SEED BANK EMERGENCE FOLLOWING PRESCRIBED BURNING IN THE OZARK HIGHLANDS

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Abstract.—Much information is available describing the effects of fire on the survival, growth, and sprouting ability of hardwood stems. This information is generally used for predicting the response of established trees and advance reproduction to various burning treatments during the process of regenerating new stands. This study describes an often overlooked component of reproduction—the soil seed bank. The seed bank consists of stored seeds that are freshly fallen or older seeds that are viable but dormant. In order to predict stand-level regeneration treatments that incorporate burning, accurate assessment of the effects of burning on this source of regeneration is important. The number of tree species germinating from the seed bank was very low in both pre- and post-burn samples. The burning treatment increased species richness and abundance. Shifts in species presence/absence were also noted, with graminoid species more prevalent after burning.

INTRODUCTION

Historically, many forests in the Ozark Mountain region of Arkansas had relatively large representation of oak stems (*Quercus* spp.) in the overstory with open midstory and understory strata that were described as having park-like appearances (Park 1955). The maintenance of these forest stand conditions has been linked, at least in part, to fires that frequently burned these areas. Mean fire return intervals ranged from 3 to 7 years in many parts of this region (Guyette and Spetich 2003). Oak species are known for their resistance to fires even at young ages due to thick bark, a propensity to sprout, and hypogeal germination that protects the cotyledons during the first year of establishment. However, due to long-term fire suppression, the current forest conditions commonly have a resurgence of the under- and midstory strata, which are composed of shade-tolerant non-oak species (Soucy and others 2005). Difficulties in regenerating oak species have ensued, prompting a new look at the importance of periodic fires in maintaining oak communities.

Prescribed burning is the purposeful and intentional application of fire to reduce fuel loadings and control competing vegetation. Numerous scientific studies have documented its utility in significantly improving the composition of oak (Adams and Rieske 2001, Barnes and Van Lear 1998) by reducing the quantity of fire-sensitive species and improving the seedbed conditions for oak species. Prescribed fires often are advocated where tolerant woody species like blackgum (*Nyssa sylvatica* L.), red maple (*Acer rubrum* L.), and black cherry (*Prunus serotina* Ehrl.) suppress or intensively compete with established oak stems (Brose and others 1999). Both dormant-season and growing-season fires can be successful in reducing non-oak competitors.

The soil seed bank is the storehouse for newly fallen seeds and older but viable seeds that have remained dormant. For some woody species, seed viability is limited to one season, meaning they must germinate immediately in the fall following seed fall (e.g., white oak [*Q. alba* L.]) or the following spring (e.g., northern red oak [*Q. rubra* L.]; privet [*Ligustrum sinense* L.]; loblolly pine [*Pinus taeda* L.]). Others are capable of “carry-over”, meaning seeds can accumulate over time ranging from 2 years (e.g., red maple)

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Table 1.—Pre-burn overstory species composition for two upland oak stands in the Arkansas Ozark Highlands

	Falling Water		Meadows Knob	
Species	Dormant Season	Growing Season	Dormant Season	Growing Season
	----------------Percent of basal area----------------			
Quercus alba	35.9	35.2	34.4	44.2
Quercus rubra	16.3	30.8	14.8	31.2
Quercus velutina	14.1	4.4	34.4	11.7
Nyssa sylvatica	13.0	9.9	4.9	6.5
Carya spp.	10.9	7.7	4.9	1.3
Quercus stellata	5.4	6.6	0.0	3.9
Pinus echinata	2.2	2.2	0.0	0.0
Acer rubrum	2.2	1.1	3.3	1.3
Prunus serotina	0.0	1.1	3.3	0.0
other	0.0	1.1	0.0	0.0

to a decade (e.g., yellow-poplar [*Liriodendron tulipifera* L.]) to a century or more (e.g., pin cherry [*Prunus pensylvanica* L.])(Tierney and Fahey 1998).

