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Long-Term Study of Prescribed Fire Effects on Stand Dynamics and Oak Regeneration Potentials in Degraded Upland Oak-Hickory Stands in Northwestern Arkansas

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LONG-TERM STUDY OF PRESCRIBED FIRE EFFECTS ON STAND DYNAMICS AND OAK REGENERATION POTENTIALS IN DEGRADED UPLAND OAK-HICKORY STANDS IN NORTHWESTERN ARKANSAS

By

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ABSTRACT

Upland oak-hickory forests in the Ozark Mountains of northwestern Arkansas and south central Missouri were impacted by oak decline during the early 2000s. This decline event was caused by predisposing (e.g., mature, dense stand conditions), inciting (i.e., drought), and contributing (e.g., red oak borer, *E. rufulus* H., outbreak) factors. Immediately following onset of the decline, substantial crown dieback and tree mortality, particularly for two red oak species (northern red oak, *Quercus rubra* Michx. and black oak, *Q. velutina* Lam.), were observed. In addition, densities of advanced oak regeneration were inadequate at this time, resulting in poor regeneration potentials for oak across much of this region. Absence of regular, frequent disturbances (e.g., fire and harvesting) in these systems for an extended time period prior to the decline, had allowed mesophication (more closed-canopy, increases in more shade-tolerant, fire-sensitive species, and the resulting cool, damp conditions with less flammable fuel beds) to occur. The creation of mortality-related gaps provided an opportunity to examine the efficacy of prescribed fire as a restoration treatment in these forests. This research evaluated the effects of single dormant season prescribed fire treatments on changes in stand dynamics and oak regeneration potentials in these degraded upland oak-hickory forests two and twelve years after implementation. Changes in overstory, sapling, and seedling strata were quantified for oak compared to mesophytic competitors (red maple, *Acer rubrum*;

blackgum, *Nyssa sylvatica*; black cherry, *Prunus serotina*, etc.). Changes in crown health conditions (i.e., crown dieback) were quantified by species group (red oak, white oak, hickory, and other) and compared between treatments. Sapling and seedling height, diameter, and sprouting dynamics (sprouting response and sprout density) were compared among species in the dormant and no-burn control treatments.

Twelve years following the treatments oak basal area, specifically for red oak, continued to decrease in both treatments. Greater decreases were observed in the dormant than in the control treatment. Two years following treatment, red oak species also demonstrated the greatest reduction in both the no-burn control and dormant treatment, while in the control, other species increased slightly. Red oaks classified with a healthy crown condition (< 25% crown dieback) increased by 39% in the dormant treatment while the percentage classified with dead/dying crown conditions (> 95% dieback) decreased.

Twelve years after treatment, red oak (dormant: +386%; control: +167%), white oak (dormant: +80%; control: -34%), and other species (dormant +147%; control: +57%) demonstrated significantly greater increases in sapling density in the dormant treatment compared to the control. Sapling heights were greater for non-oak competitors (15 to 23 ft.) in the no-burn control prior to and two years following treatment, but were slightly greater for oaks (17 to 18 ft.) in the dormant until twelve years following treatment (oak: 13 to 17 ft.; non-oak: 17 to 18 ft.). Sapling diameter (dbh) remained relatively similar among species groups within the two treatments. Red oak (93%) demonstrated a greater rate of topkill than white oak (63%), red maple (74%), and other species (73%) two years following in the dormant treatment. Sprouting response was greater for oak species than non-oak with, ≥ 75% resprout percentage and greater density of sprouts (15 sprouts per rootstock). Seedling densities in the dormant treatment of oaks increased two (oaks: 1,482 stems/ac; non-oak: 3,480 stems/ac) and twelve (oaks: 1,093 stems/ac: non-oak: 3,822 stems/ac) years following treatment, as well as, non-oak competitors maintaining dominance. Although seedling heights for oak species were lower than that of non-oak competitors, the basal diameter for oaks was greater two (dormant oak basal diameter: ~1.8 in.; control oak basal diameter: 0.9 to 2.8 in.; dormant non-oak basal diameter: ~3.2 in.; control non-oak basal diameter: ~3.5 in.) and twelve (dormant oak: 3.3 to 4.0 in.; control oak: 2.3 to 3.6 in.; dormant non-oak: 4.1 to 4.6 in.; control non-oak: ~4.0 in.) years following treatment in the control and dormant treatment. Oak species had a greater sprout density per rootstock than non-oak competitors two years following implementation of dormant season fires, with all species groups experiencing ~100% topkill. Twelve years after the dormant season fires, oak species (red oak: 1.3 in.; white oak: 1.2 in.) had greater dominant sprout basal diameters, as well as greater height (red oak: 10.6 ft.; white oak: 10.5 ft.) than the non-oak competitors (red maple: 1.1 in and 12.3 ft.; blackgum: 1.0 in. and 8.1 ft.) for tagged seedlings.

Previous literature has shown that frequent prescribed fires can be used to increase the density of oak while reducing the amount of shade-tolerant, fire-sensitive

species. Forest health disturbances along with the implementation of a single dormant season burn, reduced overall overstory basal area, while improving overall crown health conditions and increased oak sapling and seedling densities compared to pre- treatment values. Prescribed fire also favored oak species for sprouting dynamics including, percent of resprout, sprouts per clump and sprout density for both the sapling and seedling strata. Sapling density and height (lower values may be attributed to topkill and strata recruitment) of oak improved with the reduction in basal area and prescribed fire providing increased oak regeneration potentials.

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INTRODUCTION

Oak species (*Quercus* spp. L.) are ecologically, economically, and culturally important and are a major component in 68 percent of hardwood forest cover types in North America (Stein et al., 2003). Oaks provide hard mast to numerous wildlife species (e.g., eastern wild turkey, *Meleagris gallopavo silvestris* Viellot and white-tailed deer, *Odocoileus virginianus* Zimmermann) and have aesthetic value (Brose et al., 2014). Prior to European settlement, many forested areas dominated by oaks (e.g., upland oak and oak-pine woodlands) were maintained by frequent disturbances (i.e., fire). Native Americans frequently used fire to clear land for agriculture and enhance browse production for wild game. Anthropogenic disturbances, along with natural disturbances (e.g., wind and ice storms), created canopy gaps allowing sunlight to reach the forest floor and dry the fine fuels, further promoting and facilitating frequent, low-intensity understory fires (Van Lear, 2004). After almost a century of fire exclusion and inconsistent/reduced frequency of harvesting disturbances, densities in upland oak-hickory forests have increased, increasing the stress level on individual trees, which has resulted in a greater frequency of disease infestations and pest outbreaks. Under contemporary forested conditions, oak regeneration potentials have decreased and recruitment of oak into the mid- and overstory strata has often failed, allowing for an increase in the occurrence of more shade- tolerant, fire-intolerant species (Heitzman et al., 2007; Vickers et al., 2014). The lack of regular fire disturbances in current eastern deciduous forests has become one of the main factors contributing to “mesophication” (conversion to more closed-canopy forests dominated by shade-tolerant, fire-sensitive species that maintain cool, damp conditions with less flammable fuel beds through positive feedbacks), resulting in oak regeneration and recruitment problems (Nowacki and Abrams, 2008; Keyser et al., 2017).

Increased frequencies of stressors and mortality coincide with increased forest density (Starkey and Oak, 1989; Foti, 2004; Spetich, 2004; Fan et al., 2006). Characterized by increased overstory canopy dieback and mortality pockets, oak decline has been a notable issue in the Interior Highlands in northwestern Arkansas since the 1970s (Fan et al., 2008). Declines are the combined result of the effects of climatic events (i.e., drought), insect attacks, and pathogen-induced infections (Haavik et al., 2012; Manion, 1990; Rosson, 2004). Areas in northwestern Arkansas experienced increased overstory mortality due to severe drought conditions between 1998 through 2002, which was followed by a red oak borer (*Enapholodes rufulus* Haldeman) outbreak in 2000 (Heitzman et al., 2007). Red oaks, pre dominantly northern red oak (*Quercus rubra* L.), but also black oak (*Q. velutina* Lam.), demonstrated the greatest mortality following these forest health disturbances, with 51-75% of standing red oak basal area being classified as dead or dying (50-70% crown dieback) in 2007 and 2008 (Heitzman et al., 2007; Fan et al., 2008). Before the decline events impacted the Boston Mountains, red oak species occurred at unprecedented or unhealthy densities, making them highly susceptible to red oak borer infestation and mortality (Heitzman et al., 2007). The drought events that occurred also exacerbated the decline of the white oak species group (e.g., white oak, *Q. alba* and post oak, *Q. stellata*).

In the Central Hardwoods region, upland forests evolved under a fire regime characterized by frequent, low-intensity surface fires (Engbring et al., 2008). Fire scar analyses from the Ozark Mountains of Missouri indicate upland oak forests have been burned for hundreds of years (Engbring et al., 2008). Naturally ignited fires from lightning strikes accounted for 1-5 ignitions per 400,000 ha (Guyette et al., 2006), making anthropogenic ignitions prior to European settlement (around 1821 with population reaching 14,000) the primary source of fire in the Central Hardwoods region (Guyette et al., 2006). Prior to European settlement, anthropogenic fires were used by native peoples to cultivate land for crops (Bass and Region, 1981; Strausberg and Hough, 1997), hunting purposes, enhance nut and berry production, and pest control (Brose et al., 2014). During the post-European settlement era of Timber Exploitation (1880-1909), harvesting in this region was often followed by more intense, severe fires which ignited in the logging slash and created stand replacing wildfires which created low coppice forests dominated by oak (Dey and Jensen, 2002).

Oak species possess several adaptations to fire providing a competitive edge over fire-sensitive, shade-tolerant non-oak species. Fire adaptations of more fire-tolerant upland oaks include thick bark, particularly along the base of the stem, and an ability to resprout when topkilled during fire disturbances. Thick bark near the basal portion of the stem provides thermal protection of adventitious buds, from which basal sprouts are produced, and reduces the probability of topkill (Dey and Hartman, 2005; Hammond et al., 2015; Varner et al., 2016; Shearman et al., 2018; Kidd and Varner, 2019). Oak species utilize a conservative strategy for growth, including the development of a large, complex root system which facilitates the ability to resprout after topkill occurs and for efficient water and nutrient supply (Alexander et al., 2008). Given these adaptations to fire, periodic fires reduce more shade-tolerant, fire-sensitive species, increasing the competitive capacity of more shade-intolerant oaks due to increased light availability in the understory following disturbance (Abrams, 1992; Alexander et al., 2008).

In the absence of frequent, low intensity fires, more shade-tolerant, fire-intolerant species such as red maple (*Acer rubrum* L.) and blackgum (*Nyssa sylvatica* Marshall) have become more prevalent in the understory strata, contributing to increased competition with site-specific oak species (Nowacki and Abrams, 2008). With upland oaks being more fire-resistant than these more shade-tolerant species, implementation of disturbances (i.e., fire) at appropriate intervals and intensities provide a management option to encourage the establishment and favor recruitment of oak regeneration. Regeneration methods, such as shelterwood in combination with prescribed fires, can be used to favor oak by reducing competition with the more mesophytic species and increasing light availability to lower strata (Van Lear, 2004). With fire being absent from these systems for such an extended period and the changing climate resulting in more intense droughts and extreme weather events, there is a need to understand the effects of implementation of prescribed fire as a restoration tool in these contemporary forests. This study analyzed the long-term efficacy of prescribed fire as a restoration treatment, in a region that was severely impacted by forest health (i.e., oak decline) and climatic (i.e., drought) disturbances and characterized by low oak regeneration potentials (Soucy et al., 2005; Heitzman et al., 2007).

GOAL AND OBJECTIVES

To evaluate the effects of a dormant season prescribed fire two and twelve years following treatment on stand dynamics in degraded upland oak-hickory forests, the objectives were to:

1. quantify changes in forest overstory density, species composition, and crown dieback conditions;

2. analyze changes in sapling and seedling density, composition, height, and diameter; and

3. determine if prescribed fires and forest health disturbances favored oak regeneration compared to other non-oak competitor species based on density, height, diameter, and sprouting dynamics.

LITERATURE REVIEW

Upland Oaks: Distribution and Silvics

Upland oak communities in the Central Hardwoods region developed after the retreat of the Wisconsin ice sheets, replacing the tundra and boreal vegetation with predominantly broadleaved deciduous hardwoods (Braun, 1950; Van Lear, 2004). The Central Hardwoods region covers 220 million acres, with half forested and includes seven national forests in the southern half of the region in Arkansas, Missouri, Illinois, Indiana, Ohio, Kentucky, and Tennessee (Johnson et al., 2002). The use of anthropogenic fire manipulated the landscape and shaped the structure of vegetation in this region (Van Lear, 2004). Black oak, white oak, scarlet oak (*Q. coccinea* Muenchh.), chestnut oak (*Q. montana* Willd.), northern red oak, southern red oak (*Q. falcata* Michx.), and bur oak (*Q. macrocarpa* Michx.) are the dominant oak species in this region (Johnson, 2009). Fire exclusion in this region has resulted in closed-canopy, more mesic forests and allowing non-oak competitors (e.g., red maple, black cherry) to outcompete oaks (Johnson et al., 2002). Oaks evolved under a fire regime utilized by Native Americans, who burned frequently and often outside (i.e., between November and April) of the natural lightning ignition fire season (March-June) (Hicks et al., 2004; Van Lear, 2004; Jurney, 2012). Oaks developed adaptations (e.g., thick basal bark, resprouting capabilities) through exposure to these frequent fires which allowed them to outcompete more fire-sensitive species on these sites. Upland oak species have thick bark that provides thermal insulation, protecting vascular cambial tissues and adventitious buds during surface fires, whereas, more fire-sensitive species such as red maple that have thinner bark and are more susceptible to cambial fire damage (Brose et al., 2014; Fan et al., 2012a; Iverson et al., 2017; Van Lear, 2004). These oak species also possess the ability to resprout tenaciously when topkilled (aboveground tissues killed) (Van Lear, 2004; Knapp et al., 2009; Brose et al., 2014). Hardwoods such as red maple also have the capacity to resprout after being topkilled, but with repeated fires the vigor as well as the propensity of these species to resprout is reduced (Brose and Lear, 2004.; Green et al., 2010) Furthermore, germination of acorns is hypogeal, which allows for increased thermal protection of oak root collar tissues and an initial belowground root system growth advantage during earlier stages of life compared to species such as red maple, which utilize an epigeal germination strategy (Burns and Honkala, 1990). The chemical composition and drying properties of oak leaf litter helps/favors the facilitation of recurrent fires (Van Lear, 2004).

