OAK SAVANNA RESTORATION: OAK RESPONSE TO FIRE AND THINNING THROUGH 28 YEARS

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Abstract.—We used a small plot study on Pushmataha Wildlife Management Area in southeast Oklahoma to determine the efficacy of fire frequency and thinning as management tools for restoration of oak savanna, oak woodlands, pine-bluestem woodlands, and pine savanna for application on a landscape scale. On selected experimental units, we initially reduced stand density to favor either oak canopy dominance or pine dominance to near presettlement stand density. Thinned stands were then subjected to 0-, 4-, 3-, 2-, and 1-year late dormant season (late February - early April) fire frequency regimes for 26 years. For comparison, we withheld control units from treatment and also included unthinned but with 4-year burn regime treatment units. We included two additional thinning treatments, the oak-savanna and pine-bluestem treatments, both with annual burn regimes; the oak-savanna had all pine removed (approximately 50 percent of the basal area) and the pine-bluestem had half of the hardwood thinned (approximately 25 percent of the pre-treatment basal area). We compared mortality rate, acorn production, and growth response of selected post oaks and blackjack oaks. We also assessed nutrient content of post oak acorns to determine prescribed fires potential influence on nutrient status. We found a differential response by species to presence or absence of fire; but all selected trees responded favorably in diameter growth to thinning. Blackjack oak mortality was highest on unthinned and unburned sites versus any of the fire treatments because of hypoxylon cancer, an indirect result of high stand density (competition) and drought stress. Mortality of post-oaks was related to initial burns, and to some extent, cumulative effects of fire frequency interacting with fuel loads. Although thinning efforts on a landscape level were applied on the Wildlife Management Area beginning in 1978, fire frequency was >4-year intervals, inadequate for maintenance of savanna and woodland structure. Based on small plot study results we begin landscape application of frequent fire on a 1-3 year cycle in 1997 and increased thinning in 1999-2001. Restoration thinning and a more focused burn regime was applied in a site specific manner on the landscape in 2008 through present. Woodland-grassland and forest-shrub obligate songbirds, white-tailed deer, and Rocky Mountain elk have responded favorably.

INTRODUCTION

Fire suppression along with attendant forest densification has had a pervasive, deleterious influence on numerous ecosystems across eastern North America (Nowacki and Abrams 2008). In particular, the interior Highlands of Oklahoma, Arkansas, and parts of Missouri have over the last century and more succeeded from a landscape matrix composed of prairie elements, oak and pine savanna (see Appendix for list of common and scientific names), and oak or pine woodland-grassland complexes to a dense homogeneous hardwood or oak-pine dominated land cover (Beilmann and Brenner 1951; Foti and Glenn 1991; Masters and others 1995, 2007). Historically associated wildlife species included bison, elk, white-tailed-deer, many other mammals, and birds in abundance (Featherstonhaugh 1844, Smith and Neal 1991).

This forest densification and homogenization has led to declines in species richness and abundance of flora (Gilliam and others 2006, Sparks and others 1998) and fauna. Declines in wildlife species included extirpation of bison, elk, some meso-mammals (Smith and Neal 1991), and near-loss of some small mammals and woodland-grassland obligate songbird species, particularly those associated with pine-grasslands (Masters and others 1998, 2002; Wilson and others 1995).

As forest density and canopy cover increases, understory herbage production declines and understory structure changes (Fenwood and others 1984; Masters and others 1993a, 1996). This has a profound influence on many species of wildlife in several respects. In closed canopy forests of the Ozark and Ouachita Mountain regions similar to other Interior Highlands in the eastern United States, the understory forage base for white-tailed deer and elk is often inadequate to meet nutritional requirements to sustain healthy populations year round. This problem is compounded in winter because of little or no suitable evergreen winter browse (Masters and others 1993a, 1997; Segelquist and Pennington 1968; Segelquist and others 1969, 1972). In addition to herbage declines, structural complexity changes with densification and canopy closure, thus precipitating major impacts on songbird and small mammal communities (Engstrom and others 1984; Masters and others 1998, 2002; Wilson and others 1995).

Oak mast provides a valuable food resource for numerous wildlife species (McShea and Healy 2002). Oak mast failures in this region have been linked to winter mortality of deer, decreased productivity, and summer fawn mortality (Logan 1972; Segelquist and others 1969, 1972). During late fall and winter, deer preferentially select hard mast and only turn to browse and herbage in appreciable amounts when acorns are unavailable (Harlow and others 1975, Segelquist and Green 1968).

Establishment of food plots has been the traditional approach to provide additional forage as a contingency for mast failure (Masters and others 1993a, 1997). Some value has been shown for providing supplemental forage in the limited productivity forests of the Interior Highlands (Segelquist 1974, Thompson and others 1991). Deer mortality is less in years of mast failure in areas of contiguous closed canopy forest where comparatively large forage clearings have been developed (Segelquist and Rogers 1974). However, adequate nutrition for deer in years of mast shortfall can only be provided in unique situations because oak mast is substantially higher in nutritional quality than typically available winter forage (Harlow and others 1975).

Pine-grassland restoration efforts via thinning and use of frequent fire have resulted in favorable population responses of pine-grassland obligate songbirds, small mammals, and in successful restoration of understory herbaceous communities and improved food resource availability for deer (Masters and others 1996, 1998; Sparks and others 1998; Wilson and others 1995). However, little research attention has been given to comparative efforts using thinning and frequent fire for restoration of oak savannas or mixed oak-pine woodlands on the effects on wildlife occurrence or on the long-term effects of varying fire frequency on oak survival and development.

In the late 1960s and early 1970s, the Pushmataha Wildlife Management Area (PWMA) in southeast Oklahoma experienced a precipitous decline of the deer population and of a recently established elk population. Because of the importance of oak mast for deer and the need for improving the forage base for these two focal species, the Oklahoma Department of Wildlife Conservation began long-term research on thinning and frequent fire strategies that retained selected oaks at lower stand densities on a series of small plots designated as the Pushmataha Forest Habitat Research Area (FHRA) (Masters 1991a, 1991b; Masters and others 1993a). The goal was to critically examine then current strategies to develop early succession openings (ESOs) for forage and to improve mast production by releasing selected oaks from competition.

The forest management strategy at that time employed commercial thinning of mixed oak-pine stands to create ESOs. These were created by harvesting merchantable pine and thinning remaining hardwoods to a target basal area (BA) of about 9 m^2/ha, approximating presettlement stand density in parts of the Ouachita Mountains (Foti and Glenn 1991, Masters and others 2007). The fire frequency needed to perpetuate early succession openings was unknown as was the effects of frequent fire on oak survival and general health. Conventional wisdom at that time suggested frequent fire was deleterious to oaks. Following mid-term results, management strategies were to be developed and applied on the landscape of PWMA.

To that end we examined post oak and blackjack oak response in untreated control, thinned only, and thinned and burned stands at 4, 3, 2, and 1 year burning cycles on the FHRA beginning in 1983. Our goal was to evaluate the validity of a current forest management strategy for determination of leave trees in timber harvest units. As an objective, we wanted to determine the effects of fire frequency on survival, diameter growth, crown development, and acorn production. Further, we wanted to determine if fire had an influence on nutrient content of acorns. Following thinning we predicted that selected trees would experience increased radial and crown growth and increased acorn production as a result of decreased canopy, water, and nutrient competition. We expected a cumulative increase in oak mortality within a 10-year study horizon, commensurate with crossing some fire-interval threshold encompassed within our increasing fire frequency treatments. Further, we expected that longer interval repeated burning would have positive cumulative effects on growth and survival over time as selected trees were freed from canopy and moisture competition.

Results from the small plot study would then be used to develop a restoration strategy for treatment application to the PWMA landscape. A critical part of that strategy included monitoring and evaluating deer, elk, and songbird response to landscape application of restoration treatments.