To the best of our knowledge, however, there are limited studies focusing on the impacts of fire on the soil seed bank. Some studies have used simulated fires or artificial seeding to explore some of these effects. For example, Cain and Shelton (1998) demonstrated reduced germination capacity for acorns placed at the surface litter layer, but no effect on acorns located at the mineral soil surface. In their simulated burning experiment using artificially placed blackberry (*Rubus* spp.) and sumac (*Rhus copallina* and *R. glabra*) seeds, Cain and Shelton (2003) showed the potential variability among species. Sumac germination was enhanced 6- to 8-fold on burned plots relative to non-burn controls, whereas blackberry seed on the litter exhibited less than 1 percent viability following burning.

We still do not know the degree to which prescribed fires can offer selective control of certain species, or how the timing of the fire (dormant vs. growing season) will affect seed viability. Complete sterilization of the surface and upper layers of the soil may lead to significantly delayed recolonization following prescribed fires, which may result in serious problems with soil erosion, nutrient leaching, and loss of biodiversity. By contrast, improved germination conditions for nontarget species may serve to further exacerbate the already difficult process of regenerating oak in new forest stands.

The objectives of this study were to (1) compare the seed bank pre- and post-burn by examining the number of species and individual germinants within each species and (2) compare the fire temperature with the germination patterns established in the above objective.

SITE DESCRIPTIONS

Two sites (Falling Water and Meadows Knob) near Russellville, AR, that currently support mature oak stands suffering from severe decline were sampled. Preburn species composition for each site and burn treatment is described in Table 1. Both stands were fully stocked and did not have a recent history of harvesting, but some mortality of red oak species was noted. Basal areas for trees greater than 11.7 cm averaged 25.7 and 19.2 m^2 ha^{-1} for Falling Water and Meadows Knob, respectively.

Each site was scheduled to receive separate dormant-season and growing-season prescribed burns. Dormant-season prescribed burns were conducted in February 2007. Actual fuel loadings are unavailable. Air temperature, relative humidity, and wind speed averaged 24 °C, 39 percent, and 8 km hr^{-1}, respectively, at both sites. The growing season burns for each site were planned for early in the summer of 2007. Unfortunately, extremely wet weather prevented the application of the growing-season burn treatment.

MATERIALS AND METHODS

Seed Bank Sampling

The seed bank was sampled using eight to nine sample plots per burning treatment at each site. Two seed bank subsamples at each sample plot (north and south locations) were collected pre- and post-burn for the dormant-season prescribed burn in February 2007. Preburn samples for the growing-season prescribed burn treatments were collected in June in anticipation of the growing-season burn the following week. As mentioned above, the growing-season burns were not conducted due to prolonged rains during the early summer, and consequently the post-burn growing-season samples were not collected.

Sample locations for pre- and post-burn samples were identified prior to burning to avoid sampling bias. Additionally, pre- and post-burn subsample locations were placed no more than 1 m apart and located in such a way that fire impacts were not affected (i.e., subsamples were not arranged up and down the slope). Each seed bank subsample consisted of a 900-cm^2 area and included the litter layers and mineral soil to 5.0 cm in depth. Collected samples were stored on ice or refrigerated at 4 °C until germination testing began (<1 wk).

Germination Tests

The litter and soil from each subsample was mixed with approximately 100 g of heat-sterilized peat moss to improve the porosity and the water-holding capacity of the soil sample. The subsample-peat moss mixture was added to sterilized plastic germination trays (28 x 56 cm flats without holes) and transferred to a greenhouse for germination testing. Sixty-eight dormant-season and 32 growing-season samples (trays) were placed in a greenhouse for testing. Greenhouse conditions were maintained at 16 h of light and 8 h of darkness, and temperature was maintained at or near 21 °C for optimum germination conditions (Gross 1990). In some cases, maximum daily greenhouse temperatures rose to around 30 °C in the afternoon during exceptionally hot days (>38 °C). Germination tests were conducted for 60 days to quantify the "readily germinated" seed. For the dormant-season samples, a subsequent 60-day germination test was conducted following a 60-day stratification period at 4 °C to quantify the "dormant seed" pool. Time constraints prohibited the second stratification period for the growing-season samples.

Over each 60-day germination test, newly emerged germinants were assessed weekly. Once germinants developed sufficiently for identification, they were recorded and discarded to prevent any potential inhibition of other germinating seeds. Unknown individuals were carefully extracted from the sample, potted, and allowed to develop until flowering to aid in the identification process.