Oaks (*Quercus* spp.) represent one of the most diverse and geographically widespread groups of tree species in North America, with approximately 50 species found from the deciduous forests of the Appalachians to the open savannahs of California (McShea and Healy, 2002). The diversity of oak species increases from the northern (nine species in Minnesota) to southern (55 species in Alabama) regions of the central U.S. (McWilliams et al., 2002).

Oaks are some of the most economically and ecologically important species in the U.S., with northern red oak being one of the most valuable timber species in the red oak group (Stein et al., 2003). Oak forests in North American provide economic value through multiple forest resource uses, such as during outdoor recreation (e.g., hiking, birding, and hunting), aesthetic appeal, and timber harvests (e.g., veneer for furniture and white oak staves for barrel production). Approximately 186 species of birds and mammals feed on the hard mast of oaks, including high-value game species such as eastern wild turkey, bobwhite quail (*Colinus virginianus* L.), white-tailed deer, and elk (*Cervus canadensis* Erxleben) (Dersal, 1940). Oaks are common in the Ozark and Appalachian Mountains, and the greatest density of oaks in the central U.S. occurs in the Ozark Plateau of Missouri and Arkansas. The most prevalent forest cover type in this region is the white oak-red oak-hickory type (McWilliams et al., 2002), which accounts for one-third of the oak-hickory association, and dominates much of the Central Hardwoods Region (Van Lear, 2004). The Ozark region of southern Missouri, northeastern Oklahoma, and northern Arkansas comprises the largest contiguous area dominated by the oak-hickory association (McWilliams et al., 2002). The forests in this region originated from extensive fire-maintained savannahs which developed prior to European settlement, but have since developed into closed-canopy forests with fire exclusion (Johnson et al., 2002). Fire-maintained oak savannahs are estimated to have covered about 32 million acres (Lorimer, 1992). In 1804, William Dunbar and George Hunter travelled up the Ouachita River and reported to that the highland areas were bearing pines interspersed with hickory, oak, and dogwood (Strausberg and Hough, 1997). Thomas Nuttall also provided reports of pines on the southern aspect slopes and hardwoods on the northern slopes and also noted burning by the indigenous people in these areas (Strausberg and Hough, 1997).

Historical Fire & Harvesting Disturbance Regimes in Northwestern Arkansas

Fire

Fire frequency differed due to differences in topography and fuels, as well as shifts in human populations and their uses of fire (Dey and Hartman, 2005). Despite having 50-70 thunderstorm days per year in the Ozarks, only about 1-5 natural lightning-based ignitions occur per 400,000 ha, which demonstrates the importance of these anthropogenic ignitions (105 fires per year for 400,000 ha.) (Guyette and Spetich, 2003). Historical changes in frequency and seasonality of fires is attributed to the timing and density of human populations shifts in this region. Prior to the European exploration in Arkansas, Native Americans (e.g., the Hopewell Civilization) routinely cleared and maintained the forestlands through the use of fire (Van Lear, 2004). Native Americans burned at return intervals of 3-18 years, with frequent (1-13 years) fires continuing through European settlement (Chapman et al., 2006). Western Cherokee that occupied northern Arkansas from 1817 to 1829 were found to have an association with increased fire frequency (~6.7 fires per decade); this short interval may have coincided with an intentional effort by these peoples to create a less dense forest (Guyette et al., 2006). Travelers who came to the Ozark region pre-European settlement described wide variations in ecosystems ranging from native prairies, oak savannahs, and oak-pine forests which were maintained by natural and anthropogenic fires (Cutter and Guyette, 1994). With increases in human density there was a decrease of fire frequencies (2.8/yr to 24/yr from 1740 to 1850) as well as, changes in seasonality from a single late summer-early fall to a spring and fall with increases of Anglo settlement (Cutter and Guyette, 1994; Guyette et al., 2006).

European settlement in the western mountains of Arkansas occurred slowly, starting around 1686 (Strausberg and Hough, 1997). As settlement increased, so did the fire frequency for the Arkansas region. Early settlers, similar to the Native Americans, cleared the land for grazing pastures and farming. Farmers in Arkansas typically burned annually in the fall or early spring to encourage forage and create pastures. Many in this region recognize that spring burns were also a method to reduce ticks and drive out snakes (Strausberg and Hough, 1997). Fire scar analyses revealed that over 90% of cambial injuries caused by fire were during the dormant season (fall, winter, and early spring). When cambial growth is inactive and the climate conditions consist of lower humidity levels, higher surface winds, and increased solar exposure drying surface fuels, burning is favored (Guyette et al., 2006). Increases in fire frequencies also occurred during the Regional Development Period from 1901-1930. During this time period, accumulation of slash from logging operations and ignitions from railroad logging provided ideal conditions for fire ignitions due to the accumulation of slash, railroad activities, and the public indifference to fire suppression. With the establishment of the Ozark National Forest (1907-1909), fires were deliberately set by the local people to gain employment by the Forest Service for suppression efforts overall fire frequencies increased (Engbring et al., 2008).

Harvesting

In Arkansas, commercial logging began in 1879 following the construction of westward railroads (e.g., the St. Louis, Iron Mountain and Southern railroad) (Strausberg and Hough, 1997). Logging in Arkansas was well established by 1890 following the demand for telephone poles, barrel staves and crossties. Common practices of lumber companies included harvesting timber and abandoning the land, as well as high-grading. These practices resulted in genetically inferior seed sources for future stands. From 1906 to 1909 the last of the virgin forests in Arkansas were harvested, with a total of 2.1 billion board feet produced in Arkansas in 1909. In combination, these activities resulted in the depredation of the forests in the Ozark and Ouachita Mountains (Strausberg and Hough, 1997).

A presidential proclamation in March of 1908 designated approximately 1.7 million acres north of the Arkansas River as the Ozark National Forest. At this time, this forest was the only major hardwood forest under governmental protection providing a renewable resource of profitable hardwood timber (Strausberg and Hough, 1997). Although the forests in this region had been exploited during the Timber Exploitation period, fire protection was the number one job in this newly established National Forest. Fire suppression was abandoned due to the local subsistence farmers who would intentionally light fires in order to offer their services to help extinguish them for pay. Growing trees as a crop began to gain interest around 1925, when a pine seedling nursery was established at Arkansas Polytechnic College to supply the Ozark National Forest. As interests in growing trees increased, so did the demand for fire protection. In 1930, Congress passed the Knutson-Vandenberg Act authorizing funds for reforestation efforts. National Forests could use these funds to reforest and improve stands through thinning, pruning or cutting (Strausberg and Hough, 1997).

A few years later, the Civilian Conservation Corps (CCC) was established to provide young, unemployed men work (Strausberg and Hough, 1997). The CCC, along with other organizations (e.g., the Soil Conservation Service and Works Progress Administration), built and repaired roads, cleared right-a-ways, and constructed lookout towers and ranger stations increasing accessibility to the forests. With nine CCC camps in the Ozark National Forest consisting of 200 men per camp, the Forest Service had adequate resources for fire protection. With the start of World War II most of the CCC camps in Arkansas were abolished, which reduced fire protection, and improvements that were constructed in the pre-war years deteriorated. Many state and federal nurseries had been shut down, essentially ending replanting programs. Simultaneously, increased timber production was requested by the government in order to support the war effort; species common to the Ozarks, (e.g., hickory and white oak) were used for skis and ship beams. Demand for timber during the war years and the lack of skilled foresters due to the draft resulted in the forests being extremely vulnerable to fire and sustainable management of the resources was replaced by logging activities. It was estimated that only 17 percent of the timber in the Ozark National Forest was considered commercially valuable after World War II (Strausberg and Hough, 1997): Arkansas' National Forests were in need of a massive replanting effort post-war.

Even-aged timber management practices were implemented in the early 1960s following the passage of the Multiple Use-Sustained Yield Act in 1960. Timber management plans on these forests included converting uneven-aged stands to even-aged by clearcutting and planting improved shortleaf pine seedlings. During the 1960s the demand for softwood building materials increased, which led to the increased planting and harvesting of softwood species (Strausberg and Hough, 1997).

The Ozark National Forest approved a plan in 1986 that contained uneven-aged silvicultural systems on sites where hardwood species were dominant (Strausberg and Hough, 1997). By the 1990s Forest Service researchers and scientists from other federal agencies and universities established demonstration stands to examine different regeneration methods including single-tree and group selection harvests on upland hardwoods. Research was also conducted to address public questions about past and present harvesting techniques in the National Forest, demonstration stands including non-traditional cutting such as techniques which leave both pine and hardwood in the overstory were established (Strausberg and Hough, 1997).

Consequences of Departures in Historical Fire and Harvesting Regimes

In ecosystems where frequent, low-intensity fires were common, fire-tolerant species thrived. Fire disturbances maintained open forested conditions favoring shade-intolerant species and an abundance of shrubs, forbs, and grasses in the understory (Nowacki and Abrams, 2008). On average, pre-settlement forests consisted of large trees (30-42 cm or 11.8-16.5 in. dbh) with a low to moderate basal area (9-22 m^2/ha or 39.2-96.8 ft^2/ac) that was maintained by frequent low to moderate intensity fires (Chapman et al., 2006; Nowacki and Abrams, 2008; Yacht et al., 2018).

A considerable portion of the Ozark region is characterized by relatively xeric conditions, which theoretically should favor oak advanced reproduction (Soucy et al., 2005). However, in the Ozark Mountains of northwestern Arkansas, the regeneration of oak forests has become more difficult due to the absence of regular disturbance (Soucy et al., 2005). The absence of fire for extended time periods has allowed for mesophication to progress increasing moisture levels in the understory and forest floor and favoring shade-tolerant, fire-intolerant species in the under- and overstory strata limiting establishment and recruitment of oak seedlings and saplings (Soucy et al., 2005; Chapman et al., 2006; Alexander and Arthur, 2010).

At the Sylamore Experimental Forest in the Ozarks of Central Arkansas, shortleaf pine and upland oaks were the dominant mid- and overstory tree species. Tracking the change of forest structure over 50 years showed that the increased stand density, basal area and continuation of fire suppression resulted in an increase of shade-tolerant, fire sensitive species in the understory (Chapman et al., 2006), limiting shade intolerant oak species recruitment (Larsen et al., 1997; Chapman et al., 2006).

The success of fire exclusion and the lack of broadcast burning starting in the 1930s culminated in forests dominated by more shade-tolerant and fire-intolerant species forests. In the absence of periodic fires, forests have developed closed, dense canopies reducing the amount of light reaching the forest floor (Nowacki and Abrams, 2008); under these reduced light conditions cool, moist microclimates are inadequate for promoting and facilitating surface fires (Heitzman et al., 2007; Nowacki and Abrams, 2008; Kreye et al., 2018; Yacht et al., 2018). In upland mixed oak stands in the central Appalachians, mesophytic species (e.g., red maple) have increased in dominance in stands once dominated by oaks (Fei and Peilin, 2010). The absence of fire disturbance has allowed more fire-sensitive species to spread away from natural firebreaks and alter fire-prone vegetation dynamics, altering species distributions and dominance (Hanberry et al., 2012).

Altered forest structure and composition due to mesophication has reduced the flammability through increased dampness and accelerated decomposition, reducing the amount of available fuel (Nowacki and Abrams, 2008; Keyser et al., 2017), leaf litter differ, and in turn change the composition of the forest floor: oak leaf litter has high loading and low bulk density, as well as higher lignin content, slowing decay and higher nitrogen content and phenols which propagate the movement of fire through the forest floor (Nowacki and Abrams, 2008; Dickinson et al., 2016). Mesophytic species, on the other hand, gain more moisture, have lower loading, higher bulk density and retain moisture longer which reduces the overall flammability of the forest floor (Kreye et al., 2018). Leaf litter from oaks is more resistant to decay and has a natural tendency to curl when dried, which provides ready fuel for fires to move across the landscape (Van Lear, 2004; Nowacki and Abrams, 2008). Factors such as carbon content and packing ratios also influence the flammability of litter. Lower packing ratios, like that of oak species litter, create a more open, aerated litter layer and propagate surface fires, while litter with higher lignin content decomposes more slowly. For instance, red maple has a very low lignin content compared to oak species, which increases decomposition and eliminates fuel to facilitate fire across the landscape whereas, oak leaves are irregularly shaped and rigid allowing them to dry effectively and remain dry increasing flammability compared to mesophytic hardwoods (Nowacki and Abrams, 2008).

Upland Oak Ecology and Management

Factors of Oak Regeneration Failures

There are several factors leading to regeneration failures, such as acorn predation, insect infestation, lack of disturbance, and climatic effects. Poor seed source due to high consumption of acorns by animals can have significant impacts on regeneration (Galford et al., 1991; Lorimer, 1992). Additional factors leading to poor acorn crop include weather conditions (e.g., drought) and insect damage to seed-producing overstory trees (Lorimer, 1992). Production of acorns can be erratic, varying year to year due to variations in climate and tree physiology. Once established as a seedling, stand structural characteristics such as density can have influences on survival of young oak seedlings (Hodges and Gardiner, 1992; Dey, 2014). Under dense canopy cover with low light availability, oak seedlings are dependent on stored reserves. When those stored reserves are depleted oak seedlings survive on photosynthates produced by the leaves and thus light becomes a limiting factor for growth and survival (Hodges and Gardiner, 1992; Dey and Hartman, 2005; Keyser et al., 2017).

Successful regeneration depends on the presence of an adequate density of advanced oak regeneration (≥1 in. dbh and ≥4.5 ft. in height) to ensure oaks can compete, establish, and be recruited into the overstory (Dey and Hartman, 2005; Iverson et al., 2008). Although there may be numerous oak seedlings on a site, the small size of seedlings makes it difficult to reach a competitive height rapidly following release due to their more conservative growth strategy (Hodges and Gardiner 1992; Fan et al., 2012). Slow growth and high mortality of oaks in the understory may be related to dense understories in these stands (Crow, 1988; Lorimer, 1992). On dry-mesic or xeric sites, oaks growth strategy is to produce a stout taproot and persists for years despite topkill and dieback events and when an opening does occur, they are able to grow rapidly (Lorimer, 1992).

