STAND DYNAMICS 12 YEARS AFTER PRESCRIBED FIRE TO RESTORE DEGRADED UPLAND OAK-HICKORY FORESTS IN THE OZARK-ST. FRANCIS NATIONAL FOREST, ARKANSAS

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Abstract—Prescribed fire, when applied at an appropriate frequency and intensity, has proven to be an effective management tool to promote and enhance upland oak (*Quercus* spp.) regeneration, particularly on xeric sites. Relatively thick protective basal bark, strong resprouting capabilities, and flammable leaf litter are fire-adapted traits that more fire-tolerant upland oaks possess, providing a competitive advantage over more fire-sensitive, mesophytic species (for example, red maple, *Acer rubrum*; blackgum, *Nyssa sylvatica*; black cherry, *Prunus serotina*). This study quantified the effects of prescribed fire on long-term changes in overstory (≥4.5 inches diameter at breast height, d.b.h.), sapling (0.6 to less than 4.5 inches d.b.h.), and seedling (>6 inches height, <0.6 inches d.b.h.) dynamics 12 years after burn treatments. Fires were implemented across three sites that experienced significant red oak (Section *Lobatae*) overstory mortality following severe drought (1998 to 2000) and a red oak borer (*Enapalodes rufulus*) outbreak (early 2000s). Twelve years after a single-dormant season burn, overstory basal area had been reduced across all sites with red oaks comprising the majority of mortality. In the no-burn control, an increase in overstory basal area was observed due to non-oak ingrowth. Densities of oak and non-oak seedlings increased 2 years post-dormant burn, but then began to decline as a result of these seedlings growing into saplings or being outcompeted. After 12 years, oak and non-oak sapling densities had rebounded, substantially, over pre-burn levels with red and white oaks (Section *Quercus*) present in greater densities and at competitive heights, positioning them to be recruited into the overstory.

INTRODUCTION

Oak (*Quercus* spp.) species are ecologically and economically important. Oaks are a major component in 68 percent of North American hardwood forest cover types (Stein and others 2003). They provide hard mast to numerous wildlife species such as white-tailed deer (*Odocoileus virginianus*) and eastern wild turkey (*Meleagris gallapavo*) (Brose and others 2014, Dersal 1940, Miller and Lamb 1984, Stein and others 2003). Large contiguous blocks of upland oak-hickory (*Carya* spp.) forests characterize the Ozark Plateau in southern Missouri and northwestern Arkansas, dominating the Central Hardwoods region of the United States (Chapman and others 2006, Guyette and others 2006, McShea and Healy 2002). These forests developed under frequent, low-intensity fires. Many of these fires were ignited by Native Americans and early European settlers, oftentimes extending past the natural fire season (Hicks and others 2004, Van Lear 2004). Through repeated exposure to fire disturbances, oaks evolved adaptations including thick basal bark protecting the cambium from heat damage and the ability to resprout following disturbance (Alexander and others 2008, Brose and others 2014). However, after long periods of fire suppression, decreases in oak regeneration potentials and recruitment of oak into the mid- and overstory strata has allowed for an increase of more shade-tolerant, fire-sensitive species (Heitzman and others 2007, Nowacki and Abrams 2008, Vickers and others 2014). “Mesophication,” or the positive feedback in which closed canopy conditions favor shade-tolerant, fire-sensitive species, by maintaining cool, damp conditions, has further complicated oak regeneration and recruitment problems (Keyser and others 2017, Nowacki and Abrams 2008). In addition to oak regeneration problems, the absence of fire has allowed for over-mature, dense, even-aged closed canopy forests, increasing stress on overstory trees making them more susceptible to climatic and forest health disturbances such as drought, insect outbreaks, and pathogens (Haavik and others 2015, Vander Yacht and others 2018).