STUDY AREA

The study area was 29.1 ha in size and located within the FHRA (34°32’N, 95°21’W) on the 7,395 ha PWMA near Clayton, Oklahoma. The PWMA is located in the Kiamichi Mountains along the western edge of the Ouachita Highland Province. The study area is on thin, drought prone Hector-Pottsville soils developed from cherty shales and resistant sandstones. They belong to the Carnasaw-Pirum-Clebit association with a high proportion of surface rock and areas of rock outcrop (Bain and Watterson 1979). Soil nutrient levels and their response to our periodic prescribed fire and thinning treatments have been described by Masters and others (1993b). Available P, K, Ca, and Mg increased and nutrient cycling was enhanced when thinning and burning were applied together.

The climate is semi-humid to humid with hot summers and mild winters (Bain and Watterson 1979). Rainfall is somewhat unequally distributed throughout the year with August being drought prone and the driest month ($\bar{x}$ = 6.0 cm) and May the wettest ($\bar{x}$ = 14.7 cm) (Masters 1991b). From 1978-2010 average annual precipitation on or in the study area vicinity was 124.4 cm (unpublished data from Department of Natural Resource Ecology and Management, Oklahoma State University and Oklahoma Department of Agriculture, Forestry Services). From 1984 to 1996 annual precipitation was 146.5 cm (SD = 26.1), well above the 34 year average, and from 1997-2010 annual precipitation was 113.5 cm (SD = 27.6), which was significantly lower ($P > T$ =0.004) than the previous period. We obtained Palmer Drought Severity Index (PDSI) data during our study period for Oklahoma and Arkansas from the National Oceanic and Atmospheric Administration (2011). We used an October-September water-year for rainfall and drought indices data summarization (Fig. 1). In spring 1987, a late freeze affected acorn production and ice storms followed by high winds and crown damage to trees on FHRA occurred in December 1996, December 1997, December 2000, and January 2007.

Prior to acquisition from 1946-54, PWMA was grazed, selectively harvested, and frequently burned. The Forest Habitat Research Area was protected from further logging, grazing, and fire until 1984. The FHRA has been excluded from fire at least since 1969.

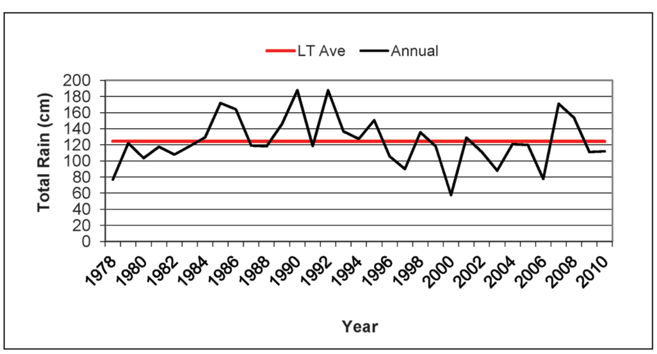

Figure 1.—Annual and long-term average (LT AVE) annual rainfall (cm) based on an October-September water-year for Pushmataha Forest Habitat Research Area 1978-2010, Pushmataha Wildlife Management Area, OK. Rainfall for the period 1983-1996 was higher (P=0.004) than for the period 1996-2010.

Prior to treatment and on unharvested sites (control and rough reduction burn), post oak, shortleaf pine, mockernut hickory and blackjack oak were respective dominates in the overstory. The BA of unharvested treatments ranged from 24-30 m^2/ha. Common understory species included: tree sparkleberry, poison ivy, Virginia creeper, greenbriar, and muscadine grape. Although sparsely occurring, the most prevalent understory herbaceous plants were little bluestem, panicums, and sedges (Masters 1991a, b).

Post-treatment harvested and thinned openings were dominated by tall grasses and woody sprouts of varying density, depending on fire frequency and time since burned for a given site. Grasses included big bluestem, little bluestem, and to a lesser extent, Indiangrass, and in drainages switchgrass. Post oak, blackjack oak, winged sumac, and blackberry were dominant understory woody species. The thinned overstory was comprised of sparse (~9 m^2/ha BA stems >5 cm at 1.4-m height) post oak and blackjack oak (Masters 1991a,b; Masters and others 1993a). The clearcut treatment was planted with loblolly pine in 1986. Masters (1991a,b), Masters and Engle (1994), Masters and others (1993a,b, 1997), and Crandall (2003) have described the study area, management, and vegetation of these stands. The deer population on the entire PWMA was estimated at 7.3 deer/km^2 ± 3.8 ($\bar{x}$ ± SE) in 1984 based on spotlight counts. At that time the total elk population was six animals (Masters 1991b).

METHODS

Experimental Design

Beginning in summer 1984 through present, 10 treatments with 1-4 replications were applied to 36, units (0.2-1.6 ha in size) in a completely randomized experimental design (Masters and others 1997). For the purposes of this paper, only the eight treatments that retained and involved monitoring of selected oaks were utilized (Table 1). The HT treatment included one replication until 1989 when a spot-over burned part of the unit. Because the monitored trees were not in the

Table 1.—Study treatment acronyms, descriptions, and number of replications (N) for the Pushmataha Forest Habitat Research Area, Pushmataha Wildlife Management Area, Oklahoma, for 1983-present

Treatment	Description	N
Control	Control, no thinning, no burning	3
RRB	Rough reduction, late-winter prescribed burn, 4-year interval	3
HNTI	Harvest pine timber only, late-winter prescribed burn, 1-year interval; Oak savanna, except 1995	3
HT	Harvest pine timber, thin hardwoods, no burn (natural regeneration to a mixed stand) (initially 1 replication was monitored, then an additional 3 were monitored after 1989)	4
HT4	Harvest pine timber, thin hardwoods, late-winter prescribed burn, 4-year interval	3
HT3	Harvest pine timber, thin hardwoods, late-winter prescribed burn, 3-year interval	2
HT2	Harvest pine timber, thin hardwoods, late-winter prescribed burn, 2-year interval, except 1995	3
HT1	Harvest pine timber, thin hardwoods, late-winter prescribed burn, 1-year interval, except 1995	3

burned area, the trees on this unit were retained for the purposes of this study. Three additional replications of the treatment were included at that time that had not previously been monitored.

During summer 1984, merchantable pine trees were harvested in assigned treatments, and hardwoods were selectively thinned by single stem injection using 2,4-D to approximately 9 m^2/ha basal area. Prescribed strip-head fires were applied on appropriate treatment units in mid-March and early April 1985 and in succeeding years at 1-, 2-, 3-, and 4-year intervals. Fireline intensity of March 1988 burns ranged from 628-903 kW/m (Masters and Engle 1994).

On each treatment unit, 10 permanent plots were established at 20 m intervals on two randomly located lines perpendicular to the contour. No sampling was conducted within 20 m of any edge to prevent bias from adjacent treatment units (Mueller-Dombois and Ellenberg 1974, Oosting 1956). Basal area of overstory vegetation was quantified each year using the variable radius plot method (Avery 1967). Basal areas of stems ≥5 cm diameter at breast height (d.b.h.) were measured with a 10-factor wedge prism at each permanent plot location. Baseline sampling before cultural treatment application was conducted in 1983. Overstory canopy cover was determined from mid-September to mid-October prior to leaf abscission. Estimates were made with a 9-point grid in a sighting tube with vertical and horizontal levels at plot center and cardinal points at 2 m and 4 m from each permanent plot location in most years from 1985 to 2010 (Mueller-Dombois and Ellenberg 1974).

Mast Tree Sampling

We selected three post oaks and three blackjack oaks, where available, as study trees from each treatment unit, following commercial pine harvest in 1984. Initially we sought to include black oaks as well, but given the paucity of this species on the study area and unequal distribution, only a few were available and chosen for monitoring. Black oaks did not occur in all units or treatments.