Silvicultural Treatments and Problems with Oak Regeneration

Several regeneration methods are used in order to promote the new reproduction and development of advanced reproduction in oak, including shelterwood, clearcutting, single-tree selection and group selection (Sander et al., 1984; Helms, 1998; Johnson et al., 2002). In order to promote the establishment and development of advanced reproduction in the Ozark Highlands, 400-600 stems per acre at the advanced reproduction size is suggested as adequate stocking following the removal of the overstory (Sander et al., 1984). Uniform shelterwood harvesting method has been the most applied in oak forests across the United States; the overstory trees are uniformly removed in order to release overtopped intermediate crown classes and remove canopy trees until the desired density is reached (Helms, 1998). In these forests this method does not provide enough reproduction for oak and the light levels do not control competitive species, especially in the absence of fire or the use of herbicide, and results in the poor accumulation of advanced oak reproduction (Smith, 1986; Hicks et al., 2004). When a higher intensity fire is applied during the growing season 3-5 years following a shelterwood harvest, an oak dominated cohort returns (Lanham et al., 2002).

Clearcutting in upland stands mimics the large-scale disturbances such as fire and windstorms, which historically had a role in the creation of southern hardwood stands. This method has been successfully used in these more xeric forests of the Central Hardwoods region, but the regeneration success depends on the establishment of reproduction for a decade or more, and all trees greater than 2 inches dbh will be removed if the stand regeneration potential is adequate (Sander, 1971; Hicks et al., 2004). Shifts to non-oak competitors can happen if oak regeneration is low, so measures including pre-harvest herbicide application and low intensity surface fires can be used to eliminate the shade-tolerant species and give a competitive edge to oaks (Lanham et al., 2002). In order for group selection harvests to promote oak regeneration and recruitment, advanced reproduction needs to be present to prevent competition by non-oaks and other woody and herbaceous plants (Fischer, 1981).

Oak-Fire Relationship

Fires can promote oak seedling establishment by reducing the density of competitor species allowing increased light and other resources, destroying competitor seeds, and scarifying the seedbed (Brose et al., 2014). When cached by wildlife, acorns that are underneath wet matted litter are protected from winter fires, and due to soils' poor heat conductivity, acorns buried beneath mineral soil are also protected from fires

(Brose et al., 2014). Greenberg and others (2012) saw that white oak and red oak germination rates were lower for acorns located on the surface than of those buried in at least 2 inches of mineral soil following a low-intensity dormant season fire.

The abundance of adventitious buds and carbohydrates stored belowground allows oak species to be superior sprouters (Brose et al., 2014). The larger, more developed root systems of oaks allow for increased survival on dry, nutrient deprived sites compared to that of more mesic, shade-tolerant competitors. As the basal diameter of seedlings increases, so does the ability to sprout; those seedlings with larger diameters have larger root systems and they are able to have a greater sprouting capacity following disturbance (Dey and Hartman, 2005; Brose et al., 2014).

Saplings not only have a thicker bark insulating the cambium, but position of the canopy is higher than that of other species, which limits heat damage to newly developed tissues (Loomis, 1973; Dey and Hartman, 2005; Brose et al., 2014). The larger saplings typically have thicker bark and crowns occurring well above the forest floor (Canadell and Rodà, 1991; Dey and Parker, 1996; Brose et al., 2014). The ability to compartmentalize wounds prevents decay through the stem and increases survivability and longevity, this trait allows mature oaks to maintain its seed producing capabilities.

When prescribed fires were applied on xeric sites in eastern Oklahoma, in the following growing season the number of sprouts per clump increased compared to subsequent years, with black oak experiencing increases in sprouts per clump with increases of fire frequency, but that occurred when the fires per decade were low; when the fires per decade increased the sprouts per clump of black oak decreased rapidly (DeSantis and Hallgren, 2011). In the Missouri Ozarks, repeated low-intensity surface fires favored advanced reproduction of oaks and hickory compared to non-oak competitors, (Fan et al., 2012). On unburned sites in the Missouri Ozarks there have been decreases in advanced reproduction of oak due to increases of non-oak densities and oak mortality. Stem size is a major component of these species' responses to repeated burns, with the smaller stemmed species experiencing increased mortality. Although oaks and hickories remain a component of advanced reproduction following repeated fires, the movement into the overstory strata will be limited due to the high stocking of the overstory and the prescribed fire caused topkill to the smaller diameter trees (Fan et al., 2012).

In eastern Kentucky prescribed fire was implemented over six years to compare the effects between single and repeated fires. The initial canopy cover was 90-94%, and when fire was implemented once there was a reduction of three percent of the canopy cover, with a 10% reduction on sites that had repeated burns. With a single burn there was a significant increase in the mean basal diameters of red oak and seedlings with larger initial basal diameters, and these classes had the greatest survivability across all sites and treatments (Lorimer, 1992; Alexander et al., 2008). With higher burn temperatures on single treatment sites, red oak seedlings had larger increases in basal diameter and height when compared to untreated sites with high canopy cover (Crow, 1992; Dey and Parker, 1996; Alexander et al., 2008). However, on sites with high canopy cover, regardless of temperature, non-oak competitors such as red maple and sassafras experienced annual growth 1.5-2.5 times faster than the oaks on the site (Abrams and Downs, 1990; Alexander et al., 2008). Red maple also demonstrated delayed mortality, which may reflect the depletion of resources following sprouting due to the non-conservative growth strategy of this species (Brose and Van Lear, 2004; Alexander et al., 2008).

During the dormant season, when most prescribed fires in eastern US forests are applied, the leaf litter fuel bed is receptive to the burns, and damage to the vegetation is reduced due to dormancy (Knapp et al., 2009). However, when applied during the growing season, the more intense fires favor oaks over species such as yellow poplar (*Liriodendron tulipifera*) (Knapp et al., 2009). When treatments are applied during the dormant season seedlings possess the greatest capacity to resprout because of the carbohydrate reserves in the root system, but fires that occur during the growing season result in reduced sprouting because fires typically burn hotter actively growing vegetation have higher levels of damage, and carbohydrate reserves in the root system are lower (Dey and Hartman, 2005).

Prescribed fires can help create or maintain woodland and forest communities as well as favor oak regeneration and competitiveness by controlling non-oak species, (Dey and Hartman, 2005), and can also alter the stand structure and light environment while also top-killing poorly formed oak seedlings and releasing more competitive sprouts (Loftis, 2004). Repeated burning can also limit the growth of competing vegetation, alter the seedbed, and reduce insect predation on acorns, providing an increase in oak establishment.

Prescribed fire can be implemented as a tool to restore native biodiversity and return historic disturbances back into the landscape (Dey and Hartman, 2005). Fire increases and maintains understory plant diversity through decreases in stem density and increases light levels to the forest floor, which promotes shade-intolerant fire adapted species such as oaks and alters species composition and structure (DeSantis and Hallgren, 2011; Brose et al., 2014). The openness or "park-like" structure of these communities allows for a diverse understory of forbs and grasses with widely-spaced trees; for implementing these restoration burns, growing season fires should be heavily used to increase mortality to the understory strata and then dormant season treatments application to maintain the structure and promote more shade intolerant fire adapted species such as oaks (Brose et al., 2014).

Oak Decline

Effects of oak decline range from partial crown dieback to tree morality and typically the red oak group is more severely affected than white oaks (Johnson et al., 2002). In the last 50 years there have been increases of oak decline in the upland forests of the eastern United States (Haavik et al., 2012), and may be a result of increased even-aged stand maturation and fire suppression (Haavik et al., 2012). Oak decline typically occurs in stands where the overstory has reached sawtimber size and predisposing factors such as insect attack, climatic events and increased age have occurred (Fan et al., 2008; Haavik et al., 2012). While red oak borers attacks are not always lethal in healthy oak stands, coupled with predisposing and inciting factors, stand mortality can be great (Manion, 1990; Johnson et al., 2002). Abundant saplings and regeneration in the understory following a decline event could return the impacted stand to a closed canopy system rather than reverting to a historical open woodland.

In the Ozark- St. Francis National Forest approximately 300,000 ac has been affected by oak decline events. Drought affected this area from 1998-2002 in stands consisting of old mature trees and high densities. In the Boston Mountains of Arkansas, northern red oak experienced the highest mortality rates, and within one year, snag densities doubled while other species remained at similar levels prior to the decline events (Spetich, 2004). Red oak borer can attack trees with healthy crowns as well as declining crowns. Fan et al. (2008) found that 80% of scarlet and black oaks not exhibiting crown dieback were infested with red oak borer. As crown dieback increased so did oak mortality, with black oak having the greatest total mortality.

Stem boring insects such as red oak borer benefit from drought events in oak stands (Haavik et al., 2015). Compartmentalization as a result from wound response is decreased due to the stress of drought, which is an important mechanism to resist boring insects. With the decrease of red oak as the dominant species groups, the composition has shifted towards more a mixed composition of white oak, hickory, blackgum and red maple. Though there was an increase of gap openings due to the mortality of the overstory trees, they may be too small for oak recruitment and the more available resources can be used by shade intolerant non-oak competitors (Heitzman et al., 2007).

METHODS

Study Area

This study was conducted in upland oak-hickory forests in the Big Piney District of the Ozark-St. Francis National Forest in northwestern Arkansas. The Ozark- St. Francis National Forest encompasses approximately 1.2 million acres in northwestern Arkansas (USDA, 2019). These “mountains” are actually plateaus with the ruggedness resulting from erosion by the swift rivers in this area (USDA, 2019). The Boston Mountains, an ecoregion in the Ozarks, are characterized by narrow V-shaped valleys with steep-sided slopes and vertical sandstone cliffs (USDA, 2019). Early Pennsylvanian sandstones and shale with minor limestone make up the underlying parent material of this area (Arkansas Geological Survey, 2019). Classified as a humid subtropical climate by the Köppen Climate Classification, these areas experience an average of 49.5 inches of rainfall and 2.1 inches of snowfall annually. The average high temperature in July is 92°F and the average low 28°F in January. The study area is characterized as an upland oak-hickory cover type with northern red oak, white oak, black oak, post oak, mockernut hickory (*Carya tomentosa*), and bitternut hickory (*C. cordiformies*) as the dominant overstory species (Eyre, 1980).

Selected Study Sites

This study was conducted at three sites (Falling Water, Meadows Knob, and Pilot Knob) located in Johnson and Pope Counties in northwestern Arkansas (Figure 1). These sites were severely impacted by factors associated with oak decline; (drought occurred on these sites in 1998 and from 2000 to 2002, followed by a red oak borer outbreak; Spetich, 2004). As part of a previous study (Booker, 2008), these sites were located near ridgetops on south to southwest facing slopes of 20 to 40 percent and at elevations that range from 1,575 to 2,034 ft. (Booker, 2008). Soils series at the sites are: Nella and Enders (Pilot and Meadows Knob) and Nella, Enders, and Mountainburg (Falling Water). These soils are cobbly loam, gravelly fine sandy loam, fine sandy loam, and from the taxonomic group Typic Paleudult, Typic Hapludult and Lithic Hapudult respectively (Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture, 2019)

Plots were randomly located across the three sites within no-burn control, single dormant season fire, and single growing season prescribed fire treatments between 2005 and 2006 (Booker, 2008). In this current study, only the no-burn control and a dormant season prescribed fire treatments were analyzed as only the Pilot Knob site received the single growing season prescribed fire treatment due to weather conditions. A single dormant season prescribed fire was implemented between 2006 and 2007 at each of the sites (Booker, 2008). Falling Water (six control, nine dormant), Meadows Knob (eight control, eight dormant), and Pilot Knob (six control, six dormant) had six to nine plots (Figures 2-4).

Plot Layout

Plots were established in a previous study by Booker (2008) in August 2005 at Pilot Knob and in August 2006 at Meadows Knob and Falling Water (Table 1). Initially, eighteen plots at Pilot Knob were established, and twenty-three at Meadows Knob and Falling Water. Plot centers were permanently marked with rebar and labeled with a steel tag. Centers of the plots were located on the upper slopes at each of the study sites (Booker, 2008). Plots were randomly located across the burn treatments with only the control and dormant plots were used for this study. Each plot included five 0.005-acre subplots, one plot at the center and four additional subplots 30 feet from plot center in the cardinal directions (N, E, S and W) (Figure 5). Overstory was tallied in each of the center subplots, while sapling and seedling inventories were collected within all five of the subplots. Randomly located tagged seedlings were also established at initial plot establishment up to 50 ft. from plot center.