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In the early 2000s, increased overstory mortality was noticed in northwestern Arkansas following a period of significant drought and an outbreak of red oak borer (*Enapalodes rufulus*). In this region, red oak (Section *Lobatae*) species experienced increases in mortality with northern red oak (*Quercus rubra*) and black oak (*Q. velutina*) experiencing the greatest mortality (~126 trees per acre). White oaks (Section *Quercus*; *Q. alba, Q. stellata*) affected by the drought demonstrated severe crown dieback and in most cases when affected, failed to rebound (Fan and others 2008, Spetich 2004). Mortality events were attributed to oak decline or effects of pre-disposing (for example, advanced tree age; shallow, rocky soils; and dense forest conditions), inciting (for example, drought), and contributing (for example, red oak borer and hypoxylon canker (*Biscogniauxia atropunctatum*)) factors (Heitzman and others 2007, Johnson and others 2002, Manion 1990). These forest health disturbances were coupled with documented decreases in oak regeneration and failed recruitment of oak species following mortality events (Bendixsen and others 2016, Larsen and others 1997) Decreases in regeneration and increases in mortality caused by red oak borer and drought prompted the investigation of the use of prescribed fire as a restoration tool on these sites in northwestern Arkansas. This study evaluated the long-term effects of prescribed fire on the stand dynamics in degraded upland forests and the interactions with forest health and climatic disturbance events. To do this, the objectives of this study were to characterize changes in overstory basal area and species composition; sapling density and composition, diameter, and height; and seedling density and composition.

MATERIALS AND METHODS

Study Area

This study was conducted on the Big Piney Ranger District in the Ozark-St. Francis National Forest in northwestern Arkansas. Sites were located in Johnson and Pope Counties, Arkansas, and were within the Boston Mountains Ecoregion. Early Pennsylvanian sandstones and shale with a minor limestone component made up the parent material and Nella-Enders, Nella, and Mountainburg soils were found on the sites (USDA NRCS 2018). This region was classified as a humid subtropical climate receiving an average of 49.5 inches of rainfall and 2.1 inches of snowfall annually. The average high temperature was 92 °F (July to August) and average low temperature was 28 °F (January to February). The overstory was an upland oak-hickory cover type with northern red oak, white oak, black oak, post oak (*Quercus stellata*), mockernut hickory (*Carya tomentosa*), and bitternut hickory (*C. cordiformis*) as the dominant species (Eyre 1980, McWilliams and others 2002). Surveys indicated over 295,000 acres were moderately to severely affected by oak decline events in this region (Starkey and others 2004).

Treatments

Three sites (Pilot Knob, Meadows Knob, and Falling Water) were located near ridge tops on south to southwest facing slopes of 20 to 40 percent and were characterized by increased stand age and density (Booker 2008). Each site was divided into two treatments: a dormant season burn and no-burn control treatment. A single dormant season fire was implemented at Pilot Knob in February 2006 and at Falling Water and Meadows Knob in early March 2007. Within each treatment, six to nine plots were randomly located (Booker 2008). To characterize the overstory, a 10 basal area factor (BAF) prism plot was located over each plot center. Each plot also contained five subplots, one located at plot center and four at a distance of 30 feet in each cardinal direction (north, south, east, and west). Each subplot contained a sapling plot (0.005 acres) and a nested seedling plot (0.001 acres).

Field Methods

Overstory, sapling, and seedling data were collected at each site at the end of the growing season (late July/ early August) 1 year prior to treatment (pre-burn), 2 years following treatments (post2), and 12 years following treatments (post12). Overstory was classified as a living tree with a d.b.h. of 4.5 inches and greater. Variables collected for the overstory strata were d.b.h., species, and crown dieback and transparency. Saplings were considered living stems with a d.b.h. ranging from 0.6 inches to 4.5 inches and seedlings were greater than 2 feet in height and less than 0.6 inches d.b.h. Within each sapling plot species, height, and d.b.h. were determined. For seedlings, species, height, basal diameter, and vigor were recorded.

Data Analysis

Overstory basal area (square feet per acre) mean values were determined for each species group (red oak, white oak, hickory, and other, non-oak) in each treatment for the pre-burn, post2, and post12 measurement periods. Mean change in basal area from pre-burn to post2 (post2 minus pre-burn) and pre-burn to post12 (post12 minus pre-burn) were calculated for each species group by treatment. The same calculations were conducted for the sapling strata for red oak, white oak, red maple (*Acer rubrum)*, and other species groups using change in mean stems per acre from pre-burn to post2 and pre-burn to post12. Mean height and d.b.h. were determined for saplings to indicate post-burn changes in competitive status for species groups. Mean seedling stems per acre were determined and changes were summarized for pre-burn to post2 and pre-burn to post12 periods for each species group.

