 0.005$), though J' did not ($P = 0.241$). American beech (*Fagus grandifolia*), chestnut oak, sourwood (*Oxydendrum arboreum*), Fraser magnolia (*Magnolia fraseri*), and sumac (*Rhus* sp.) were present, though not abundant, before prescribed burning, but absent afterward and contributed to the decline in mean species richness. Other species of relatively low abundance in the sample included white and red oak, cucumbertree (*Magnolia accuminata*), sassafras (*Sassafras albidum*), black cherry (*Prunus serotina*), striped maple (*Acer pensylvanicum)*, red maple, and greenbrier (*Smilax* sp.). We found no evidence that the abundance of these species in the seed bank was altered by prescribed burning.

DISCUSSION

Following prescribed fire, seeds in the forest floor may germinate, remain viable but not germinate, or be killed by the fire (Fig. 2). At the inception of this study, we knew that the seed bank was a robust source of woody regeneration but there was little information on how repeated prescribed fires might affect it. We hypothesized that repeated fires reduces the number of viable seeds in the seed bank and fundamentally alters post-fire stand dynamics. Here we focus on the seed bank itself because little is known about the direct effects of fire on the seed bank in mesic forests. The seed bank may contribute to new seedlings following perturbations to the forest, for example during different stages of a shelterwood harvest. Before the onset of burning, seeds of black birch and yellow-poplar together totaled nearly 100 m^{-2}, reflecting values reported for the central Appalachians by Wendel

Figure 2.—Typical forest floor conditions in June 2005 following the second prescribed fire (April 2005).

(1987) and Adams and others (2004). Seed densities for black birch and yellow-poplar were reduced significantly following prescribed burning but remained above 30 m^{-2}. Thus, even after two prescribed fires, the seed bank remains an abundant source of potential tree regeneration that may overwhelm many competitors, including small oak seedlings (Beck and Hooper 1986, Brashears and others 2004). In more xeric mixed-oak forests it has been reported that the seed bank harbors an order of magnitude less of seeds of tree species, regardless of recent fire history (Schiffman and Johnson 1992, Schuler and Liechty 2008). Seed bank differences between xeric and mesic mixed-oak forests create fundamentally different challenges to sustaining oak species. In xeric forests, we believe the primary challenge is to overcome the buildup of advanced regeneration of shade-tolerant species. In mesic conditions, a significant additional step is to overcome the buildup of non-oak competitors in the seed bank.

Although the seed bank we studied was robust, overall abundance decreased substantially after burning due to decreases in black birch, yellow-poplar, and grapevine even though post-fire sampling occurred 2 years after the last prescribed fire. During this time, the seed bank could have been partially replenished from surrounding overstory trees. As a result, our estimates may be conservative regarding total seed reductions. However, the significant reduction in black birch is intriguing because past research demonstrated that prescriptions designed to enhance oak seedling development also enhanced birch seedling germination and development, and birch can be a particularly problematic species in oak regeneration (Schuler and Miller 1995). Both black birch and the primary oak species in the central Appalachians are intermediate in shade tolerance (Trimble 1975) and can respond positively to partial reductions in overstory density (Thomas-Van Gundy and Schuler 2008). Ecologically significant seed bank reductions of black birch and yellow-poplar should equate to a higher incidence of understory oak persistence and greater probability of oak recruitment into the overstory. We cannot yet conclude that the significant reductions in birch and yellow-poplar we documented are ecologically significant in meeting goals for oak restoration.

The implication with regard to blackberry resilience to prescribed burning in our study is not fully understood. Blackberry is a common early successional, shade-intolerant shrub that persists until trees species emerge through the shrub layer and form a continuous canopy over it. Dense blackberry thickets can compete vigorously with hardwood seedlings (Whitney 1986), but also may benefit hardwood seedlings by making them less visible to browsers. Blackberry is a true seed banker in that some seeds may remain viable in the seed bank for more than a century. However, seeds are less abundant in stands older than 95 years (Graber and Thompson 1978). We speculate that higher levels of blackberry abundance in the seed bank relative to some tree species do not preclude oak seedling persistence and development, but additional research is needed to understand how oak and blackberry interact following prescribed fire in the mixed-oak forest type.