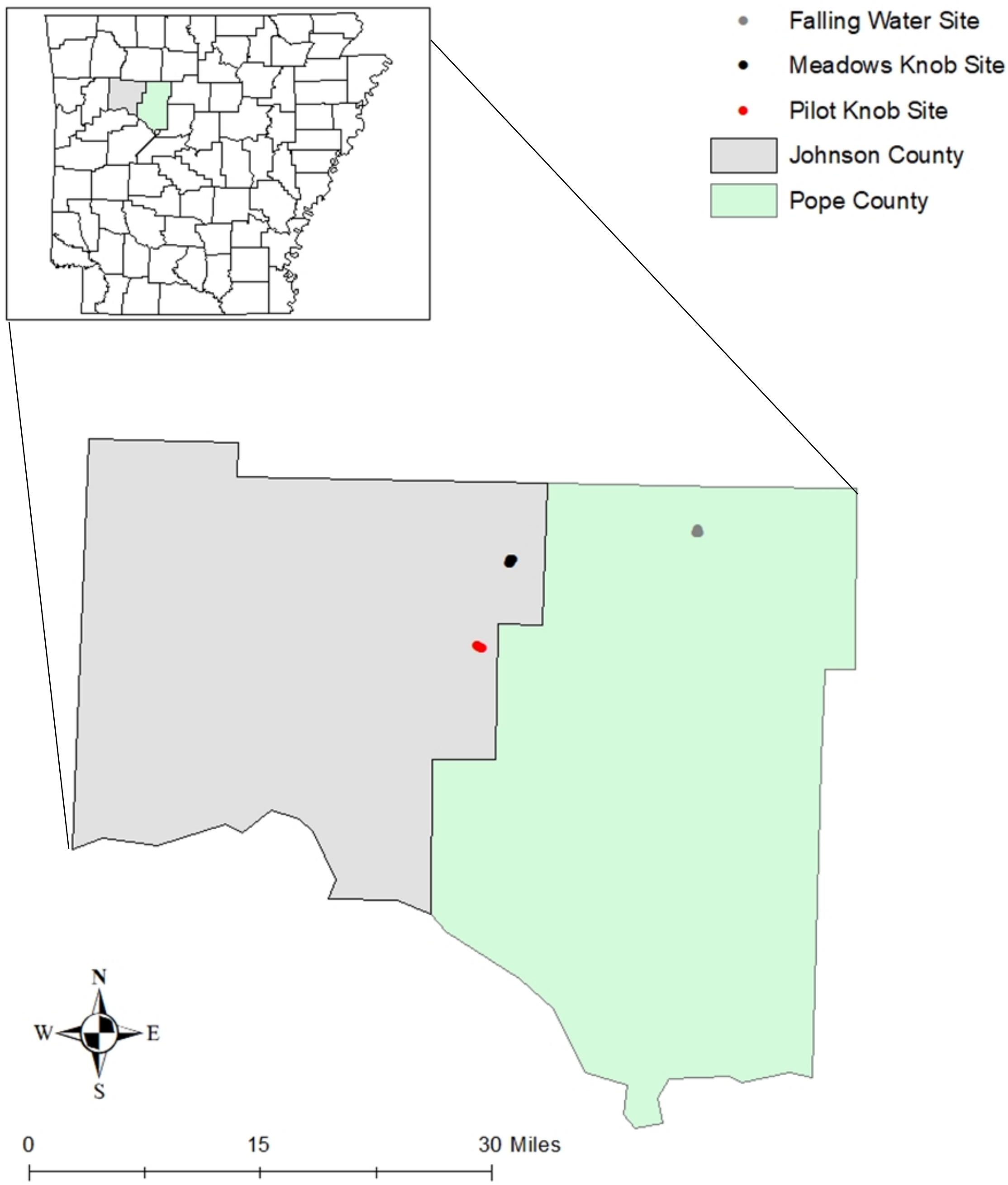

Figure 1. Location of study sites within Johnson and Pope Counties in Arkansas.

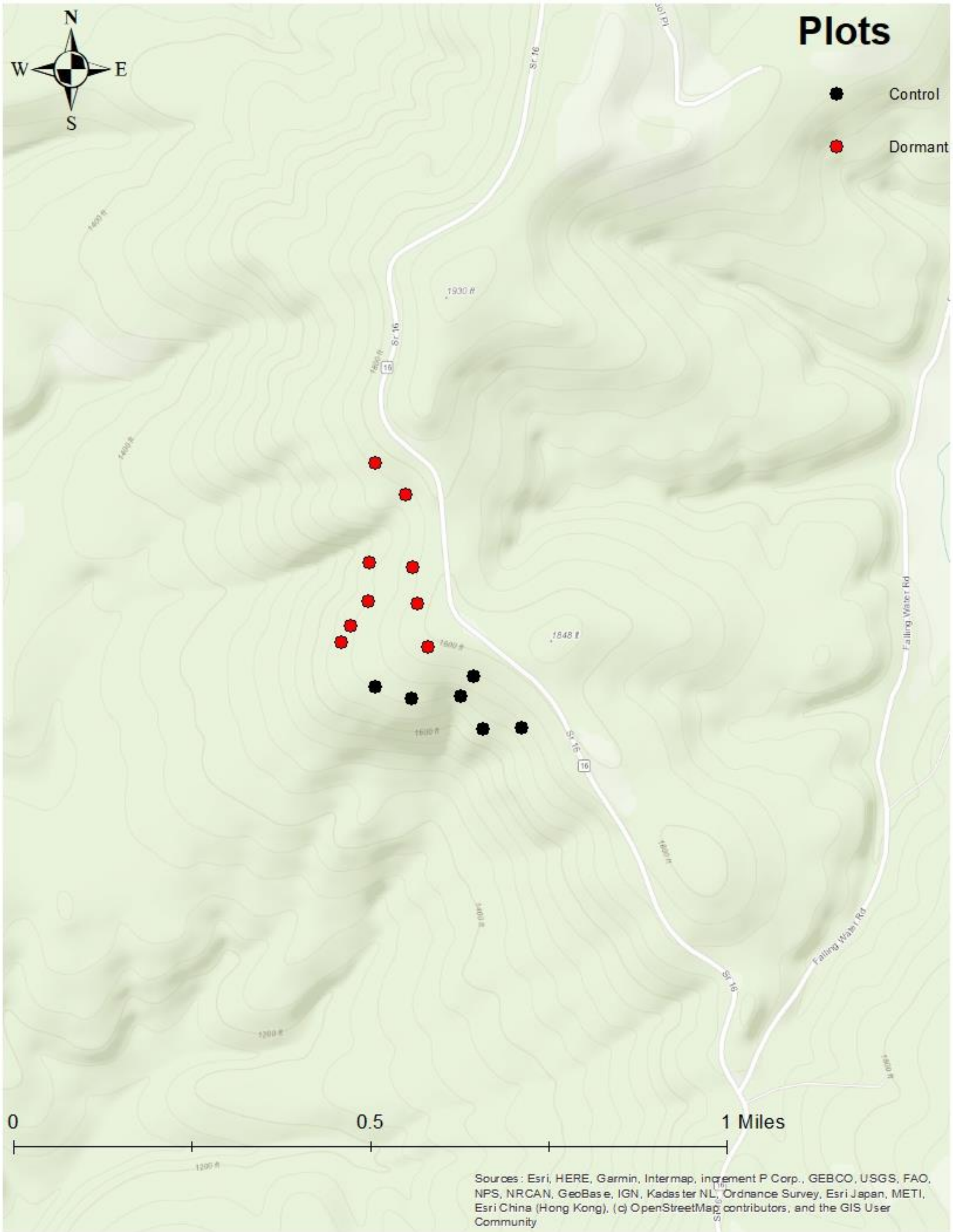

Figure 2. Location of dormant and control plots at the Falling Water site in Ozark-St. Francis National Forest, Arkansas.

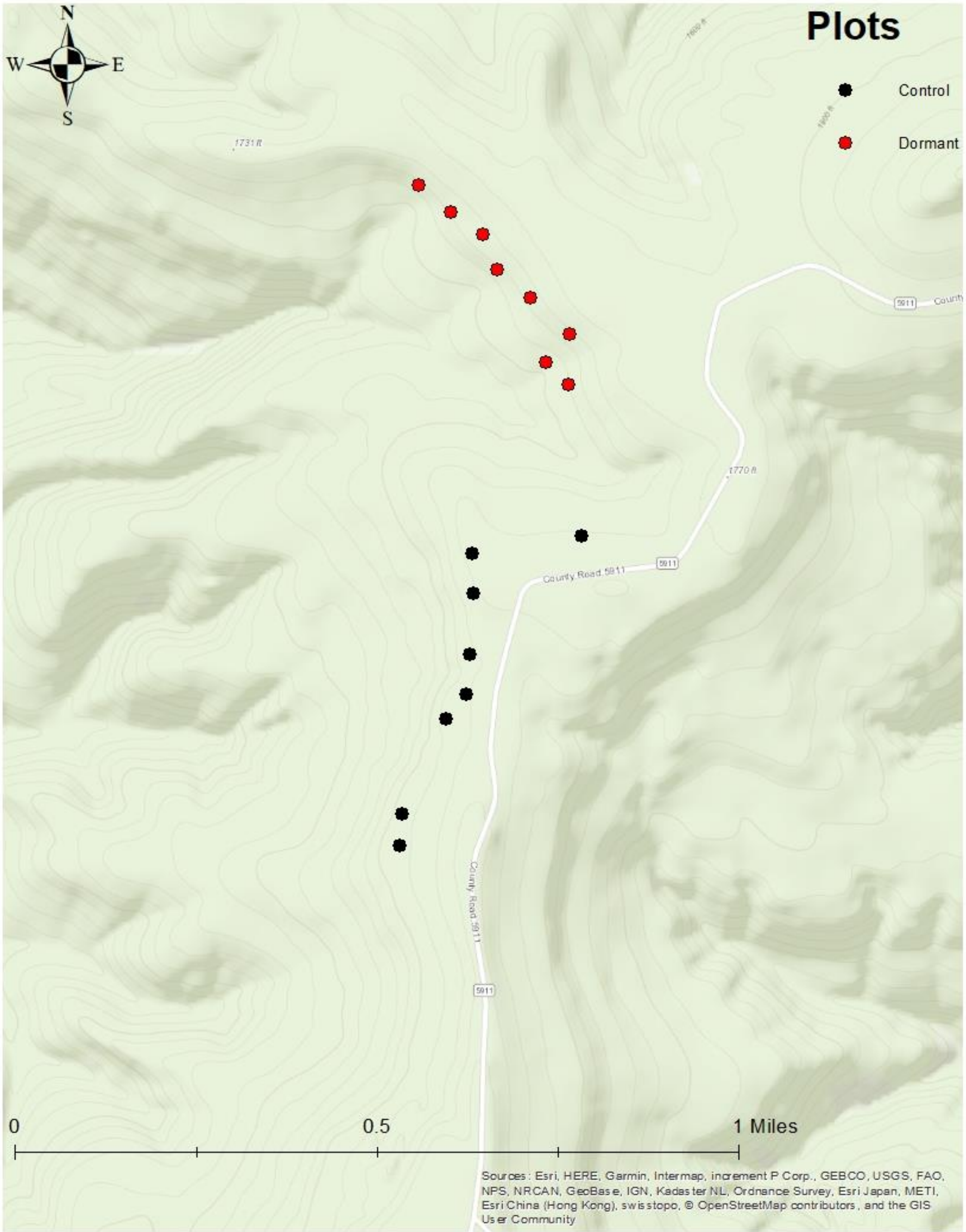

Figure 3. Location of dormant and control plots at Meadows Knob site in Ozark-St. Francis National Forest, Arkansas.

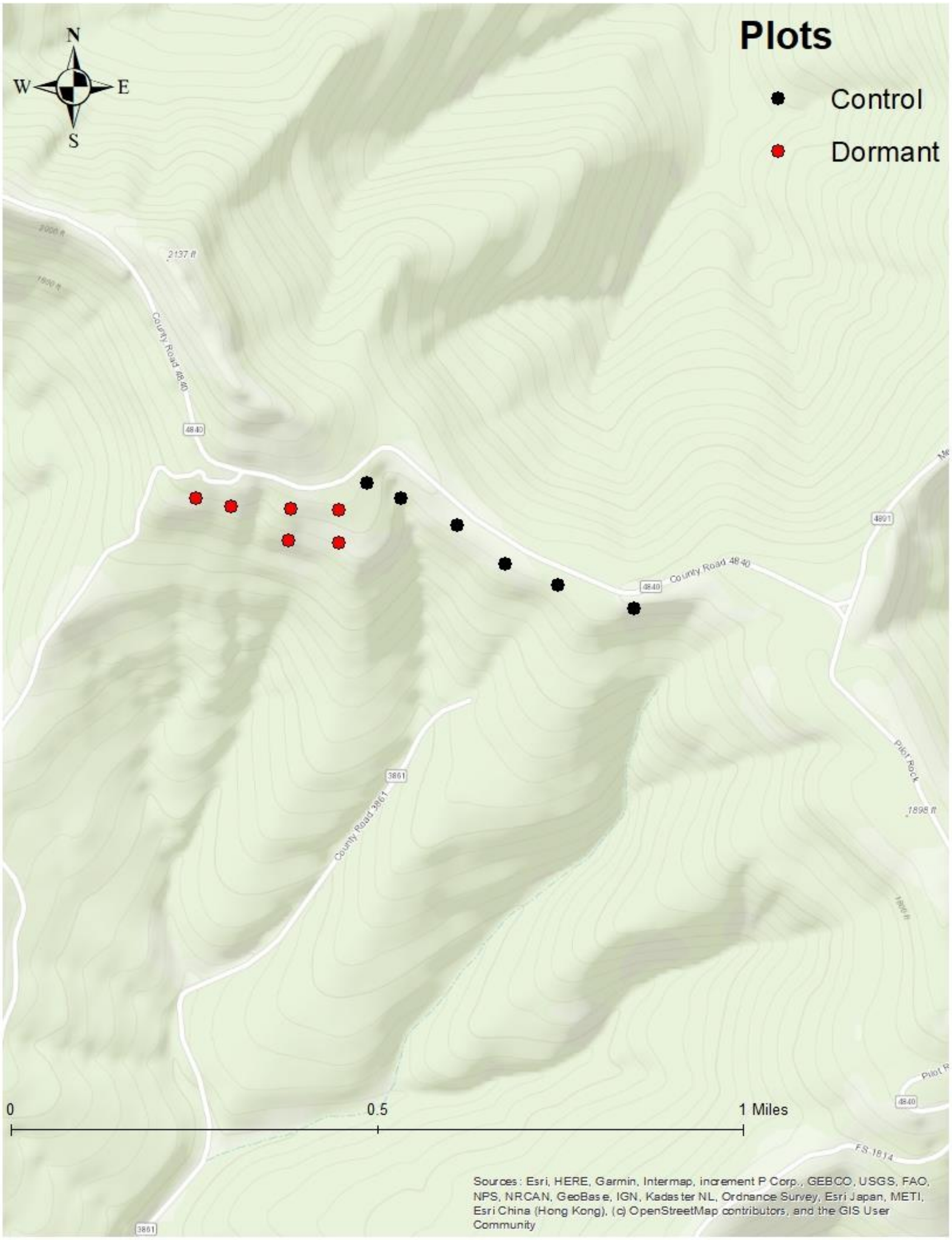

Figure 4. Location of dormant and control plots at Pilot Knob site in Ozark-St. Francis National Forest, Arkansas.