RESULTS AND DISCUSSION

Overstory

Basal area decreased for all species groups except other 2 years following treatments (table 1). Overstory oaks, affected by oak decline events, continued to experience mortality as illustrated by continued decreases in basal area. Red oak species, which were most negatively impacted by oak decline associated events, experienced a similar rate of decrease in basal area (12 to 13 percent) 2 years following both the no-burn control and dormant treatment. While mortality continued for red oaks in the control treatment (19 percent decrease in basal area), a greater decrease in basal area (43 percent) was observed from pre-burn to post12 in the dormant treatment. White oak basal area decreased 2 years following both treatments (2 to 4 percent). Twelve years following the control treatment white oak basal area continued to decrease (10 percent), whereas in the dormant treatment, white oak stems had begun to grow into the overstory strata as demonstrated by a 1 percent increase in basal area. Treatments appeared to have little impact on hickory basal area. The other species group experienced an initial decrease in basal area 2 years following the dormant treatment (15 percent), but began to increase in basal area (3 percent) by 12 years post dormant treatment. In the control, the other species group increased in basal area both 2 (7 percent) and 12 (15 percent) years post treatment (table 1).

Across our three study sites, basal area was reduced for the white and red oak groups across treatments due to the combined effects of oak decline and a single prescribed fire (table 1). Areas in the Boston Mountains are highly susceptible to decline-associated events due to stands being composed of dense, mature oaks. Spetich and He (2008) suggested that under the current low frequency fire regime, the potential for oak decline events would remain high within the Boston Mountains in northwest Arkansas until the older cohort died out. In contrast, under a more historical regime characterized by increased frequency of fires, oak decline events would impact a smaller portion of the landscape overall as a result of more frequent removal of physiologically weak and mature overstory trees. Understanding the impact of frequency of intermediate disturbances (such as prescribed burns) can impact vulnerability to oak decline may help project future stand compositions. Events remove older, wounded and diseased trees from the overstory increasing available light to the forest floor and thus, light reaching the regeneration strata. This should favor growth and development of oak reproduction while reducing mesophytic competitors (Brose and others 2014).

Saplings

Sapling densities (stems per acre) decreased 2 years following treatments for all species except the others species group, which increased in density in the control (table 2). The single dormant season treatment initially reduced densities for all sapling species groups as a result of topkill. Sapling densities were reduced by 94 percent for red oaks, 72 percent for white oaks, 74 percent for red maple, and 70 percent for other species groups 2 years following the dormant burn treatments. The majority of these reductions was attributed to topkill by the dormant season burn. As a result of resprouting

Table 1—Summary of mean overstory (≥4.5 inches d.b.h.) basal area prior to (Pre-burn) burn treatments and change in basal area 2 (Post2) and 12 years (Post12) following treatments across Pilot Knob, Falling Water, and Meadows Knob sites

		Basal area		
Species group	Treatment	Pre-burn	Post2 change	Post12 change
		square feet per acre		
Red oaks	Control	26.7 (7.6)	-3.3 (1.4)	-5.0 (2.5)
	Dormant	46.1 (5.1)	-6.1 (1.6)	-20.0 (4.0)
White oaks	Control	43.9 (7.7)	-1.1 (0.8)	-4.4 (2.8)
	Dormant	33.5 (4.5)	-1.3 (0.7)	+0.4 (2.1)
Hickory	Control	19.4 (6.4)	-1.7 (1.2)	0.0 (2.7)
	Dormant	6.1 (2.3)	-0.4 (0.4)	-1.3 (0.9)
Other	Control	15.0 (2.9)	+1.1 (1.8)	+2.2 (2.5)
	Dormant	11.7 (3.5)	-1.7 (1.2)	+0.4 (1.6)

Red oaks: northern red oak, black oak; white oaks: white oak, post oak; and other: blackgum, black cherry (*Prunus serotina*), red maple, etc.

Standard error presented in parentheses.