On each unit, all oak trees were systematically examined before selection. Those selected must not have been damaged by commercial timber harvest, in terms of canopy breakage or bark damage from felled trees or skidders. Further, trees were evaluated based on canopy development, height, and d.b.h. Oaks in the dominant or codominant position in the canopy were selected over intermediate or suppressed trees. However, some of the selected blackjack oaks were in intermediate canopy position as these were all that were available. The best formed and most vigorous appearing trees were selected from all candidate trees because acorn production is strongly related to tree diameter, crown area, and condition (Goodrum and others 1971). Trees on harvested units had complete crown release from competition and were generally farther than 20 m from the nearest residual tree. All competing residual trees greater than 5 cm in diameter that had touching or overlapping crowns were single stem injected as described earlier. We chose to select trees based on specified criteria rather than at random because we were evaluating validity of the current forest management strategy for determination of leave trees in timber harvest units.

Variables included for measurement included age, species, d.b.h., total height, crown area, and since 2000 crown density. Measurements were taken every year until 1989 and at least every 2 years thereafter. Mortality was tracked each year. In the first years of the study we did not measure crown area and height of trees on the annually burned treatments.

We measured d.b.h. annually to the nearest 0.1 cm using a standard diameter-tape. We used a clinometer to estimate total tree height to the nearest 0.5 m at 20 m distance until 2000. In following years a calibrated hypsometer was used to estimate height to the nearest 0.1 meter height.

To estimate crown area, we measured live crown diameter at two perpendicular axis and then calculated area based on the formula for the area of an ellipse whose semiaxes are a and b, $A = \Pi ab$. To assess crown density and health, from 1994 to 2010 we estimated canopy density beneath each sample tree from mid-September to early October prior to leaf abscission at cardinal points half the distance from the tree bole to canopy edge.

Postburn measurements after the initial thinning and first prescribed burn included bark-char height and height of limb scorching. Residual bark char prevented remeasurement in succeeding years. During early burns, fire behavior was estimated and fireline intensity was calculated after Masters and Engle (1994) and later modeled with BEHAVE or based on flame length estimates.

Acorn Sampling

We evaluated acorn production and viability from 1984-1989 and 1998 in Control, HT, HT4, HT3 and HT2 treatments. We used 18.93 liter buckets with an opening diameter of 28.96 cm for an effective trap area of 658.52 cm^2. Mast traps were fitted with wire screen covers to prevent wildlife depredation and placed at four quadrants under each tree; trap center was half the distance from the bole of the tree to the edge of the crown. We checked acorn traps at 1 week intervals beginning in early September until acorn drop was completed, generally late November during each sampling year. Acorns were counted, bagged, and the green weight recorded to the nearest 0.1 g. We also recorded the percent of acorns that were sound based on a viability rating of the percentage of sound acorns in the trap (Christisen and Kearby 1984, Goodrum and others 1971). We extrapolated total acorn production of viable acorns for each tree based on the crown area and percent of crown sampled.

In 1988, acorns from all post oaks on selected experimental units were collected for nutrient analysis by tree. Nutrient analysis of samples was conducted by Servi-Tech, Inc. (Dodge City, KS) and included moisture content, dry matter content, ash, crude protein, acid detergent fiber (ADF), total digestible nutrients (TDN), calcium, phosphorous, magnesium, and potassium.

Landscape Treatment and Wildlife Response

We selected stands to apply landscape thinning and burning treatments based on topographic position, site characteristics, and species composition. Historical references and settlement period tree density, basal area, and fire regime were also used to determine thinning levels and fire regime on targeted sites (Foti and Glenn 1991; Johnson 1986; Kreiter 1994; Masters and others 1995, 2007). Restoration thinning and burning began in 1999. Target stand types and target basal areas were oak-savanna and oak-pine savanna (7 m^2/ha), and oak-pine woodland and pine-bluestem woodland (14 m^2/ha). Riparian corridors and upland drainages were not thinned but were included in the adjacent administrative unit fire regime. More detail on proportion and juxtaposition of restoration treatments may be found in (Masters and Waymire 2012).

During August and September each year, spotlight counts were conducted for a minimum of 10 nights on a 16.1 km route using standardized Oklahoma Department of Wildlife Conservation protocols to index deer population status. In February of each year, total elk counts are made by driving the same route in late afternoon with the high count of the survey used as the population index. We used Breeding Bird Survey (BBS) data for Pushmataha County to derive trend data of target species of interest for PWMA (Sauer and others 2011). We chose 20 species to examine based on published accounts of habitat association and response to habitat change and whether or not they were species of special management concern (Cox and Widener 2008, Masters and others 2002, Wilson and others 1995). A total of 37 of the 50 stops in Pushmataha County were located on the PWMA. Individual stop data for each year from 1994-2009 were obtained for these 37 stops.

Data Analysis

Means were tested for homogeneity of variance among treatments using Levene's test (Snedecor and Cochran 1980). When variances were unequal we used the Kruskal-Wallis nonparametric test to determine treatment differences in acorn production, average annual diameter growth, tree height, and crown diameter (Steel and others 1997). Unit × year × treatment type III mean square was the error term (SAS Institute 1985). We used multiple comparisons between mean ranks with the Least Significant Difference (LSD) test with $P = 0.050$ (Steel and others 1997). We used rank transformations to analyze percentage data. Correlation analysis was used to examine relationships between weather, fire characteristics, and tree mortality and regression to examine linear trends in BBS data.

RESULTS

Stand Response

Pretreatment stands were characterized by closed canopy overstory and dense pine-hardwood midstory with extensive leaf-litter cover in the understory. Pine, hardwood, and total basal area ($\bar{x} \pm$ SE; 25.3 m^2/ha ± 0.5) were similar (P>0.05) across all experimental units in 1983 but different (P<0.05) in 1984 after thinning and in following years (Table 2). Stand

Table 2.—Pine, hardwood, and total basal area (BA) (m^2/ha) change by treatment on Pushmataha Forest Habitat Research Area, Pushmataha Wildlife Management Area, OK. Data in 1984 were post-thinning and in 2010 following fire frequency directed tree succession. Means with same letter were not different (P > F <0.004). See Table 1 for treatment descriptions. Most burns were in late February through mid-March.

Pine BA (m^2/ha)

Treatment	1984 Mean		SE	2010 Mean		SE
CONT	12.6	a	2.5	14.3	ab	2.0
RRB	13.9	a	1.7	15.5	ab	1.3
HNT1	0.3	b	0.2	0.9	d	0.3
HT	0.9	ab	-	21.1	a	6.2
HT4	1.1	ab	0.7	9.9	abc	3.7
HT3	0.6	b	0.3	2.0	cd	0.4
HT2	2.2	ab	0.7	2.6	bcd	0.5
HT1	0.5	b	0.2	1.1	d	0.6

Hardwood BA (m^2/ha)

Treatment	1984 Mean		SE	2010 Mean		SE
CONT	13.9	a	0.8	12.9	a	1.8
RRB	11.7	a	1.2	9.9	a	1.2
HNT1	9.6	ab	1.7	6.2	bc	1.1
HT	8.3	ab	-	10.0	ab	2.2
HT4	7.8	ab	0.9	3.9	cd	0.4
HT3	4.8	b	0.5	3.1	cd	0.1
HT2	6.3	ab	1.7	3.0	cd	0.3
HT1	6.8	ab	0.2	2.1	d	0.3

(Table 2 continued on next page)

Table 2 (continued).—Pine, hardwood, and total basal area (BA) (m^2/ha) change by treatment on Pushmataha Forest Habitat Research Area, Pushmataha Wildlife Management Area, OK. Data in 1984 were post-thinning and in 2010 following fire frequency directed tree succession. Means with same letter were not different (P > F <0.004). See Table 1 for treatment descriptions. Most burns were in late February through mid-March.