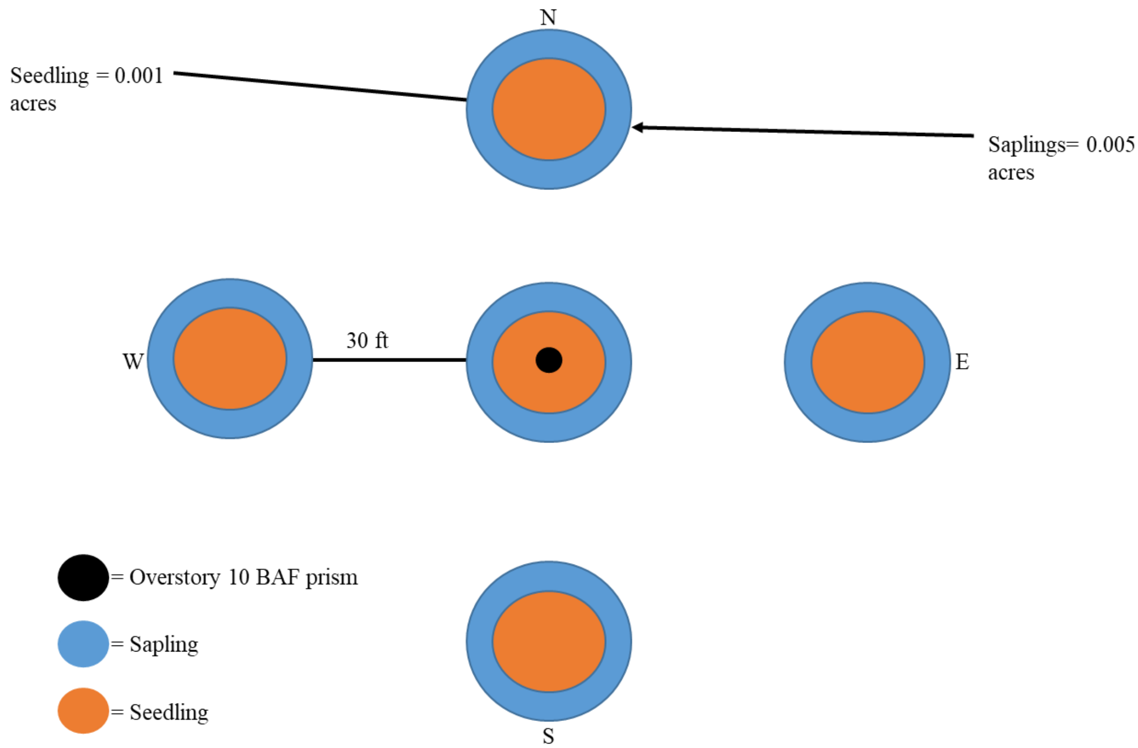

Figure 5. Overstory (dbh ≥ 4.5 in.), sapling (dbh ≥ 0.6 and < 4.5 in.) and seedling (dbh < 0.6 in. and height ≥ 2.0 ft.) plot layouts for all plots at Falling Water, Meadows Knob, and Pilot Knob study sites in the Ozark-St. Francis National Forest. Sapling and seedling subplots were located in cardinal directions (N, E, S, and W) 30 feet from center subplot.

Past Stand Inventory and Treatments

Previous stand inventories were conducted prior to implementation of treatments and then annually for four years after treatments (Table 1). All data were collected at the end of the growing season (end of July, beginning of August), on the overstory (living tree with a dbh ≥ 4.5 in.), sapling (dbh ≥ 0.6 in. and < 4.5 in.), and seedling (dbh < 0.6 in. and height ≥ 2 ft.) strata. Additionally, seedlings were tagged at each plot to track the survival and sprouting response of oak versus non-oak competitors (five oak, red maple, and blackgum). The dormant season burn treatment at Falling Water and Meadows Knob sites occurred on March 12, 2007. The Pilot Knob single dormant season treatment occurred on February 7, 2007 (Table 1). A total of three plot inventories were utilized for this study (Table 1). Two of the three plot inventories (pre1 and post2), were performed and presented as part of a previous thesis (Booker, 2008). Post12 plot inventories were performed and analyzed as part of this current study. As part of the previous study (Booker, 2008), Templaq paint was used at each subplot to determine temperature of the burn. Wind direction, wind speed (mph), air temperature (°F), relative humidity (%), and fuel consumption (tons/ac) was also collected and used as analysis and reference for the previous and current study.

Table 1. Summary of treatments and codes conducted at the three study sites in the Ozark-St. Francis National Forest, AR. Pre1 stands for the pre-burn measurements, post2 is two years after treatment, and post12 is 12 years following treatment.

Site	**Year**	**Treatment**	**Year code**
Pilot Knob	2005	Dormant fire (Feb.)	Pre1
	2006	Growing fire (May)	
	2008		Post2
	2017		Post12
Meadows Knob	2006		Pre1
	2007	Dormant fire (March)	
	2009		Post2
	2018		Post12
Falling Water	2006		Pre1
	2007	Dormant fire (March)	
	2009		Post2
	2018		Post12

Table 2. Dormant season prescribed fire conditions for burns conducted at Falling Water, Meadows Knob, and Pilot Knob study sites in the Ozark-St. Francis National Forest, AR, including: mean, minimum, and maximum fire temperatures; wind direction; wind speed; air temperature and relative humidity at time of the treatment; and tons/ac consumed.

Site	**Date**	**Mean Temp. (°F)**	**Min. Temp. (°F)**	**Max Temp. (°F)**	**Wind Direction**	**Wind Speed (mph)**	**Air Temp. (°F)**	**Relative Humidity (%)**	**Fuel Consumption (tons/ac)**
Falling Water	3/12/2007	358	275	425	SW	2.0-6.9	69-80	34-44	5
Meadows Knob	3/12/2007	531	325	900	SE	2.0-6.9	72-80	34-42	5
Pilot Knob	2/7/2007	671	350	1100	S-SW	2.5-5.0	46-51	33-39	4

Field Measurements

Inventory data were collected at the end of the growing season (September, 2017 at Pilot Knob and August, 2018 at Meadows Knob and Falling Water) 12 years after the treatments were conducted (Table 1) (Booker, 2008). Data were collected to evaluate effects of the treatments on the overstory, sapling and seedling strata. At the sapling and seedling strata, sprouts were defined as multiple stems from the same rootstock creating a clump; the number of stems per clump were tallied as well as the dominant sprout height (ft.), basal diameter (in.) and dbh (in.) if applicable. Selected seedlings that were previously mapped and tagged, were re-located and total number of sprouts, height, and basal diameter of the dominant sprout were measured (Booker, 2008). These seedlings consisted of up to five oak (mix of red and white oak species), blackgum, and red maple seedlings that were initially tagged to monitor post-treatment survival and sprouting responses.

Initially, Booker (2008) located each overstory tree using a 10 BAF prism at plot center and tagged each tree with a unique number. Overstory trees within a 10 BAF prism plot were again tallied from plot center and if any untagged trees were located they were given a tag number for future recording (post2 and post12). Species, dbh, percent crown dieback, percent transparency, sprout presence and dominant sprout height and basal diameter were recorded for each living tree within the plot. Crown dieback, from the tip of the branches towards the trunk, was recorded in percent classes: 0-5, 5-25, 25-

50, 50-75, 75-95 and >95 (Schomaker et al., 2007). Transparency, (the percent of skylight visible through the live portion of a tree crown), is an indicator of tree health due to the impacts that insect defoliation, diseases or other stresses can have (Schomaker et al., 2007). Crown transparency was visually estimated in percent classes of 0-5, 5-25, 25-50. 50-75, 75-95 and >95.

For saplings within the 0.005 ac subplots, species, height, dbh, and the percentage (10 percent classes) of crown dieback and normal foliage were recorded. If saplings had sprouts present, or were part of a sprout clump, number of sprouts and dominant sprout height and basal diameter were recorded. In the 0.001 ac subplots seedling height, basal diameter, percent browse, percent dieback, percent normal foliage, and whether the stem was from seed or sprout origin were recorded. If seedling sprouts were from the same rootstock, this was noted.

Data Analysis

To evaluate long-term efficacy of prescribed fire as a restoration tool in these degraded stands, data for the 11 plots at Pilots Knob were collected in September 2017; Meadows Knob and Falling Water data were collected August 2018. Previously collected data (pre-treatment, and post2) was also be analyzed to determine effects of fire treatments through time (Booker, 2008). Treatments and plot layout were initially established such that data could be analyzed in a Randomized Complete Block Design (RCBD) with the three study sites representing the blocks. However, after testing selected data variables for normality (i.e., Shapiro-Wilks) and evaluating skewness, asymmetry of distribution (-0.5 to 0.5 normal), and kurtosis, sharpness of the peak of curve (-3 to 3 normal) values, criterion data were found to be non-normal for most variables. Therefore, non-parametric statistical tests (e.g., Mann-Whitney, Kruskal-Wallis and Bonferroni post-hoc tests) were used to analyze data. All statistical analyses were conducted using $\alpha = 0.05$.

Variables were averaged by plot for each treatment and across the sites by species group. A Mann-Whitney test was conducted to identify differences between the dormant and control treatments for changes in overstory basal area (ft^2/ac) and the proportion of basal area classified in crown dieback condition classes (healthy and dead/dying) for species groups (red oak, white oak, hickory, and other). Specifically, changes two (post2 minus pre1) and twelve (post12 minus pre1) years following treatment were analyzed for each of these overstory variables. Differences between the dormant and control treatments for changes in sapling and seedling density (stems/ac) for species groups (red oak, white oak, red maple, and other) were analyzed using a Mann-Whitney test. Changes two (post2 minus pre1) and twelve (post12 minus pre1) years following treatment were analyzed for changes in density in both sapling and seedling strata.

Height (ft.), diameter (in.), and basal area (ft^2/ac) for saplings (dbh) and seedlings (basal diameter and no basal area) were analyzed to determine differences among species groups in the control and dormant treatments prior to, two, and twelve years following treatment using Kruskal-Wallis and Bonferroni post-hoc tests. Sprout dynamics, including sprouts per rootstock and dominant sprout height and basal diameter, for tagged seedlings only, were analyzed to identify the differences among species groups in the control and dormant treatments two and twelve years following treatment. Simple linear regression analysis was used to test if the changes in overstory basal area at year twelve significantly influenced mean sapling change in density and height, and mean seedling change in density, height, and basal diameter twelve years following treatment.

RESULTS

Overstory

Density & Composition

Throughout all measurement periods the majority of the overstory basal area was composed by upland red (northern and black) and white (post and white) oak species (Figure 6). Red oak reductions in basal area were significantly different ($p = 0.856$) between treatments and were similar between the control (-13%) and dormant (-14%) treatments two years after treatment (Figure 7) (Booker, 2008). Twelve years following treatment, red oak basal area reductions were more pronounced in the dormant treatment (-34%) than in the control (-9%), but were not significantly different ($p = 0.120$) between treatments (Figure 8). Two and twelve years following treatment, changes in white oak, Hickory and other species (e.g., red maple, blackgum, and black cherry) basal areas were not significantly different between treatments two or twelve years after treatment (Figures 7 and 8).

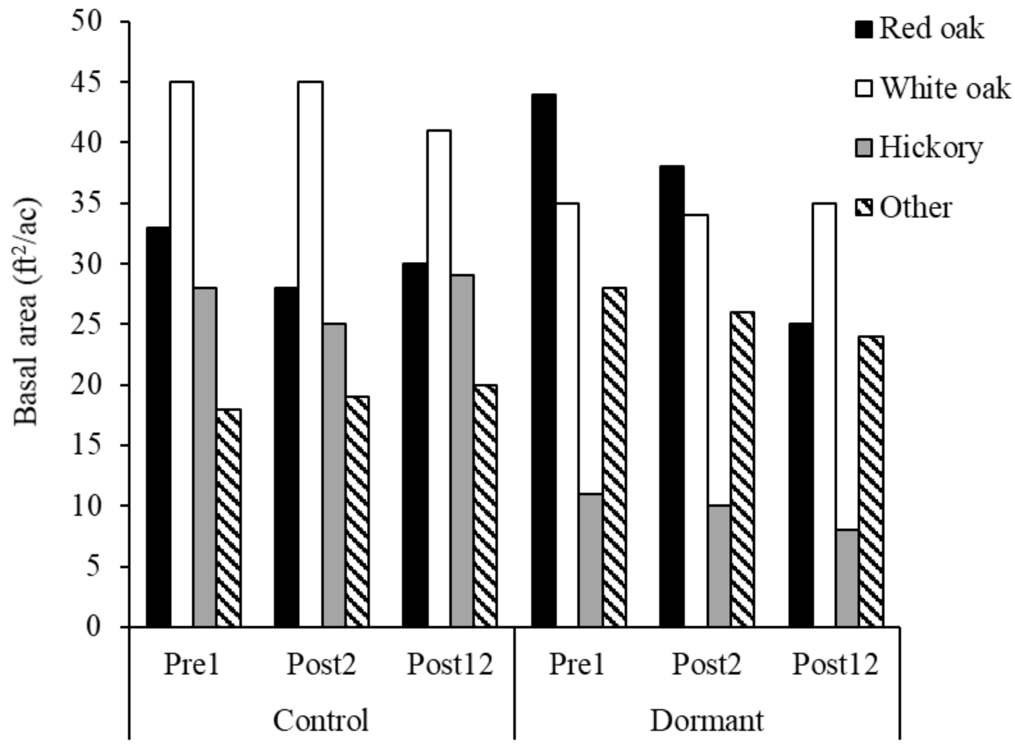

Figure 6. Mean overstory (dbh ≥ 4.5 in.) basal area (ft^2/ac) for species groups (red oak: northern red oak, black oak; white oak: post oak, white oak; hickory; and other: red maple, blackgum, black cherry, etc.) prior to (pre1) and two (post2) and twelve (post12) years following the implementation of a single dormant season prescribed fire and no-burn control treatment at the Falling Water, Meadows Knob, and Pilot Knob sites in Ozark-St. Francis National Forest, AR.