Table 2—Summary of mean sapling (0.6 to < 4.5 inches d.b.h.) density prior to (Pre-burn) burn treatments and change 2 (Post2) and 12 years (Post12) following treatments across Pilot Knob, Falling Water, and Meadows Knob sites

Species group	Treatment	Sapling density Pre-burn	Sapling density Post2 change	Sapling density Post12 change
		stems per acre		
Red oaks	Control	6 (4)	0 (0)	+9 (4)
	Dormant	52 (21)	-49 (20)	+223 (71)
White oaks	Control	44 (17)	-11 (5)	-18 (11)
	Dormant	43 (17)	-31 (13)	+35 (14)
Red maple	Control	29 (10)	-2 (2)	+80 (25)
	Dormant	89 (24)	-66 (24)	+270 (71)
Other	Control	173 (23)	+16 (17)	+104 (47)
	Dormant	195 (29)	-136 (26)	+285 (70)

Red oaks: northern red oak, black oak; white oaks: white oak, post oak; red maple; and other: hickory, blackgum, black cherry, sassafras (*Sassafras albidum*), etc.

Standard error presented in parentheses.

responses, 12 years following the dormant season fires all species groups demonstrated an increase in sapling density (table 2). Twelve years following the dormant burn, red oak densities had increased by 428 percent over pre-burn, representing the greatest relative increase from pre-burn to post12 conditions. Twelve year increases in sapling density red oaks were followed by red maple (303 percent), other (146 percent), and white oak (81 percent) species groups. Sapling density increased slightly for red oak (150 percent), red maple (275 percent), and other (60 percent) species groups after 12 years in the control treatment. White oak was the only group to experience an overall decrease (41 percent) in sapling density in the control after 12 years (table 2).

Prior to the dormant season treatment, red (2.0 inches) and white (2.2 inches) oak saplings had a slightly greater d.b.h. when compared to competing red maple (1.8 inches) and other species (1.5 inches) groups. Two years following both treatments, sapling diameter increased for all species groups. In the dormant treatment, increases were likely due to the greater topkill occurrence in the smaller diameter stems. Survival of seedlings and saplings was also found to be related to larger basal diameter stems with stems less than 6 inches being damaged by fire in the Missouri Ozarks (Dey and Hartman 2005). As recruitment into the sapling strata occurred for nearly all species groups 12 years following the dormant treatment, sapling diameter decreased for all species groups. Twelve years after the dormant burn treatment, the average d.b.h. was 1.3 inches for all species groups. Pre-burn diameters for species groups in the control were similar to those in the dormant treatment. Decreases in sapling d.b.h. also occurred after 12 years in the control treatment due to the ingrowth of a few smaller saplings (table 2). Similar trends were observed for changes in sapling height. In the dormant treatment, prior to burning, red (18.2 feet) and white (18.1 feet) oaks were taller than red maple (17.8 feet) and other (14.7 feet) species groups. Twelve years following the dormant season treatment, red maple (18.0 feet) was taller than red oak (16.8 feet), white oak (13.0 feet), and other species (16.9 feet) groups. Height rankings among species groups likely changed due to differences of inherent rate of growth (for example, red maple is a faster growing species than upland red and white oaks).

Canopy gaps created by mortality events appear to have benefited the oak regeneration potential in these stands. Newly formed gaps create areas with intermediate-light levels required for oak regeneration and the use of prescribed fire reduces the shade-tolerant, fire-sensitive non-oak competitors (Greenler and Saunders 2019). Vander Yacht and others (2018) found that burning under a heavily disturbed canopy resulted in a negative effect on mesophytic species and had a greater benefit for the more shade-intolerant, fire-adapted species (Vander Yacht and others 2018). Our findings demonstrated the benefits of prescribed fire after canopy disturbance on red oak sapling densities (table 2), particularly at the Pilot Knob site. Increases in non-oak competitor species following the dormant season treatment at the other sites may be attributed to the sites having been in various stages of mesophication prior to burning. In another study conducted in the Missouri Ozarks, it was found that 50 percent of stems, despite species, were damaged by a single dormant season fire (Dey and Hartman 2005). Further, after three or more burns blackgum (*Nyssa sylvatica*) demonstrated increases in mortality while white oak and hickory species had relatively low mortality (14 to 22 percent; Dey and Hartman 2005). Repeated fires may increase the density of oak species compared to more shade-tolerant, fire-sensitive species due to selective mortality caused by the repeated burns. Other studies in the Central Hardwoods region have found that repeated burning reduced non-oak competitors by 60 to 70 percent compared the effect on oak densities (28 to 54 percent) (Fan and others 2008).