Total BA (m^2/ha)

Treatment	1984 Mean	SE	2010 Mean	SE
CONT	26.5 a	1.7	27.4 a	0.7
RRB	25.6 a	1.0	25.2 a	0.5
HNT1	9.9 ab	1.8	7.2 bc	1.3
HT	9.2 ab	-	31.7 a	4.3
HT4	9.0 ab	1.5	13.8 ab	4.0
HT3	5.4 b	0.1	5.1 bc	0.5
HT2	8.5 ab	2.3	5.6 bc	0.7
HT1	7.3 ab	0.2	3.2 c	0.7

understory immediately following thinning was characterized by a clumped and patchy ground cover of slash and sparse cover of hardwood sprout shrubs, vines, grasses, and forbs (Fig. 2). After the first burn and following subsequent burns, grass and forb cover predominated on thinned and burned treatment stands and had 21 times greater standing crop than control. Herbaceous standing crop on unthinned but burned RRB was three times that of control stands (Masters and others 1993a) (Figs. 3 and 4). Over time tree structure developed along a fire frequency gradient with unburned stands developing into dense closed canopy stands. For frequently burned stands, as fire frequency increased tree density and basal area decreased (Table 2 and Figs. 3 and 4).

Mortality

By 2010 total mortality was 38 of the 131 selected trees for 29.1 percent (Fig. 5). Percent mortality of just blackjack oak was over double that of post oak (44.4 percent versus 18.1 percent). Fire related mortality for all trees was 16.8 percent, and hypoxylon mortality was 10.7 percent. A total of 12 blackjack oak trees and 1 black oak succumbed to hypoxylon canker. A higher proportion of total blackjack oak mortality was from disease rather than fire. Except for one tree, all blackjack oak mortality from hypoxylon canker was on unthinned treatments. Lightning mortality of two post oaks was 1.5 percent (Fig. 5).

Figure 2.—Example of stand conditions post pine harvest and hardwood thinning (HT) before the first burn. All HT units were similar in residual hardwood basal area before burning on the Pushmataha Forest Habitat Research Area, Pushmataha Wildlife Management Area, OK.

Figure 3.—Photos of different treatments after 21 years of treatment application in early October 2006. All treatments in this and in Fig. 4 were similar to the control (top left) in 1983. Pine harvest and thinning was accomplished in early summer 1984 (see Fig. 2) and burning initiated in late winter 1985. Top left to right: **Control**, no treatment; **RRB**, no harvest or thinning, late winter burn on a 4-year interval. Bottom left to right: **HNT1**, harvest pine, no hardwood thinning, annual late winter burn; **HT**, harvest pine, no thinning and no burning on Pushmataha Forest Habitat Research Area, Pushmataha Wildlife Management Area, OK.

Figure 4.—Photos of different treatments after 21 years of treatment application in early October 2006. All treatments in this figure were similar to the control (top left, Fig. 3) in 1983. Pine harvest and thinning was accomplished in early summer 1984 (see Fig. 2) and burning initiated in late winter 1985. Top left to right: **HT4**, harvest pine, thin hardwoods to approximately ½ of original basal area, late-winter burn at 4-year interval; **HT3**, harvest pine, thin hardwoods to approximately ½ of original basal area, late-winter burn at 3-year interval. Bottom left to right: **HT2**, harvest pine, thin hardwoods to approximately ½ of original basal area, late-winter burn at 2-year interval; **HT1**, harvest pine, thin hardwoods to approximately ½ of original basal area, late-winter burn at 1-year interval on Pushmataha Forest Habitat Research Area, Pushmataha Wildlife Management Area, OK.

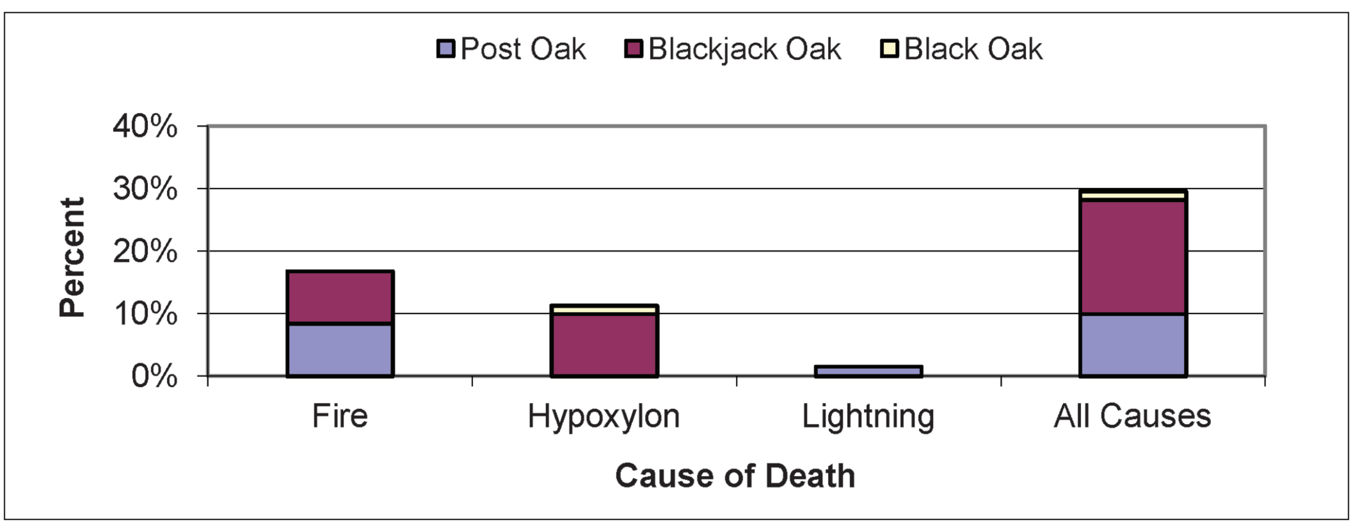

Figure 5.—Cause-specific mortality of selected post, blackjack, and black oaks on the Forest Habitat Research Area, Pushmataha Wildlife Management Area, OK from 1983-2010.

Blackjack and post oak mortality was 9.2 percent in the first growing season postburn and totaled 10.7 percent by the second year following introduction of fire on ESO treatments. This pulse of fire-caused mortality affected blackjack oak more severely than post oaks (Fig. 6). Smaller trees (lower diameter, height, and crown area) tended to succumb to fire in this initial pulse. Blackjack oak mortality leveled out following the first 2 years postfire reintroduction. The first canker-related mortality to blackjack oak occurred in 1994, and since 2002 subsequent mortality has been entirely from hypoxylon canker on control units and RRB treatments (Figs. 5 and 6). Of those trees dying from hypoxylon, 92.3 percent were during the period of below average rainfall and mortality was associated with the 2 previous years PDSI (r=0.327, P<0.05). The last fire-caused mortality of blackjack oak was in 2002. Control units experienced 87.5 percent mortality to blackjack oaks from hypoxylon canker (Fig. 7). Blackjack oak mortality on HT4, HT2, and HT1 treatments resulted from initial prescribed fires applied in the same week, and thus was not a fire frequency effect (Figs. 5 and 7).

Post oak attrition has been slight annually but steady until 2002 with 58 of the original 72 trees (81.9 percent) surviving thereafter through 2010 (Fig. 6). Post oak mortality was related largely to a fire frequency gradient on ESO treatments but also influenced by lightning mortality (Fig. 6 and 8). The HNT1 or post oak savanna treatment had the least post oak mortality of any of the thinned and burned treatments (P=0.004). Fuel loading tended to be lower on this treatment, particularly around the bole of selected trees, than on the other annually burned treatment, thus resulting in lower fire line intensity.