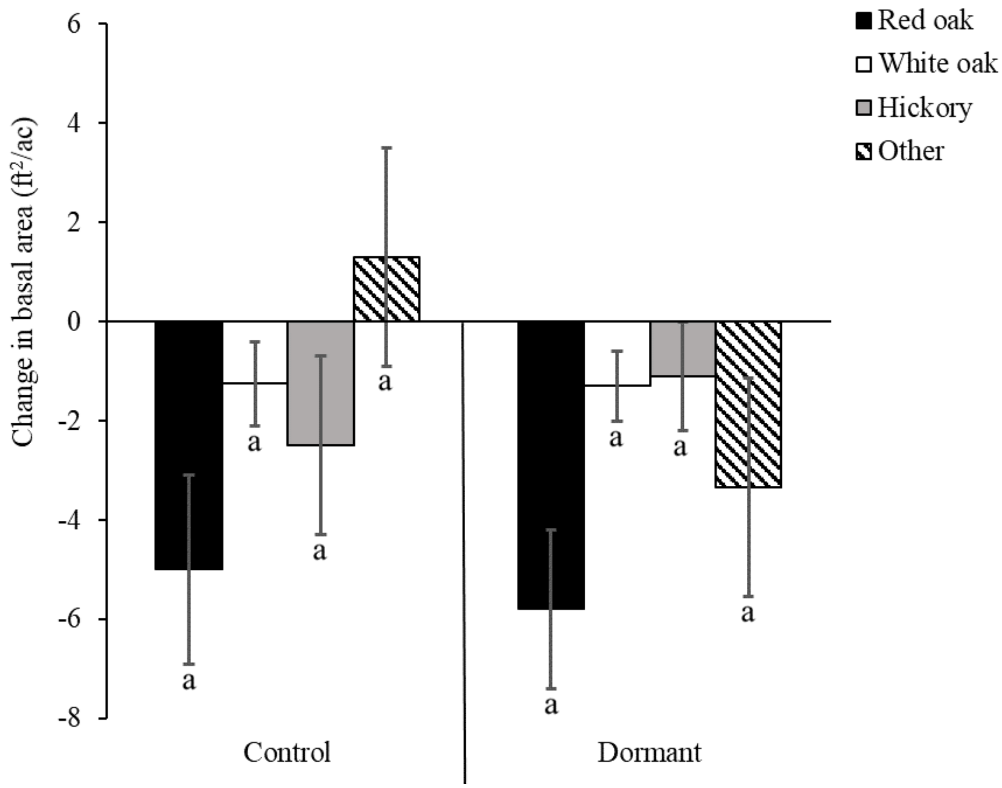

Figure 7. Mean two-year change (post2 minus pre1) (error bars indicate +/- SE) in overstory (dbh ≥ 4.5 in.) basal area (ft^2/ac) for species groups (red oak: northern red oak, black oak; white oak: post oak white oak; hickory; and other: red maple, blackgum, black cherry, etc.) following implementation of a single dormant season prescribed fire and no-burn control treatment across Falling Water, Meadows Knob, and Pilot Knob sites in Ozark-St. Francis National Forest, AR. Same letter indicates no significant difference ($\alpha = 0.05$) for species group between treatments based on a Mann-Whitney test.

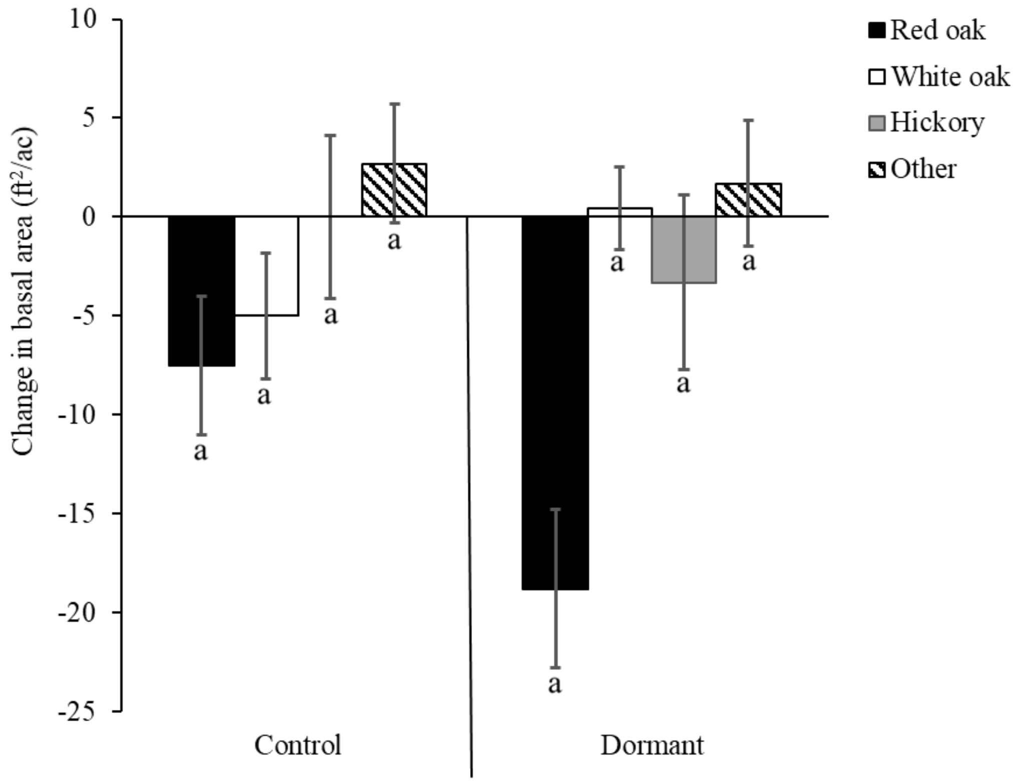

Figure 8. Mean twelve-year change (post12 minus pre1) (error bars indicate +/- SE) in overstory (dbh ≥ 4.5 in.) basal area (ft^2/ac) for species groups (red oak: northern red oak, black oak; white oak: post oak white oak; hickory; and other: red maple, blackgum, black cherry, etc.) following implementation of a single dormant season prescribed fire and no-burn control treatment across Falling Water, Meadows Knob, and Pilot Knob sites in Ozark-St. Francis National Forest, AR. Same letter indicates no significant difference ($\alpha = 0.05$) for species group between treatments based on a Mann-Whitney test.

Overstory Mortality and Grow-ins

Mean basal area for grow-in was not statistically different between treatments for any species group twelve years following treatment implementation, and basal area for red oak (5 ft^2/ac) and other (6 ft^2/ac) grow-ins was similar between treatments. White oak (2 ft^2/ac) and hickory (4 ft^2/ac) had the lowest grow-in basal area in the no-burn control. In the dormant treatment 12 years after burning, red oak (1 ft^2/ac) had a numerically lower grow-in basal area than white oak (6 ft^2/ac), hickory (3 ft^2/ac), and the other (2 ft^2/ac) species groups (Figure 9).

Percent overstory mortality twelve years following treatments did not significantly differ between the no-burn control and dormant treatment for any species group. At year twelve, red oak had a numerically greater percent mortality in the dormant (38%) than in the control (11%). Similar trends were observed between treatments for white oak (dormant = 34%; control = 26%) hickory (dormant = 25%; control = 15%) and other (dormant = 22%; control = 18%) (Figure 10).

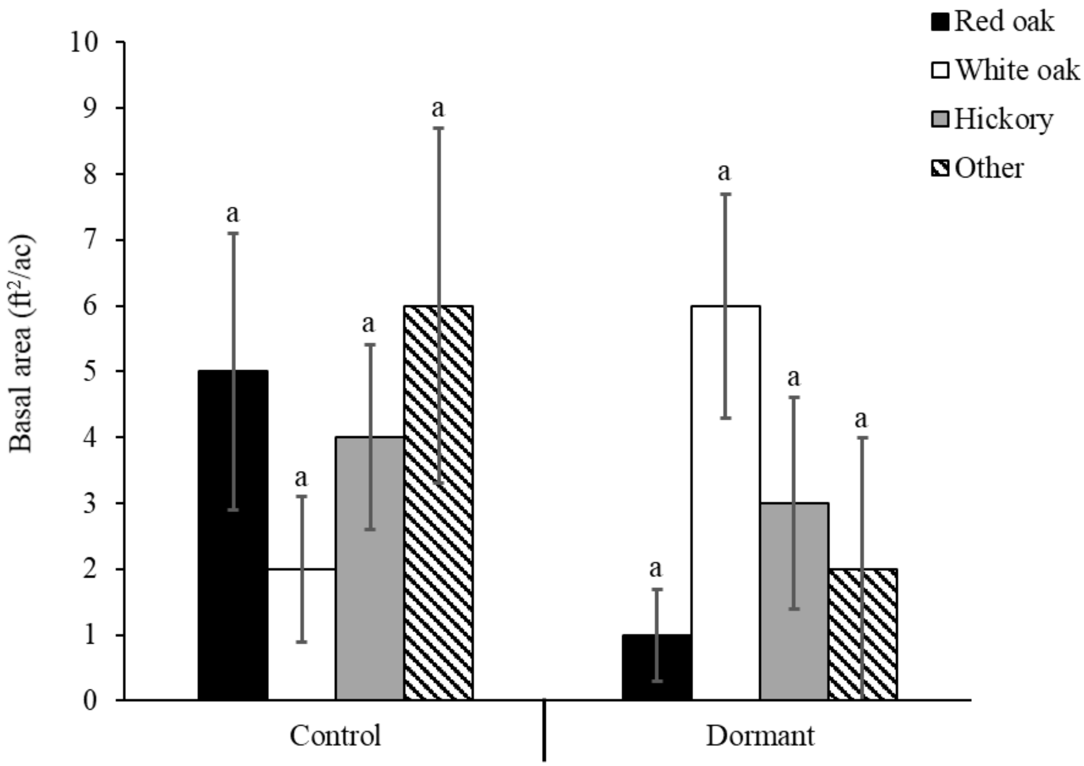

Figure 9. Mean twelve year grow-in (error bars indicate +/- SE) in overstory (dbh ≥ 4.5 in.) basal area (ft^2/ac) for species groups (red oak: northern red oak, black oak; white oak: post oak white oak; hickory; and other: red maple, blackgum, black cherry, etc.) following implementation of a single dormant season prescribed fire and no-burn control treatment across Falling Water, Meadows Knob, and Pilot Knob sites in Ozark-St. Francis National Forest, AR. Same letter indicates no significant difference ($\alpha = 0.05$) for species group between treatments based on a Mann-Whitney test.

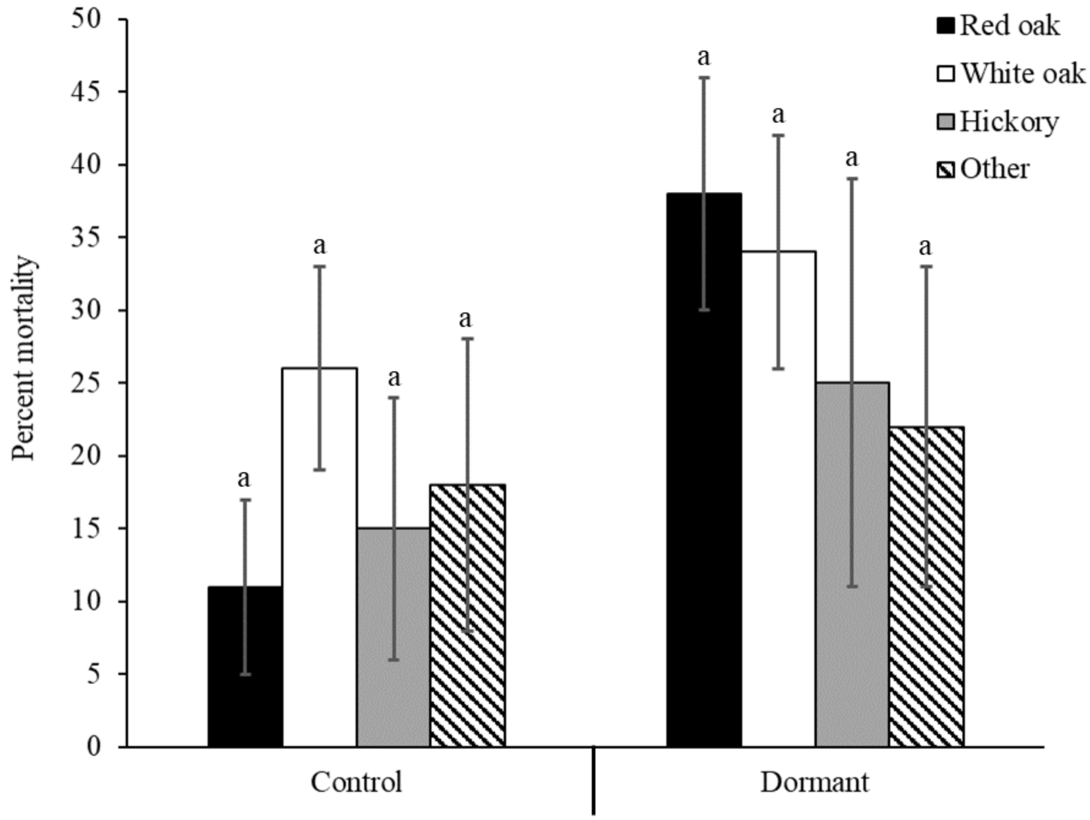

Figure 10. Mean twelve year percent mortality (error bars indicate +/- SE) in overstory (dbh ≥ 4.5 in.) basal area (ft^2/ac) for species groups (red oak: northern red oak, black oak; white oak: post oak white oak; hickory; and other: red maple, blackgum, black cherry, etc.) following implementation of a single dormant season prescribed fire and no-burn control treatment across Falling Water, Meadows Knob, and Pilot Knob sites in Ozark-St. Francis National Forest, AR. Same letter indicate no significant difference ($\alpha = 0.05$) for species group between treatments based on a Mann-Whitney test.