Fire Temperature

Fire temperature was recorded for the dormant-season burning treatments using circular aluminum tags painted with fire sensitive paints. The paints used had temperature sensitivities beginning at 93 °C, increasing at 14 °C intervals to 316 °C, from 343 to 427 °C increasing at 28 °C intervals, and ending at 482 °C. One set of painted tags per subsample location (for both pre- and post-burn samples) was suspended 30 cm above the forest floor on an aluminum wire frame and was no more than 3 m from each seed bank sample. Maximum fire temperature was recorded from the highest melting temperature of the paint on each wire rack.

Data Analysis

With the elimination of the growing-season burn treatment, no comparisons could be made between dormant and growing-season fires. The dormant-season burn was truly replicated on only two sites, which limited our ability to detect significant differences before and after burning. Instead, we elected to report descriptive statistics for each burning treatment and limited our comparisons to broader generalizations supported by the treatment trends. Calculations of the number of emergents were generated by expanding results from each 900 cm^2 subsample, not the area of the germination tray, to 1 m^2.

Additionally, regression analyses were employed to describe the relationship between maximum fire temperature and the number of individuals emerging from the seed bank. Significance testing was conducted at the alpha = 0.10 level.

RESULTS

Dormant-Season Sampling

Germination tests on the seed bank samples produced at least 30 different species or species groups between the two sites (Table 2). Species richness was greatest at the Falling Water site. Its preburn seed bank had 17 different species emerge during testing, while post-burn samples had 19 species. Seven species that were recorded in the pre-burn samples did not germinate following burning. However, nine additional species were tallied in the burned seed bank that were not present in the pre-burn samples (Table 2).

Similarly, the number of species from the Meadows Knob site that emerged during the study varied little between pre- and post-burn periods (10 and 11 species, respectively). But again, differences in species composition were sizable. Six species from the preburn seed bank were absent in post-burn germination tests. Likewise, seven species from the post-burn seed bank were absent from the preburn germination tests (Table 2).

While more diverse, Falling Water and Meadow Knob post-burn seed banks averaged 20 percent more emergents than the pre-burn seed bank. The total number of emergents following a dormant season burns averaged 38.2 compared to 31.8 emergents m^{-2} prior to burning (Table 2).

Growing-Season Sampling

Germination tests for the growing-season seed bank samples resulted in fewer numbers of species and emergents (Table 3) compared to the dormant-season collections (Table 2). Fifteen species were recorded from the growing-season collections. Again, the Falling Water site had the greater diversity in the soil seed bank (12 species), whereas the Meadows Knob site had eight species. Falling Water and Meadows Knob sites had eight and seven species that were present in the dormant-season pre-burn samples that were not recorded in the growing-season samples. Conversely, four and three species, respectively, were present in the growing-season samples that were not tallied in the dormant-season samples. The total number of emergents was low relative to the dormant-season seed bank. The initial 60-day germination tests resulted in 17.3 and 23.6 emergents m^{-2} for Falling Water and Meadows Knob sites, respectively (Table 2).

Table 2.—Pre- and post-burn emergence from the soil seed bank from two upland oak stands receiving dormant season prescribed burns

Species	Falling Water		Meadows Knob	
	Preburn	Post-burn	Preburn	Post-burn
	--------------------number of emergents m^{-2}--------------------			
Acer rubrum	2.8	2.8	2.4	0.0
Campsis radicans	0.5	0.0	0.0	0.0
Carya spp.	0.5	0.0	0.0	0.0
Desmodium sp.	0.0	1.9	0.8	0.0
Erechtites hieraciifolium	0.9	0.0	0.0	0.0
Graminoid (>4 species)	11.6	25.9	1.6	10.3
Lespedezia sp.	0.0	0.9	0.0	0.0
Nyssa sylvatica	0.0	0.9	0.0	0.0
Ostyra virginiana	0.5	0.0	0.0	0.0
Oxalis sp.	10.2	0.0	3.2	0.0
Physalis sp.	1.4	2.8	0.0	2.4
Phytolacca americana	0.9	1.9	0.8	1.6
Quercus alba	0.9	0.0	1.6	0.8
Quercus rubra	1.9	0.0	0.0	0.0
Rhus spp.	0.5	1.9	0.0	0.0
Sassafras albidum	0.0	0.9	0.0	0.0
Scutellaria ovata	6.0	4.6	1.6	2.4
Toxicodenron radicans	3.7	0.9	0.8	2.4
Vitis rotundafolia	0.0	1.9	6.3	0.0
unknown (7 species)	0.0	4.6	2.4	4.8
Total	42.1	51.9	21.4	24.6