Crown Area, Height, and Diameter Response

Following commercial pine harvest and thinning of hardwoods in 1984, selected mast trees were similar in conformation (P<0.05) across all treatments. Average crown area, height, and d.b.h. of blackjack oak was

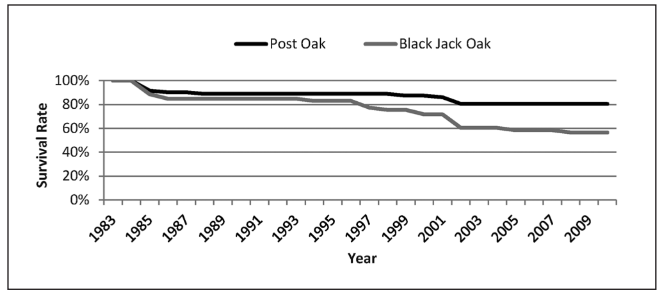

Figure 6.—Annual survival (%) of selected post and blackjack oaks from the Forest Habitat Research Area, Pushmataha Wildlife Management Area, OK from 1983-2010.

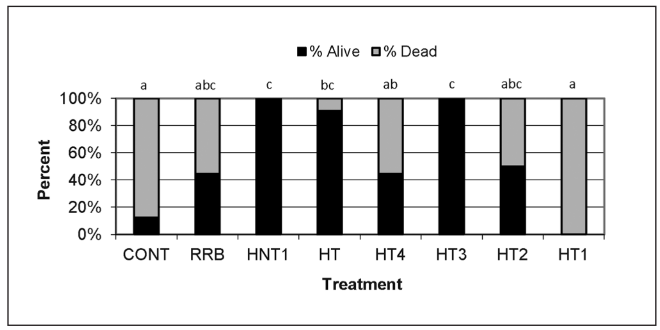

Figure 7.—Percent mortality of selected blackjack oaks by treatment on the Forest Habitat Research Area, Pushmataha Wildlife Management Area, OK from 1983-2010. See Table 1 for treatment descriptions. Mortality on the CONT, RRB and HT treatments was from hypoxylon canker. Mortality on the thinned and burned treatments was fire related. Percent mortality by treatment with the same letter was not different (P=0.014).

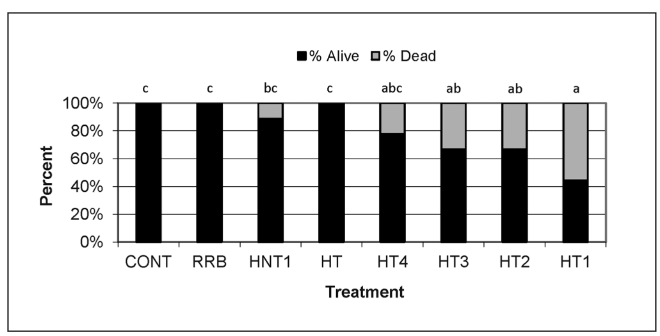

Figure 8.—Percent mortality of selected post oaks by treatment on the Forest Habitat Research Area, Pushmataha Wildlife Management Area, OK from 1983-2010. See Table 1 for treatment descriptions. Percent mortality by treatment with the same letters was not different (P=0.004).

respectively 25.1 m^2 ± 3.3, 11.0 m ± 0.4, 35.6 cm ± 1.2. Average crown area, height, and d.b.h. of post oak was 68.5 m^2 ± 4.3, 15.7 m ± 0.4, 23.6 cm ± 1.4, respectively.

It took 6 years for differences to be expressed in terms of blackjack oak physical characteristics following initial treatment. In subsequent years and during the period of above average rainfall, we found differences (P<0.050) in height in 3 years, d.b.h. in 4 years, and in crown area in 2 years for blackjack oak. When differences became apparent, the height was greater on HT2, RRB, and HT treatments than on Control treatments. However as the HT stand densified, height-growth slowed, and heights became similar to the Control by 1991 (P=0.36) but less than HT2 and RRB. Crown area and d.b.h. exhibited a similar pattern. After 1997 and throughout the period of below average rainfall, we found no differences in any of these variables between treatments for blackjack oak. Because of declining sample size and loss of some replications from both fire and disease mortality, the ability to detect meaningful differences was compromised somewhat as illustrated by average annual growth of blackjack oak across 28 years (Fig. 9).

We observed no treatment differences in average d.b.h. or crown area in any years in post oaks. However, we observed differences in average height by treatment 5 years following the ice storms. Post oaks from the HT treatment averaged greater heights than did the harvested and burned treatments. The treatments that were burned were much more open throughout the study, and crowns were more exposed to ice damage. The crowns of post oaks in the HT treatment were somewhat protected from the ice storms until 2007. Following that ice storm, post oaks in the HT treatment experienced severe crown damage and were near the lowest in height and were supplanted by the Control and RRB with highest average height. In contrast to height, average annual diameter growth was lowest for the HT treatment and highest for the HT4 (Fig. 10). Following ice storms and during the below average rainfall period, thinned and burned treatments had lower (P>0.050) heights because of top breakage in 4 years. Following the damaging storm in 2007 which affected trees across the board, we found no difference in height or crown area.

In 2010, average crown area, height, and d.b.h. of all blackjack oak across treatments was not different and was respectively 29.0 m^2 ± 4.8, 11.2 m ± 0.5, 31.4 cm ± 2.4. The same was true for post oak with average crown area, height, and d.b.h. of 78.1 m^2 ± 3.6, 15.5 m ± 0.3, 43.6 cm ± 0.9, respectively.

Acorn Production and Nutrient Content

In the first fall (1984) of the 7 years that we monitored post oak acorn production, we observed no differences among units treated alike because commercial harvest was accomplished by mid-summer and hardwood

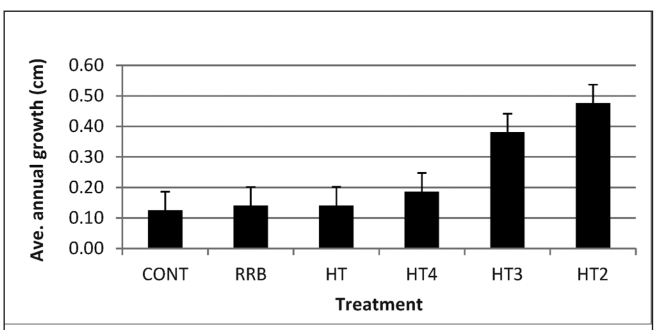

Figure 9.—Mean (± SE) blackjack oak average annual diameter growth from 1984-2010 by treatment on the Forest Habitat Research Area, Pushmataha Wildlife Management Area, OK. See Table 1 for treatment descriptions. Treatment means were not different (P=0.126).

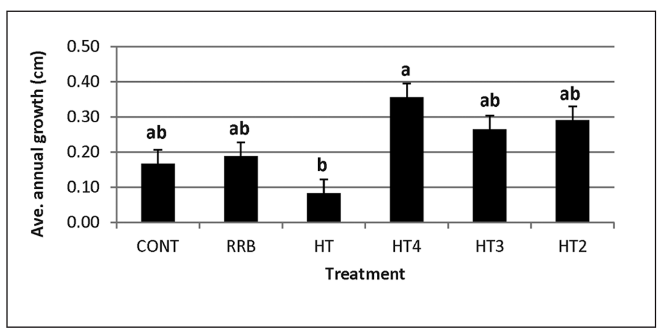

Figure 10.—Mean (± SE) post oak average annual diameter growth from 1984-2010 by treatment on the Forest Habitat Research Area, Pushmataha Wildlife Management Area, OK. See Table 1 for treatment descriptions. Treatment means with the same letter were not different (P=0.031).

thinning shortly thereafter. That year was a bumper acorn production year with an average of 105.2 kg ± 17.7 per tree across all units and the highest during the study years. Only in 1 year (1988) did post oak acorn production differ (P=0.0099) between treatments (Fig. 11). Here the thinned but unburned treatment (HT) had the highest production. The previous year showed a strong similar tendency in acorn production by treatment (P=0.071) with the HT treatment again being highest. Post oak acorn production varied widely by year exhibiting a strong year effect (P<0.0001) with 2 years of the 7 producing an average of <1 kg of acorns per tree across all treatments. Another year had very low production, and 2 years exhibited moderate production, one of which was 1988 (Fig. 9). We observed no year by treatment interaction (P=0.381) but did observe a tendency (P=0.115) for the HT treatment to have higher post oak acorn production when analyzed across all years, with the burned treatments similar in production to the control.