In areas where the seed bank does constitute an ecologically important source of non-oak propagules, particularly when it includes species of intermediate shade tolerance such as black birch, efforts to reduce the role of the seed bank in the regeneration process likely will be required to achieve management goals for oak. Seeds from most tree species are considered transient in temperate woodlands (Thompson 1992), but the annual seed input into the forest floor from common oak competitors in contemporary forests effectively creates a persistent seed bank. Black birch and yellow-poplar may persist for as many as 8 years in the seed bank (Beck and Hooper 1986), and these species may produce abundant seed crops nearly every year (Olson 1969, Brinkman 1974). Accordingly, efforts to reduce seed bank propagules (Shearin and others 1972) that do not address seed bank input, likely will have limited temporal effect. Repeated landscape-level burning by Native Americans and settlers (Van Lear and Waldrop 1989) may have altered seed bank dynamics by altering overstory composition at spatial scales large enough to slow renewal. To mimic this process today, it is essential to consider the recruitment potential of species from both within and outside of the area being managed as well as the spatial scale and shape of the area needed to achieve desired results. Small management units with a high proportion of edge are unlikely to inhibit seed bank renewal from external sources. Future research may evaluate the size and shape of burn units that are required to slow renewal.

In the past decade, prescribed burning of eastern mixed-oak forests has become a more widely accepted restoration approach as indicated by the number of new National Forest management plans that have incorporated fire into management objectives (Yaussy and others 2008). The continued use of fire to promote oak regeneration and restoration will hinge on a better understanding of when, where, and how to effectively apply prescribed fire in conjunction with other treatments. In West Virginia, landscape modeling points to the relatively more xeric conditions of the Ridge and Valley Province as the most likely area in which mixed-oak forests will be sustained through management intervention (Thomas-Van Gundy and others 2007). However, Nowacki and Abrams (2008) asserted that prescribed burning on mesic oak sites should be a high priority because species shifts are occurring more rapidly and will be more difficult to reverse than on xeric sites. They concluded that an alternative stable-state in the composition of mesophytic hardwood species will occur in the absence of fire. We assert that this stability may be linked functionally to seed bank characteristics that develop in advance of other factors already identified by Nowacki and Abrams (2008) such as less flammable forest litter of non-oak species. It is unclear whether the alternative stable-state favoring mesophytic hardwoods has already occurred when and where the seed bank is an abundant source of non-oak propagules, but oak restoration efforts that do not account for this potentially significant source of regeneration in mesic mixed-oak forests likely will be unsuccessful. Although the inferences from our study are limited due to the spatial scale of our experimental design, the results illustrate the potential importance of the seed bank in the oak regeneration process. Research is needed to determine where the seed bank is a limiting factor to oak sustainability and whether prescribed fire and other silvicultural treatments can be used to change seed bank characteristics in favor of oak and sympatric species.

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Pre- and post-treatment seed-bank characteristics of woody species were compared after two prescribed fires in a mesic mixed-oak forest in the central Appalachians. Nineteen woody species were identified from soil samples. Mean species richness declined but evenness did not after prescribed burning. The seed bank was dominated by black birch, yellow-poplar, blackberry, grapevine and Hercules club before burning. Following burning, the median density of seed bank propagules declined by 45 percent. Black birch, yellow-poplar, and grapevine declined by 69, 56, and 40 percent, respectively. The results illustrate the importance of the seed bank as a robust source of non-oak regeneration in mixed-oak forests and of the potential effect of fire in altering it.

KEY WORDS: mixed-mesophytic, West Virginia, oak regeneration, forest restoration

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