Table 3.—Preburn emergence from the growing season soil seed bank in two upland oak stands in the Arkansas Ozark Highlands

Species	Falling Water	Meadows Knob
	------number of emergents m^{-2}--------	
Erechtites hieraciifolium	0.6	3.5
Graminoid (≥1793 species)	10.5	8.3
Nyssa sylvatica	0.6	0.0
Oxalis sp.	0.6	0.0
Phytolacca americana	1.2	4.2
Rhus spp.	0.6	3.5
Sassafras albidum	0.6	0.0
Scutellaria ovata	1.2	0.0
Vitis rotundafolia	0.0	0.7
unknown (4 speceis)	1.2	3.5
Total	17.3	23.6

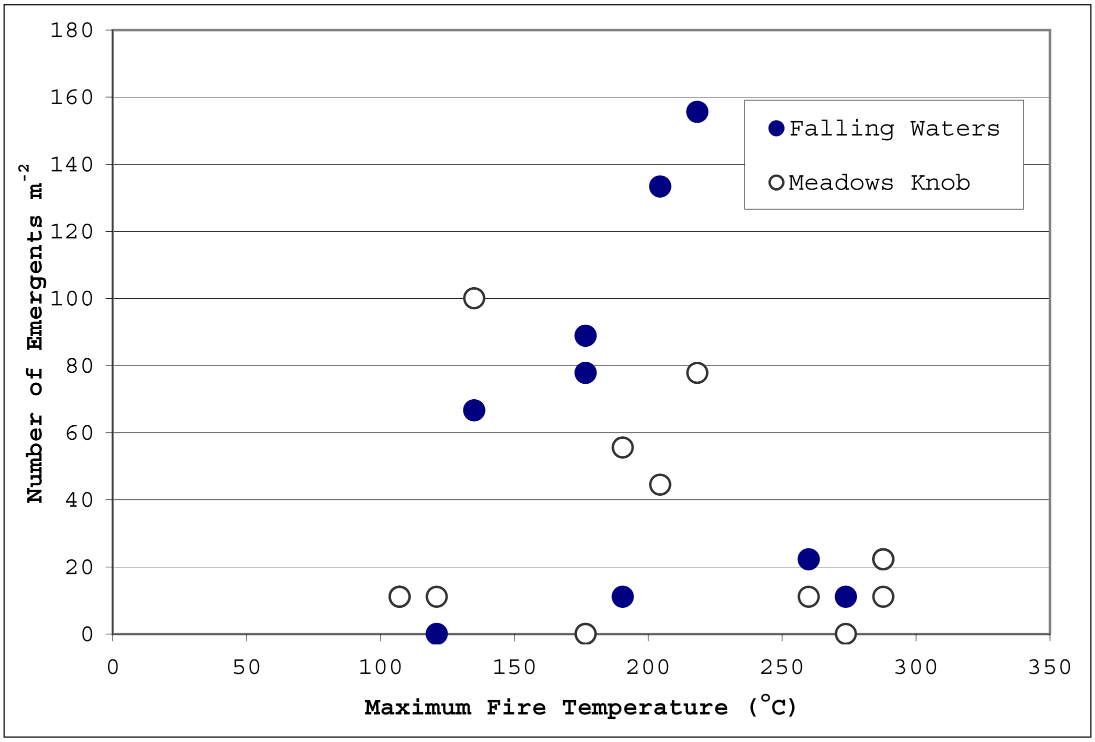

Figure 1. The effect of maximum fire temperature (30 cm above forest floor) from dormant season burns on the number of indivuduals emerging from the soil seed bank.