We found no differences in acorn production by blackjack oaks in any year as a response to thinning and burning. However this may have been a result of high fire-caused mortality following the first burn and mortality from canker on unburned controls, thus lowering sample tree number and number of replications for some treatments. When analyzed across all years that acorn production was monitored, we observed a strong tendency (P=0.052) for a treatment effect wherein the thinned (burned or unburned) treatments ranked higher in production than the control. Some blackjack acorn production, although somewhat limited at times, occurred in every year (F-test for year effect; P=0.086).

Nutrient content of sampled acorns generally varied more by tree within treatment units than between treatments (P>0.05) (Table 3). The only exception was moisture content which was different (P=0.030) depending on the time since burned and number of times burned (Table 3). Acorns from the unburned control and the burned unit three-growing seasons postburn had higher moisture content than the more frequently burned treatments. Crude protein was elevated slightly (P=0.120) in more frequently burned treatments.

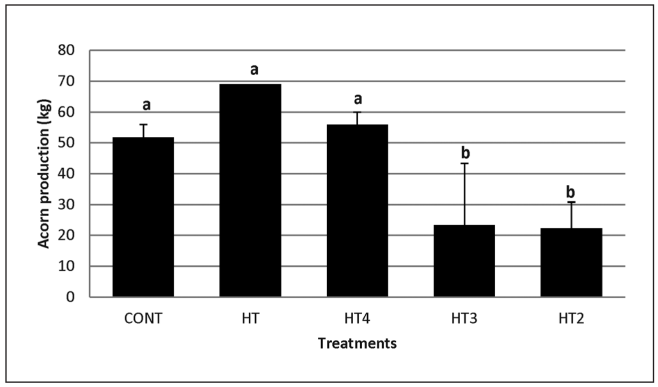

Figure 11.—Mean (± SE) post oak acorn production in 1988 by treatment on the Forest Habitat Research Area, Pushmataha Wildlife Management Area, OK. See Table 1 for treatment descriptions. Treatment means with the same letter were not different (P=0.0099).

Landscape Treatment and Wildlife Response

When initial thinning efforts were applied on a landscape level on PWMA beginning in 1978, fire frequency was >4-year intervals and inadequate for maintenance of savanna and woodland structure. Based on small plot study results, we began landscape application of frequent fire on a 1-3 year cycle in 1997, increased thinning in 1999-2001, then restoration thinning on the landscape in 2008 through present (Masters and Waymire 2012). By 2010, appropriate thinning regimes had been applied on 3,704 ha or 47.5 percent of the area. Since 1999 we have averaged 2,460 ha of prescribed burning annually. Both deer and elk populations have responded dramatically to landscape level application of thinning to presettlement basal areas and application of frequent fire across the area. Deer populations have increased from 7.3 deer/km^2 ± 3.8 in 1984 to 35.8 deer/km^2 ± 9.6 in 2010. However we note that since 1999 the average number of deer observations during spot-light counts has increased dramatically, partially a result of day-lighting of roads (complete tree removal 20-40 m

Table 3.—Mean nutrient content (% dry matter) of post oak acorns from control and thinned and burned units (1, 2 and 3 growing seasons postburn) from the Forest Habitat Research Area, Pushmataha Wildlife Management Area, OK in 1988. See Table 1 for general treatment descriptions, except that numbers represent number of growing seasons (gs) post-burn. Differences were not significant other than for percent moisture content. Means with the same letter or no letters were not different (*P* > 0.050).

	Number of Burns	Months Since Burns	Mean	SD	Max	Min
Percent Moisture						
CONT	0	>200	48.1 a	4.6	55.3	39.4
HT1 gs	2	7	40.6 b	1.9	42.1	38.5
HT2 gs	2	20	32.3 c	9.7	40.2	21.5
HT3 gs	1	42	46.8 a	7.3	55.0	40.9
Crude Protein						
CONT	0	>200	5.0	0.75	5.9	3.6
HT1 gs	2	7	6.0	0.90	6.6	5.0
HT2 gs	2	20	6.0	0.70	6.7	5.3
HT3 gs	1	42	4.8	0.89	5.5	3.8
ADF			27.9	5.5	38.0	19.5
Ash			2.7	0.3	3.4	2.2
TDN			70.5	5.0	78.1	61.2
Ca			0.44	0.13	0.86	0.29
P			0.09	0.01	0.12	0.07
M			0.10	0.03	0.20	0.08
K			0.77	0.17	1.23	0.55

either side of the road), thus inflating estimates to some extent. Never-the-less the trend is clear. Elk index numbers have increased from 6 in 1984 to 50 in 2010 (Masters and Waymire 2012).

On the PWMA portion of the BBS route from 1994-2009, a total of 70 different songbird species were reported. Average species richness per year was 39 ± 3. Of the 20 target species we selected, 8 were considered woodland-grassland associates, 6 were considered forest-shrub (edge) associated species, and 6 were considered forest interior species. All songbirds from the woodland-grassland species group except the pine warbler showed an increasing trend (Table 4). The trend was level throughout the study period. Of particular note was the strong increase for Bachman's sparrow, a species of special management concern across the southeastern United States, and in Oklahoma and Arkansas in particular (Cox and Widener 2008). The yellow-billed cuckoo was the only forest-shrub associated species to demonstrate a downward trend following landscape treatments. In this group, notable increases over the 16 year time-span for blue grosbeak and common yellowthroat were observed. For the forest interior group the summer tanager showed an increasing trend while the tufted titmouse, downy woodpecker and red-eyed vireo were level and showed no influence from the application of restoration treatments. On the other hand, we observed declining trends for only black & white warbler and chuck-will's-widow (Table 4).

Table 4.—Breeding bird trends of selected species from Pushmataha Wildlife Management Area, OK, 1994-2009 following landscape level application of restoration treatments. Trends are derived from only the Breeding Bird Survey Route data for Pushmataha County that occur on the Pushmataha Wildlife Management Area. A total of 37 stops out of the 50 for the county occur on the area. Key to trend symbol: + = increasing trend, – = decreasing trend, o = no or level trend.

Species Group/Species	r^2	Trend
Woodland-grassland		
Bachman's Sparrow[a]	0.61	+
Chipping Sparrow	0.12	+
Eastern Wood Pewee[a]	0.64	+
Indigo Bunting	0.52	+
Northern Bobwhite[a]	0.14	+
Pine Warbler	0.00	o
Prairie Warbler[a]	0.39	+
Red-headed Woodpecker[a]	0.12	+
Forest-shrub		
Blue Grosbeak	0.77	+
Blue-gray Gnatcatcher	0.40	+
Common Yellowthroat	0.81	+
Mourning Dove	0.37	+
Yellow-billed Cuckoo	0.22	–
Yellow-breasted Chat	0.26	+
Forest interior		
Black & White Warbler	0.62	–
Tufted Titmouse	0.00	o
Downy Woodpecker	0.10	o
Red-eyed Vireo	0.04	o
Summer Tanager	0.43	+
Chuck-will's-widow	0.46	–

[a] Species of special management concern in southeast U.S.