Seedlings

Prior to treatments, the other species group comprised over half of all seedlings (table 3). Seedling densities (stems per acre) increased for all species groups 2 years after treatments. In the dormant treatment, red maple (259 percent) illustrated the greatest rate of increase in seedling density, followed by white oak (191 percent), other (170 percent), and red oak (160 percent) species groups. Increases in seedling densities, although to a lesser extent, also occurred for all species groups 2 years after the control treatment. Following initial increases in seedling densities in the dormant treatment, seedling densities had decreased from 2 years post treatment to 12 years post treatment for all species groups except other. This is likely a result of initial seedling sprouts growing into the sapling strata as seedling densities continued to increase after 12 years in the control treatment (table 3).

An important physiological trait of oak seedlings is the storage of carbohydrates in their root tissue, which contributes to the survival and persistence of these species following a disturbance such as fire (Brose and others 2014). Storage of carbohydrates in the root stock by oaks is important because it supports sprouting following a top-killing fire. This, along with higher drought tolerance than mesophytic species on the more xeric sites in the Ozarks and the increased light levels due to overstory mortality, can increase oak advanced reproduction (Brose and others 2014). In our study, the effects of the dormant season prescribed fire in combination with reduced basal area likely increased the sunlight available to lower strata. This allowed seedling-sized stems to grow in height and basal diameter to be more competitive, thus increasing recruitment into the sapling class (Alexander and others 2008, Dey and Hartman 2005). Alexander and others (2008) quantified the effects of prescribed fire on upland oak and non-oak competitor seedlings in the Daniel Boone National Forest in Kentucky and found that on unburned sites, white oaks declined around 6 percent annually when compared to red maple and red oaks (which declined at about 5 percent annually); white oaks also exhibited the highest mortality on sub-mesic sites. In our study, white oak seedling densities increased following treatments, but in agreement with Alexander and others (2008) at a much slower rate than for the other, red oak, and red maple species groups.

Table 3—Summary of mean seedling (>2 feet in height and <0.6 inches d.b.h.) density prior to (Pre-burn) burn treatments and change 2 (Post2) and 12 years (Post12) following treatments across Pilot Knob, Falling Water, and Meadows Knob sites

		Seedling density		
Species group	Treatment	Pre-burn	Post2 change	Post12 change
		stems per acre		
Red oaks	Control	211 (71)	+78 (54)	+444 (198)
	Dormant	330 (91)	+530 (228)	+270 (98)
White oaks	Control	33 (18)	+22 (36)	+144 (75)
	Dormant	96 (63)	+183 (112)	+113 (84)
Red maple	Control	578 (178)	+100 (54)	+656 (270)
	Dormant	339 (139)	+878 (314)	+852 (300)
Other	Control	1222 (219)	+33 (59)	+189 (220)
	Dormant	748 (125)	+1278 (361)	+1348 (243)

Red oaks: northern red oak, black oak; white oaks: white oak, post oak; red maple; and other: hickory, blackgum, black cherry, sassafras, etc.
Standard error presented in parentheses.

CONCLUSIONS

Declines in overstory health due to oak decline events and low regeneration potentials of oaks in the understory suggested the need for management intervention. A single dormant season prescribed fire continued to reduce the basal area of the red and white oak overstory. As basal area was reduced, canopy gaps were created, allowing seedling sprouts regenerated by the fire treatments to receive more light and grow into advanced regeneration. The reduction of basal area in the overstory and increases in oak saplings and seedlings observed in this study shows the potential effect of adaptations to fire and gap-utilization that oaks possess. Although oak seedling and sapling densities increased in our study, so did the density of non-oak competitors. Variation was observed across our three sites (although not reported in this paper) in the degree to which oak versus mesophytic competitor sapling and seedling densities increased. This variation may be attributed to the different level of mesophication that existed prior to burning across the three sites as well as, topography and fire intensity. After only a single dormant season fire, red maple and other non-oak species remained competitive, which suggests additional management intervention(s) may be required.

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