Fire Temperature

Average and median maximum fire temperatures for the dormant-season burns were 204 °C and 204 °C for Falling Waters and 279 °C and 239 °C for Meadows Knob, respectively. Maximum fire temperature had no apparent relationship with the number of individuals emerging from the seed bank (Fig. 1). The slope coefficient was nonsignificant (P>0.10). Also, the relationship between the number of emerged individuals and maximum fire temperature did not vary by site (P>0.10) (Fig. 1).

DISCUSSION

Unfortunately, early summer weather patterns for northern Arkansas prohibited USDA Forest Service staff from conducting the growing-season burn. This wet weather impaired our ability to compare the soil seed banks for each site relative to the two burning regimes (i.e., dormant vs. growing season). However, interesting patterns did emerge when we compared the pre- and post-burn seed banks on the dormant-season treatments.

The number of emergents that germinated from the seed bank was 11 and 23 percent greater in samples collected after burning for the Meadows Knob and Falling Waters sites, respectively (Table 2). This trend was consistent with past work demonstrating similar increases in prairie communities (Hulbert 1969). However, other studies show reduced emergence following fire (Cain and Shelton 1998, Blodgett and others 2000).

Fire temperatures recorded during the dormant-season burns are comparable to other hot prescribed fires (Glasgow and Matlack 2007b). Maximum fire temperature, as recorded here, was not a good predictor of emergence (Fig. 1). As noted in past research, fire duration and soil moisture may be supplementary factors needed for predicting damage from burning (Iverson and others 2006). Additionally, the soil is an excellent thermal insulator. Increased soil temperatures are often detectable for the upper few centimeters of the soil profile (Auld and Bradstock 1996), which would favor seeds buried deeper in the organic layers and mineral soil. However, the samples collected for this study were not stratified by depth, so we cannot determine if the viable seed that germinated was either resistant to fire or was buried deeper in the profile.

Apparently, burning treatments have the ability to alter the composition of the viable seed bank. Eight and nine species had fewer numbers of emergents compared to the pre-burn samples (Table 2) following the dormant-season burning treatment on the Meadows Knob and Falling Water sites. However, only two species had consistently fewer individuals for each site, namely *Q. alba* and one unknown species. By contrast, 9 and 16 species had higher numbers of individuals emerging from the seed banks following burning (Table 2). Here, six species or species groups had consistently greater emergence at both sites, namely at least three graminoid species, a *Physalis* spp., *Phytolacca americana*, and one unknown species. Several studies also confirm the increased germination of species like *Rhus* spp., *Phytolacca americana*, as well as many graminoid species (Cain and Shelton 2003, Glasgow and Matlack 2007a, Hulbert 1969).

The preburn dormant- and growing-season seed bank produced very similar numbers of emerged individuals, whereas the dormant-season seed bank from Falling Waters was twice that of the summer seed bank (Tables 2 and 3). The graminoids were the most prevalent taxa for the summer collections. This result may be a response to a longer stratification period on site or possibly due to differences in collection locations. Dormant- and growing-season samples were collected on slightly different locations within each study site, whereas preburn and post-burn samples were located at most 1 m apart.

Taxa that dominate forested seed bank samples are usually species with high fecundity, effective dispersal mechanisms, and the ability to remain dormant under unfavorable conditions (Glasgow and Matlack 2007a). This usually favors early successional species like the graminoids, *Phytolacca americana* and *Rhus* spp. The lack of viable seeds from the dominant tree vegetation was unexpected, but not surprising (Shiffman and Johnson 1992). The tree species that dominated the overstory at both sites (i.e., oaks) are characterized as having relatively low fecundity, limited dispersal, reduced or no dormancy, the capability to sprout, and some degree of shade tolerance. These characteristics would favor a somewhat periodic germination process and a long-term building of an advance reproduction pool. The tree species that germinated in this study were *Carya* spp., *Ostyra virginiana*, *Acer rubrum*, *Quercus rubra*, *Q. alba, Rhus* spp., *Nyssa sylvatica*, and *Sassafras albidum*. *Rhus* spp., *O. virginiana*, and *S. albidum* were the only species that were not found in the overstory that germinated in our seed bank samples, while *Pinus echinata*, *Q. velutina, Q. stellata*, and *Prunus serotina* were species that were present in the overstory but did not germinate from the seed bank.