DISCUSSION

Presettlement forests in the Ouachita Highlands of eastern Oklahoma and western Arkansas were characterized by low-density and low basal area stands from open woodland to savanna-like conditions. They included a variety of forest cover types that expressed dominance according to topographic position and site conditions including shortleaf pine-bluestem, mixed oak-pine woodlands, and post-oak dominated savannas or oak woodlands (Foti and Glenn 1991, Masters and others 2007). Fire was a common factor that influenced density and likely a given stand's composition (Masters and others 1995, 2007).

Forest thinning and periodic fire is useful for returning natural stands to structural characteristics similar to presettlement times and managing for the full complement of native wildlife species (Masters and others 1996, 2002; Wilson and others 1995). However, following thinning the reintroduction of fire into a stand long-excluded from fire should be undertaken with some degree of understanding. Otherwise extensive mortality of the residual trees may result. Wade and Johansen (1986) concluded that reintroduction of fire into stands long excluded from fire may cause delayed mortality from stem girdling because low intensity fires may smolder in the accumulation of sloughed bark and litter around the immediate bole of the tree. Tree mortality was related to bark thickness, moisture content of the tree (Martin 1963), tree diameter, fire intensity, and residence time (Wade and Johansen 1986). Large-stemmed oaks are very resistant to fire induced mortality (Garren 1943, Komarek 1981, Kucera and others 1963, White 1986). This is due to the fact that the time for the cambium of trees to reach lethal temperatures increases with bark thickness (Hare 1965), and bark thickness increases with age (Davis 1953). Fire intensity is a causative factor in tree mortality, and mortality is determined largely by the extent of bark char and crown damage (Cain 1984) and is a function of fire type (backfire vs. headfire) (Fahnestock and Hare 1964) and season of burn (Waldrop and Van Lear 1984). The height of crown scorch on residual trees is a geometric function of fire intensity (Van Wagner 1973).

We observed a mortality pulse following introduction of fire into our experimental stands. This pulse of mortality affected blackjack oaks more severely than post oaks (Fig. 6) and was likely related to high amounts of residual logging slash, related fire behavior, and perhaps the shock of fire introduction after a long absence (Wade and Johansen 1986). However, throughout the study a higher proportion of total blackjack oak mortality was from disease rather than fire compared to post oak. Canker mortality was found in unthinned stands except for one tree in the harvested and thinned but unburned treatment (HT).

This treatment had increased in basal area 3-fold over the 25 years post-thinning. It is of note that mortality in the unthinned RRB treatment (4-year interval) was reduced compared to the control. In this treatment, some reduction of midstory hardwoods has occurred over the course of our study as a result of repeated burning. As our weather and mortality data suggested, mortality in all disease cases was likely a result of competition and late summer drought stress (Conway and Olson 2004). Our evidence suggests that thinning and burning together alleviated competition and drought stress on blackjack oak.

Aside from the high mortality rate from canker, the 100 percent blackjack mortality on the HT1 treatment but none on the HNT1 treatment also was unexpected. Because of the greater canopy cover on the HNT1 treatment versus other thinned and burned treatments, there was substantially less fuel and thus lower fireline intensity for burns on this treatment. Lower fuel loads particularly adjacent to tree stems prevented stem girdling. Post oak also exhibited similar differential mortality with annual burned treatments, but otherwise mortality was increased with increasing fire frequency.

Based on mortality alone, our thinned treatments with less frequent fire intervals (3- and 4-year or no fire) would appear to be recommended alternatives for oak-savanna restoration. However, given that over 28 years of the study, unburned treatments (HT) and the HT4 treatment had developed into immature forest stands (Table 2, Figs. 3 and 4) and were not judged viable alternatives for oak savanna restoration. Burn conditions during the first burns were lower than 40 percent relative humidity at 1400 hrs and considerable crown scorch resulted in approximately 11 percent mortality that occurred over the ensuing 3 years and beyond. If burns were conducted under higher relative humidity and firing patterns used generated less intensity than strip head fires, likely mortality could have been reduced substantially.

Conventional wisdom suggests that even mature oaks may respond with increased diameter, height, crown growth, and acorn production in response to full crown release (e.g., Cypert 1951, Drake 1991) although few studies have demonstrated this empirically and none other than this one that we are aware of with post oak or blackjack oak in the western part of its range on xeric sites.

Weather conditions such as periodic ice storms and drought is a stronger determinant of individual tree growth and development and associated characteristics of diameter, height, and crown area increment than credited in the literature, especially on xeric sites. We measured increases, due to thinning and thinning and burning to some extent, in crown expansion, diameter, and height of blackjack oak during a period of above average rainfall. These increases disappeared following a period of years with short-interval ice storms and during a period of significant below average rainfall. On an individual tree basis, those blackjack oak surviving our first burns grew vigorously on the thinned and burned treatments with 2- and 3-year intervals; however, with the loss of sample size and replication we cannot state this unequivocally. Greater development in open areas would not be surprising, however, as DeSantis and others (2010) suggested that blackjack oaks needed a growing environment with high light and further were more susceptible to drought and fire. Our data suggested that surviving blackjack oaks responded favorably in diameter growth in a high light environment, but also under drought and frequent fire conditions.

Post oaks were not as responsive to full crown release as blackjack oaks in terms of height growth and crown development. Our results were somewhat confounded by a series of ice storms that severely damaged some crowns. Blackjack oak was apparently more resistant to crown damage from ice than post oaks because of the stout and short nature of their limbs and compact nature of their crowns. We did find clear indications of higher average annual growth over 28 years on thinned and burned treatments.

Acorns are an important food item in the diet of many species of wildlife. As such any change in production and nutrient content as a result of management treatments may directly affect a given wildlife species nutritional status, especially during winter. We noted decreases in post oak acorn production with thinning and frequent fire but no difference from controls with either thinning or thinning and 4-year fire intervals (HT4). We only measured acorn production during the first half of the study period. Our trees were notably slow to respond on these xeric sites. Goodrum and others (1971) found that total mast failure never occurred during their 20-year study. We observed near complete mast failure in 2 of 7 years and low to moderate production in 4 years and 1 exceptional year. These xeric and nutrient poor oak-pine habitats in mountainous terrain such as in the Ouachita Highlands may not have the capacity for acorn production, especially in drought years, as in their study. Mast shortfalls have also been documented in the Ozark Plateau region of Arkansas (Segelquist 1974). The variability of individual trees in terms of acorn production and growth is well noted in the literature (Downs and McQuilken 1944, Drake 1991, Goodrum and others 1971) and our findings were no different. However, with increased diameter growth from thinning and burning, perhaps mast production should be revisited in a later study.

All nutrient parameters for sampled post oak acorns fell close to mean values and within the range of values reported in the literature (Short 1976, Halls 1977). However, moisture content for our samples was different according to time since burned. Samples three growing seasons postburn were similar to samples from unburned control units, and those one and two-growing season postburn were lower in moisture content. Lower moisture content may have some additional nutritional benefit to wildlife as crops with lower moisture content have been shown to have lower storage loss (from rot) and higher starch (carbohydrate) content through time compared to items with higher moisture content (Hornick 1992). If the same holds true for acorns then acorns should remain sound longer and have higher carbohydrate content during the late winter period of nutritional stress. Whether this is nutritionally significant remains to be seen. Acorns are generally very high in carbohydrates and are highly digestible, particularly those in the white oak group, and thus are an excellent energy source in winter (Kirkpatrick and Pekins 2002). Energy appears to be more important than protein or other nutrients at least for bobwhites (Giuliano and others 1996) in winter. Although a slight increase (1 percent) in crude protein was noted in acorns for the first two growing seasons postburn, that small increase may not be of biological significance given that crude protein of acorns is generally low compared to other foods (Kirkpatrick and Pekins 2002).