Crown Dieback Conditions

The majority of the overstory had a healthy (≤ 25% dieback) crown dieback condition for all time periods based on the percentage of basal area with that classification; red oak species had a lower percentage classified as healthy (Figure 11). In both the no-burn control and dormant treatment, other species group had a numerically greater percentage of basal area classified with a healthy dieback condition prior to treatment. In the dormant treatment, prior to prescribed fire implementation, red oak species had approximately 32% of basal area classified as dead/dying (≥ 95% dieback) with a lower percentage in the no burn control (20%) (Figure 9). Overstory basal area percentages classified as healthy remained similar in the control, while in the dormant treatment more noticeable decreases were observed. White oak ($p = 0.014$) and hickory ($p = 0.002$) had a greater reduction in the percent of healthy crown classification in the dormant treatment than in the control (Figure 12). Twelve years following treatment, red oak (59%) and hickory (92%) were the only groups to have an increase of the healthy crown classification in the no burn control. Hickory ($p = 0.010$) had greater occurrences of healthy crown condition in the dormant treatment than in control (Figure 13). The percentage of basal area classified as dead/dying was numerically greater in the control for red and white oaks, while in the dormant treatment, the majority of the other species group had dead/dying classification (Figure 13).

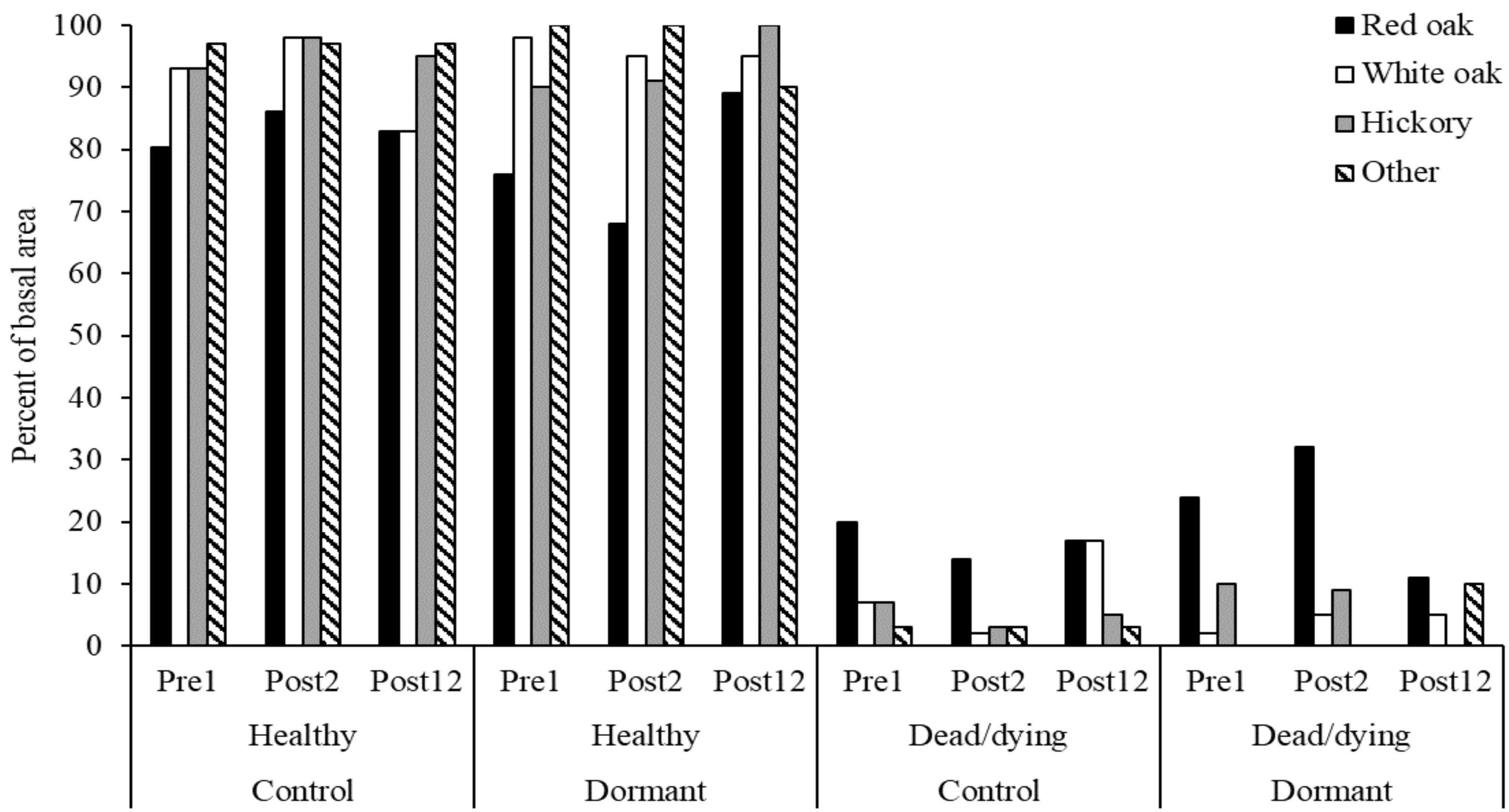

Figure 11. Mean overstory (dbh ≥ 4.5 in.) basal area (ft^2/ac) for species groups (red oak: northern red oak, black oak; white oak: post oak, white oak; hickory; other: red maple, blackgum, black cherry, etc.) by crown dieback class (healthy: ≤ 25%, fair: 25-75%; poor: 75-95%; dead/dying: ≥ 95%) prior to (pre1) and two (post2) and twelve (post12) years following implementation of a single dormant prescribed fire and no-burn control treatments at the Falling Water, Meadows Knob and Pilot Knob sites in Ozark-St. Francis National Forest, Arkansas.

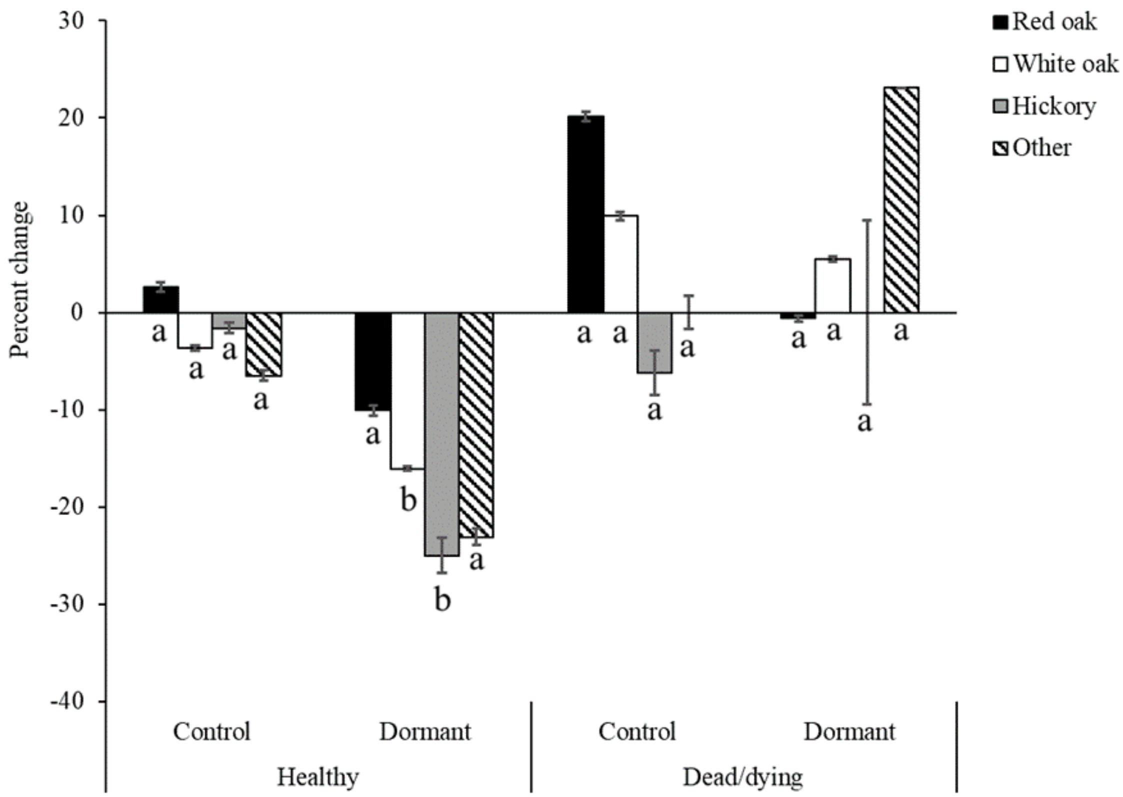

Figure 12. Mean two-year change (post2 minus pre1) (error bars indicate +/- SE) in overstory (dbh ≥ 4.5 in.) percent of healthy (≤ 25% dieback) and dead/dying (>95% dieback) for species groups (red oak: northern red oak, black oak; white oak: post oak white oak; hickory; and other: red maple, blackgum, black cherry, etc.) following implementation of a single dormant season prescribed fire and no-burn control treatment across Falling Water, Meadows Knob, and Pilot Knob sites in Ozark-St. Francis National Forest, AR. Different letters indicate significant difference (α = 0.05) for species group between treatments based on a Mann-Whitney test.

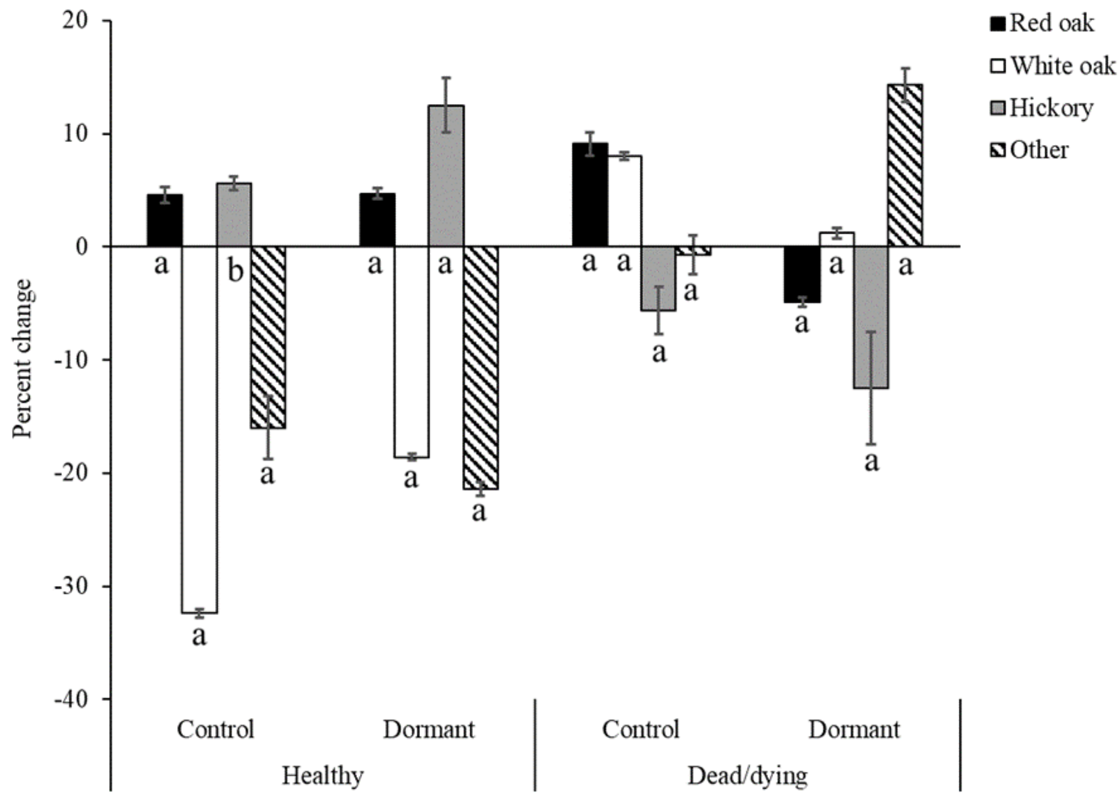

Figure 13. Mean twelve-year change (post12 minus pre1) (error bars indicate +/- SE) in overstory (dbh ≥ 4.5 in.) percent of healthy (≤ 25% dieback) and dead/dying (> 95%) crown condition for species groups (red oak: northern red oak, black oak; white oak: post oak white oak; hickory; and other: red maple, blackgum, black cherry, etc.) following implementation of a single dormant season prescribed fire and no-burn control treatment across Falling Water, Meadows Knob, and Pilot Knob sites in Ozark-St. Francis National Forest, AR. Different letters indicate significant difference (α = 0.05) for species group between treatments based on a Mann-Whitney test.

Saplings

Density & Composition

Prior to the dormant season burn, the other species group composed more than half of the total sapling density (control: 282 stems/ac; dormant: 399 stems/ac) in both treatments. Two and twelve years following the burn, the other species continued to have the greatest densities, despite spikes in red oak densities at year twelve (Figure 14). Red maple ($p = 0.039$) and other ($p < 0.001$) species groups experienced the greatest reduction in density in the dormant treatment two years following treatment. Although there were reductions for red ($p = 0.091$) and white ($p = 0.050$) oaks, there was no significant difference between treatments (Figure 15). Twelve years following treatment all species groups experienced increases in density in both the control and dormant treatment, except for white oak which had a slight reduction in density in the control (Figure 16). Increases in density in the dormant treatment by red oak ($p = 0.002$), white oak ($p = 0.004$), and other ($p = 0.020$) were significantly differently greater than the control (Figure 16).

A simple linear regression analysis was used to estimate the influence of the change in overstory basal area on sapling change in density for each species group at year twelve within each treatment. No significance was found in the control (Figure 17). All species groups experienced reductions in density with the increase of basal area by year twelve, but white oak and other species were significant predictors in the model (Figure 18).