The results of this study, although limited because one of the burn treatments from being implemented, still provides information concerning the composition of the soil seed bank of three mature upland oak sites in the Arkansas Ozark Highlands with and without prescribed fire.

The seed bank was composed almost entirely of nontree species. Most tree species found in mature upland stands do not have large persistent seed banks. This situation highlights the importance of the other sources of reproduction (sprouting and advance reproduction) when these stands are regenerated. Burning had little effect on the total numbers of germinated seed. However, there does appear to be shifts in species composition, generally favoring graminoid species.

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LITERATURE CITED

Adams, A.S.; Rieske, L.S. 2001. **Herbivory and fire influence white oak (*Quercus alba* L.) seedling vigor.** Forest Science. 47(3): 331-337.

Auld, T.D.; Bradstock, R.A. 1996. **Soil temperatures after the passage of a fire: Do they influence the germination of buried seeds?** Austral Ecology. 21(1): 106-109.

Barnes, T.A.; Van Lear, D.H. 1998. **Prescribed fire effects on advanced regeneration in mixed hardwood stands.** Southern Journal of Applied Forestry. 22(3): 138-142.

Blodgett, H.; Hart, G.; Stanislaw, M. 2000. **Annual burning decreases seed density in the upper soil layers of the seed bank.** Tillers. 2: 31-38.

Brose, P.H.; Van Lear, D.H.; Keyser, P.D. 1999. **A shelterwood burn technique for regenerating productive oak sites in the Piedmont region.** Southern Journal of Applied Forestry. 23(3): 158-163.

Cain, M.D.; Shelton, M.G. 1998. **Viability of litter-stored *Quercus falcata* Michx. acorns after simulated prescribed winter burns.** International Journal of Wildland Fire. 8(4):199-203.

Cain, M.D.; Shelton, M.G. 2003. **Fire effects on germination of seeds from** *Rhus* **and** *Rubus***: competitors to pine during natural regeneration.** New Forests. 26: 51-64.

Glasgow, L.S.; Matlack, G.R. 2007a. **Prescribed burning and understory composition in a temperate deciduous forest, Ohio, USA.** Forest Ecology and Management. 238: 54-64.

Glasgow, L.S.; Matlack, G.R. 2007b. **The effects of prescribed burning and canopy openness on establishment of two non-native plant species in a deciduous forest, southeast Ohio, USA.** Forest Ecology and Management. 238:319-329.

Gross, K. 1990. **A comparison of methods for estimating seed numbers in the soil.** Journal of Ecology. 78: 1079-1093.

Guyette, R.P.; Spetich, M.A. 2003. **Fire history of oak–pine forests in the Lower Boston Mountains, Arkansas, USA.** Forest Ecology and Management. 180: 463-474.

Hulbert, L. C. 1969. **Fire and litter effects in undisturbed bluestem prairie in Kansas.** Ecology. 50: 874-877.

Iverson, L.R.; Prasad, A.M.; Hutchinson, T.F.; Rebbeck, J.; Yaussy, D.A. 2006. **Fire and thinning in an Ohio oak forest: grid-based analyses of fire behavior, environmental conditions, and tree regeneration across a topographic moisture gradient.** In: Dickinson, M.B., ed. Fire in eastern oak forests - delivering science to land managers. Gen. Tech. Rep. NRS-P-1. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station: 180-187.

Park, H. 1955. **Schoolcraft in the Ozarks: reprint of journal of a tour into the interior of Missouri and Arkansas in 1818 and 1819 by Henry R. Schoolcraft.** Van Buren, AR: Press-Argus Printers. 191 p.

Shiffman, P.M.; Johnson, W.C. 1992. **Sparse buried seed bank in a southern Appalachian oak forest: implications for succession.** American Midland Naturalist. 127: 258-267.

Tierney, G.L.; Fahey, T.J. 1998. **Soil seed bank dynamics of pin cherry in a northern hardwood forest, New Hampshire, U.S.A.** Canadian Journal of Forest Research. 28(10): 1471-1480.