Implications of our fire and thinning treatments for landscape implementation of oak savanna and woodland restoration suggested fire regimes longer than every year because of higher cumulative oak mortality from annual burning in low density stands (<10 m^2/ha BA). However periodic annual fire may be a suitable application in stands above 10 m^2/ha BA for maintenance of oak savanna conditions. We found that a 3- or 4-year frequency allows for oak regeneration to develop into small trees, but the longer interval also allows forest development as also reported by Burton and others (2010). Therefore a rigid 4-year frequency is likely unsuitable for savanna maintenance.

Because oak recruitment was virtually non-existent in the annually burned treatments (R. Masters, unpublished data), 2-year and 3-year intervals are recommended to maintain open woodland or savanna conditions. The fire return intervals reported for the nearby McCurtain County Wilderness Area across a variety of sites ranged from 2.1-5.6 years with a range of 1-12 years (Masters and others 1995). Because the fire regime was historically variable, we implemented a fire regime across the landscape restoration units encompassing 1-4 years recognizing that north slope hardwoods, riparian corridors, and upland drainages associated with ephemeral streams will have effectively longer intervals as the understory will burn completely only in very dry conditions. With fire intervals longer than 4 years, mesic tree species begin to invade and change the character of the stands, and thus the potential for recurrent surface fire (Burton and others 2010).

Forest health issues have been raised particularly about densification of oak woodlands and savannas and oak decline, aside from the loss of herbaceous plants and associated animal species habitats. Oak decline is ascribed to various insect and disease agents associated with approaching physiological maturity (Hyink and Zedaker 1987). Relatively little attention, however, is paid to increased tree density through time, and thus increasing competition for moisture and nutrients, as an untoward influence on disease incidence and ecosystem health of fire suppression efforts (e.g., Hyink and Zedaker 1987, Oak and others 1986).

Fire is an integral process in oak or mixed oak-pine systems. Beneficial effects on ecosystem health include thinning of trees to reduce moisture and nutrient competition, thus increasing drought tolerance and lowering incidence of disease in a given stand, and for maintaining historic structure and function (Burton and others 2010, DeSantis and others 2010). Oak savanna and woodland restoration efforts as applied on a landscape level on PWMA are similar in site location, tree density, and composition to presettlement conditions. The essential test to determine the success of restoration efforts is the effects on wildlife populations. This view of restoration success is too often overlooked.

The dramatic response of deer and elk was not surprising given that a sporadic source of nutrition from acorns was supplemented with a much greater and more consistent amount of nutritious forage. However, at this point it is not clear if acorn production was enhanced, as we had postulated, to the point that it offsets that lost from thinning.

Songbirds provide rapid feedback on the effects of forest management and re-introduction of fire. Because they are closely associated with a particular arrangement of habitat structure, they respond in relatively short periods of time, and some are associated with narrow successional windows created by postfire succession in the understory in addition to forest canopy cover change (Cox and Widener 2008, Masters and others 2002, Wilson and others 1995). Woodland-grassland and forest-shrub birds have declined precipitously across the southeast United States because of fire exclusion and densification of forests (Cox and Widener 2008, Wilson and others 1995). The frequent fire connection is essential for woodland grassland birds in order to maintain suitable habitat structure (Cox and Widener 2008).

Not withstanding the needs of these groups of birds, we were also interested in any deleterious influence on forest-shrub and forest interior birds that were species of high interest although not species of special management concern. It is significant that only three species, yellow-billed cuckoo, black & white warbler, and chuck-will's-widow, showed declines over the 16 years following staged implementation of landscape level restoration. Regional trends have a strong influence on local populations of birds. Therefore, interpretation of results on a given route must be interpreted in light of regional trends. Yellow-billed cuckoo and chuck-will's-widow experienced strong regional declines from 2004-2007 (Sauer and others 2011). However, the black & white warbler exhibited a stable regional trend during this time period (Sauer and others 2011).

Our study has shown that small plot research can inform landscape level restoration and management through confirmation of the utility of restoration targeted thinning and confirmation of fire intervals used by land management as compared to presettlement landscape structure and fire regime. Studies of presettlement landscape characteristics such as structure, form, function, and fire chronology provide essential data for guiding restoration of oak woodlands and savannas as well as for other ecosystems. Researchers and land managers would do well to explore and learn from this diverse literature.

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APPENDIX

List of common and scientific names of plants, bird, and mammal species mentioned in the text and figures.

Common Name	Scientific Name (authority)
Plants	
Big bluestem	*Andropogon gerardii* (Vitman)
Black oak	*Quercus velutina* (Lam.)
Blackberry	*Rubus* spp.
Blackjack oak	*Quercus marilandica* (Muenchh.)
Bluestem grass	*Schizachyrium* spp., *Andropogon* spp.
Greenbriar	*Smilax bona-nox* (L.)
Hypoxylon cancer	*Hypoxylon atropunctatum* (Schwein.) Cooke
Indiangrass	*Sorghastrum nutans* (L.) Nash
Little bluestem	*Schizachyrium scoparium* (Michx.) Nash
Loblolly pine	*Pinus taeda* (L.)
Mockernut hickory	*Carya alba* (L.) Nutt.
Muscadine grape	*Vitus rotundifolia* (Michx.)
Panicums	*Panicum* spp., *Dicanthelium* spp.
Poison ivy	*Toxicodendron radicans* (L.)
Post oak	*Quercus stellata* (Wangenh.)
Sedges	*Carex* spp., *Scleria* spp.
Shortleaf pine	*Pinus echinata* (Mill.)
Switchgrass	*Panicum virgatum* (L.)
Tree sparkleberry	*Vaccinium arboretum* (Marshall)
Virginia creeper	*Parthenocissus quinquefolia* (L.) Planch.
Winged sumac	*Rhus copallinum* (L.)
Birds	
Bachman's Sparrow	*Aimophila aestivalis* (Lichtenstein)
Black and White Warbler	*Mniotilta varia* (Linnaeus)
Blue Grosbeak	*Guiraca caerulea* (Linnaeus)
Blue-gray Gnatcatcher	*Polioptila caerulea* (Linnaeus)
Chipping Sparrow	*Spizella passerina* (Bechstein)
Chuck-will's-widow	*Caprimulgus carolinensis* (Gmelin)
Common Yellowthroat	*Geothlypis trichas* (Linnaeus)
Downy Woodpecker	*Picoides pubescens* (Linnaeus)
Eastern Wood Pewee	*Contopus virens* (Linnaeus)
Indigo Bunting	*Passerina cyanea* (Linnaeus)
Mourning Dove	*Zenaida macroura* (Linnaeus)
Northern Bobwhite	*Colinus virginianus* (Linnaeus)
Pine Warbler	*Dendroica pinus* (Wilson)
Prairie Warbler	*Dendroica discolor* (Vieillot)
Red-cockaded woodpecker	*Picoides borealis* (Vieillot)
Red-eyed Vireo	*Vireo olivaceus* (Linnaeus)
Red-headed Woodpecker	*Melanerpes erythrocephalus* (Linnaeus)
Summer Tanager	*Piranga rubra* (Linnaeus)
Tufted Titmouse	*Baeolophus bicolor* (Linnaeus)
Yellow-billed Cuckoo	*Coccyzus americanus* (Linnaeus)
Yellow-breasted Chat	*Icteria virens* (Linnaeus)
Mammals	
Bison	*Bison bison* (Linnaeus)
Rocky Mountain elk	*Cervus elaphus* (Linnaeus)
White-tailed deer	*Odocoileus virginianus* (Zimmermann)