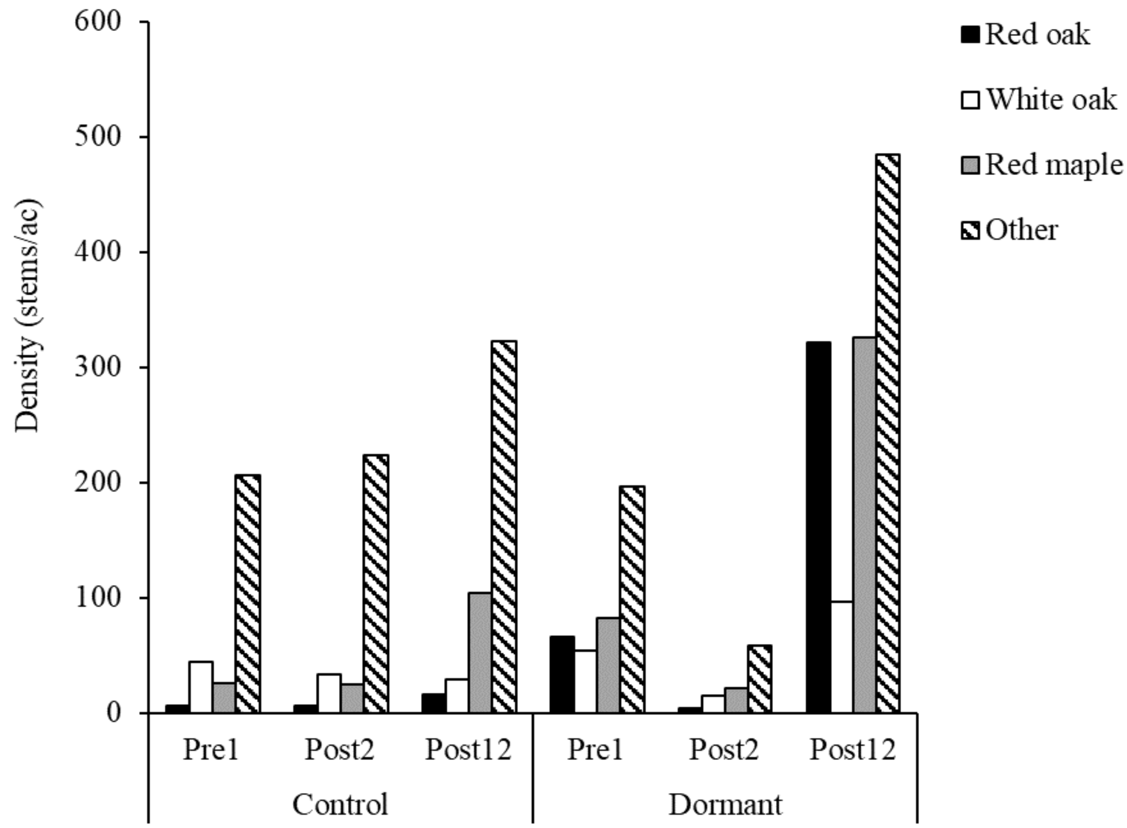

Figure 14. Mean sapling (dbh ≥ 0.6 and < 4.5 in.) density (stems/ac) for species groups (red oak: northern red oak, black oak; white oak: post oak, white oak; red maple; and other: blackgum, black cherry, etc.) prior to (pre1) two (post2) and twelve (post12) years following implementation of a single dormant prescribed fire and a no-burn control treatment at the Pilot Knob, Falling Water and Meadows Knob sites in Ozark-St. Francis National Forest, Arkansas.

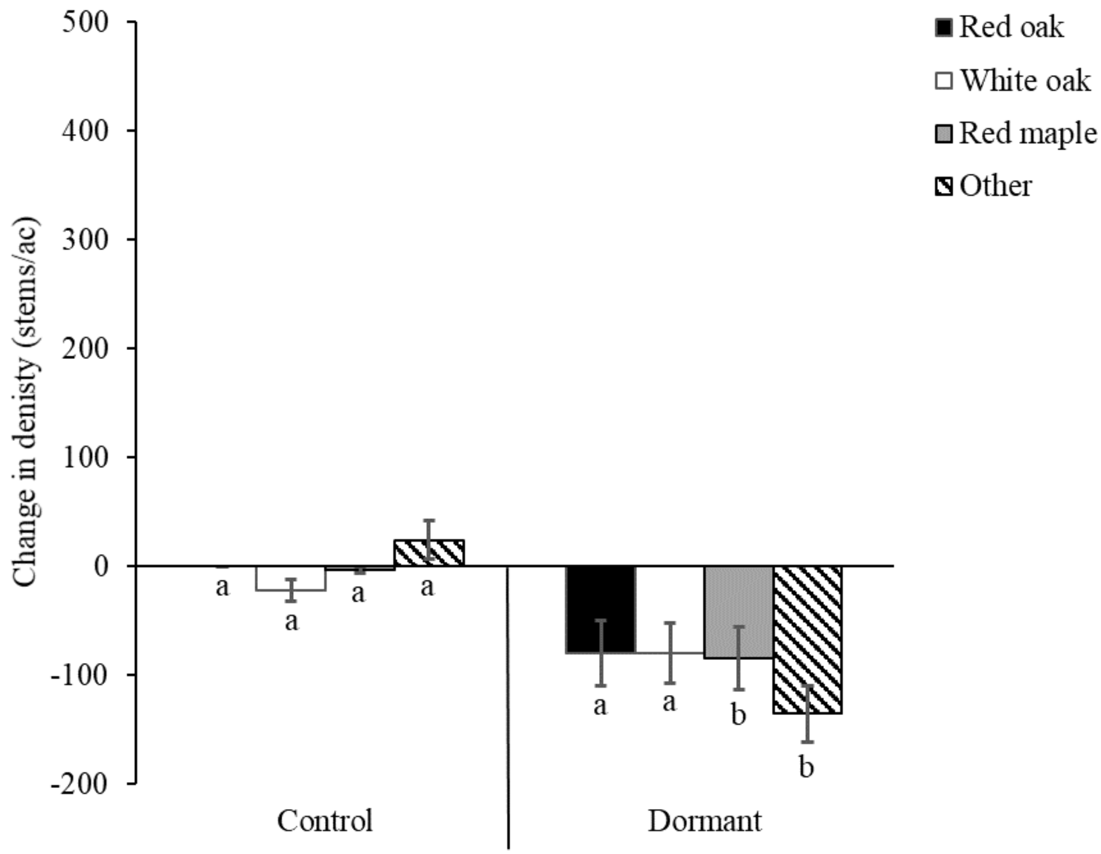

Figure 15. Mean two-year change (post2 minus pre1) (error bars indicate +/- SE) in sapling (dbh ≥ 0.6 and < 4.5 in.) density (stems/ac) for species groups (red oak: northern red oak, black oak; white oak: post oak white oak; hickory; and other: red maple, blackgum, black cherry, etc.) following implementation of a single dormant season prescribed fire and no-burn control treatment across Falling Water, Meadows Knob, and Pilot Knob sites in Ozark-St. Francis National Forest, AR. Different letters indicate significant difference (α = 0.05) for species group between treatments based on a Mann-Whitney test.

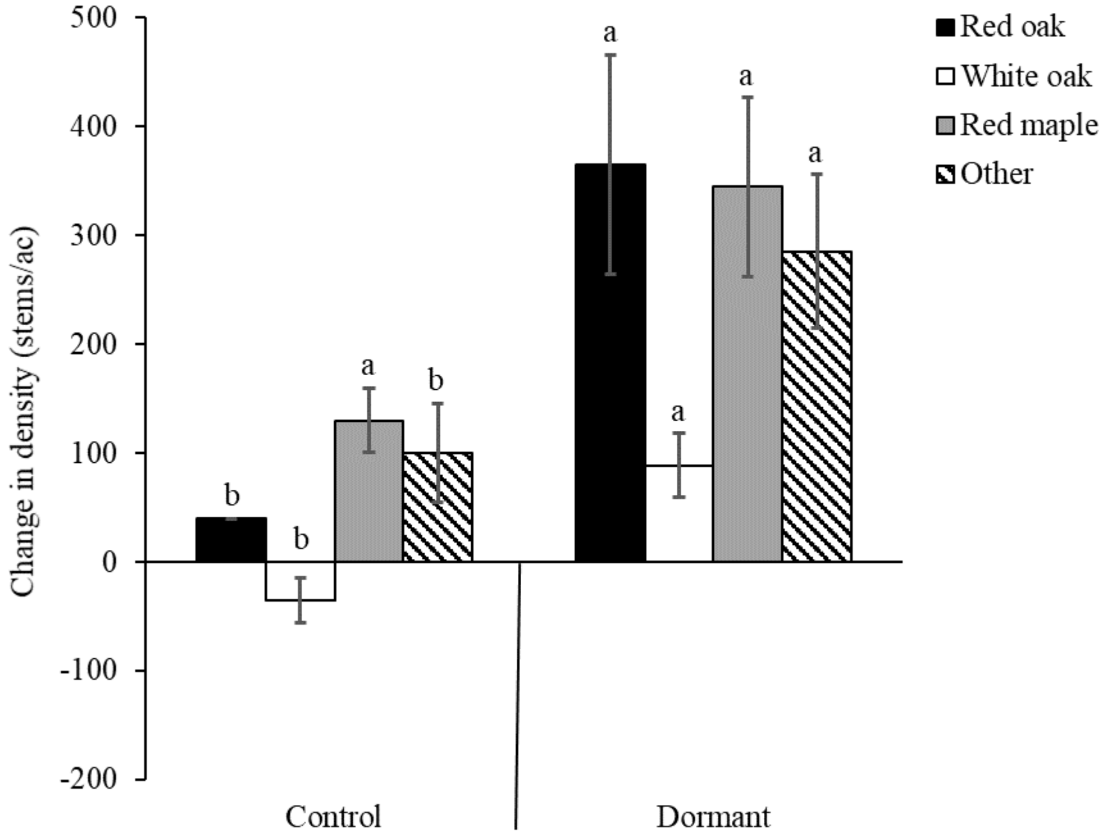

Figure 16. Mean twelve year change (post12 minus pre1) (+/- SE) in sapling (dbh ≥ 0.6 to < 4.5 in.) density (stems/ac) for species groups (red oak: northern red oak, black oak; white oak: post oak white oak; hickory; and other: red maple, blackgum, black cherry, etc.) following implementation of a single dormant prescribed fire and no-burn control treatment across Falling Water, Meadows Knob and Pilot Knob sites in Ozark-St. Francis National Forest, AR. Different letters indicate significant differences ($\alpha = 0.05$) in the change in density between treatments for species groups based on a Mann-Whitney test.

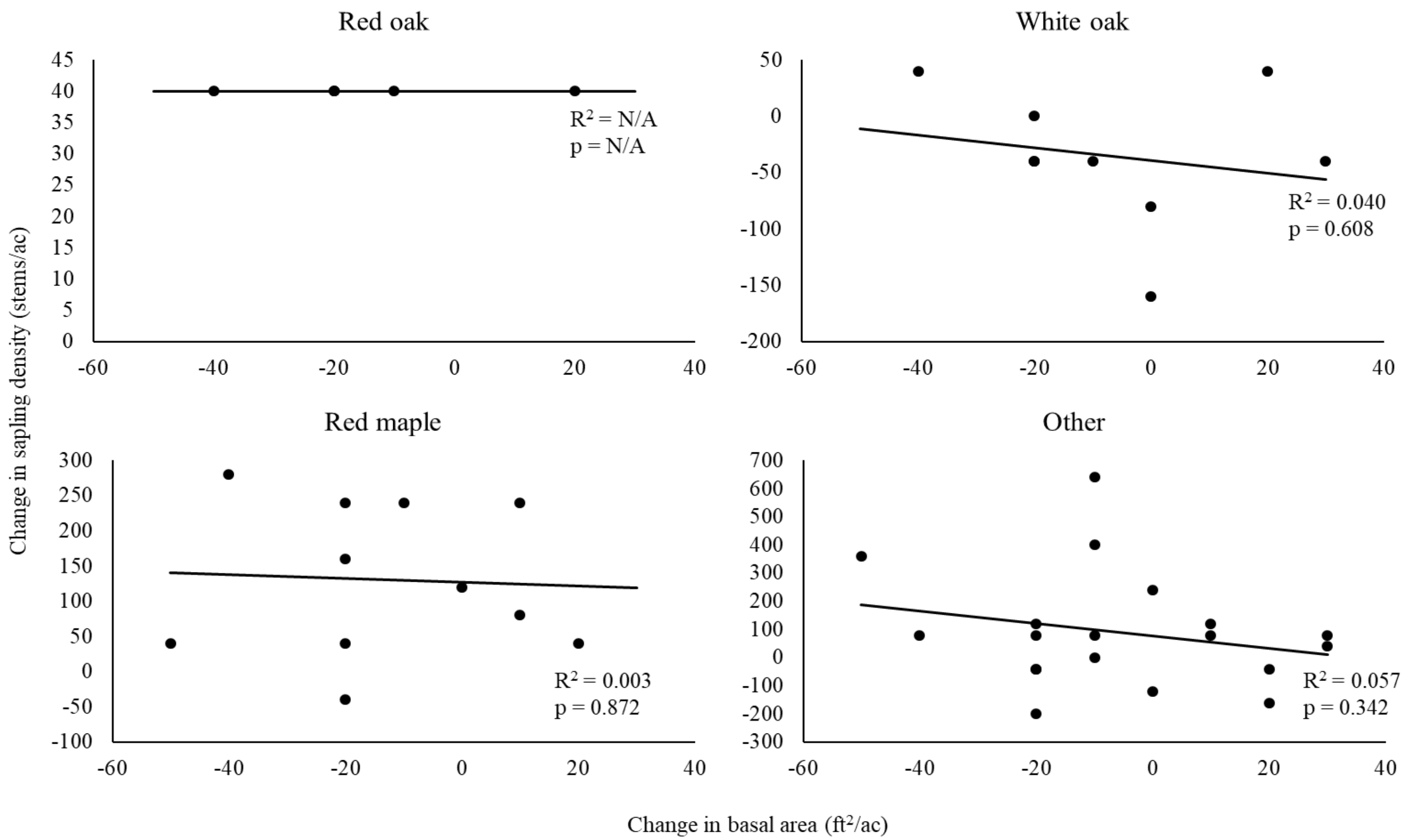

Figure 17. Cumulative change in basal area (ft^2/ac) of overstory (dbh $\geq$ 4.5 in.) compared to change in sapling (dbh $\geq$ 0.6 in. to < 4.5 in.) density (stems/ac) twelve years (post12 minus pre1) for all species groups (red oak: northern red oak, black oak; white oak: post oak, white oak; hickory; and other: red maple, blackgum, black cherry, etc.) by plot for control treatment across Falling Water, Meadows Knob, and Pilot Knob sites in Ozark-St. Francis National Forest, AR.

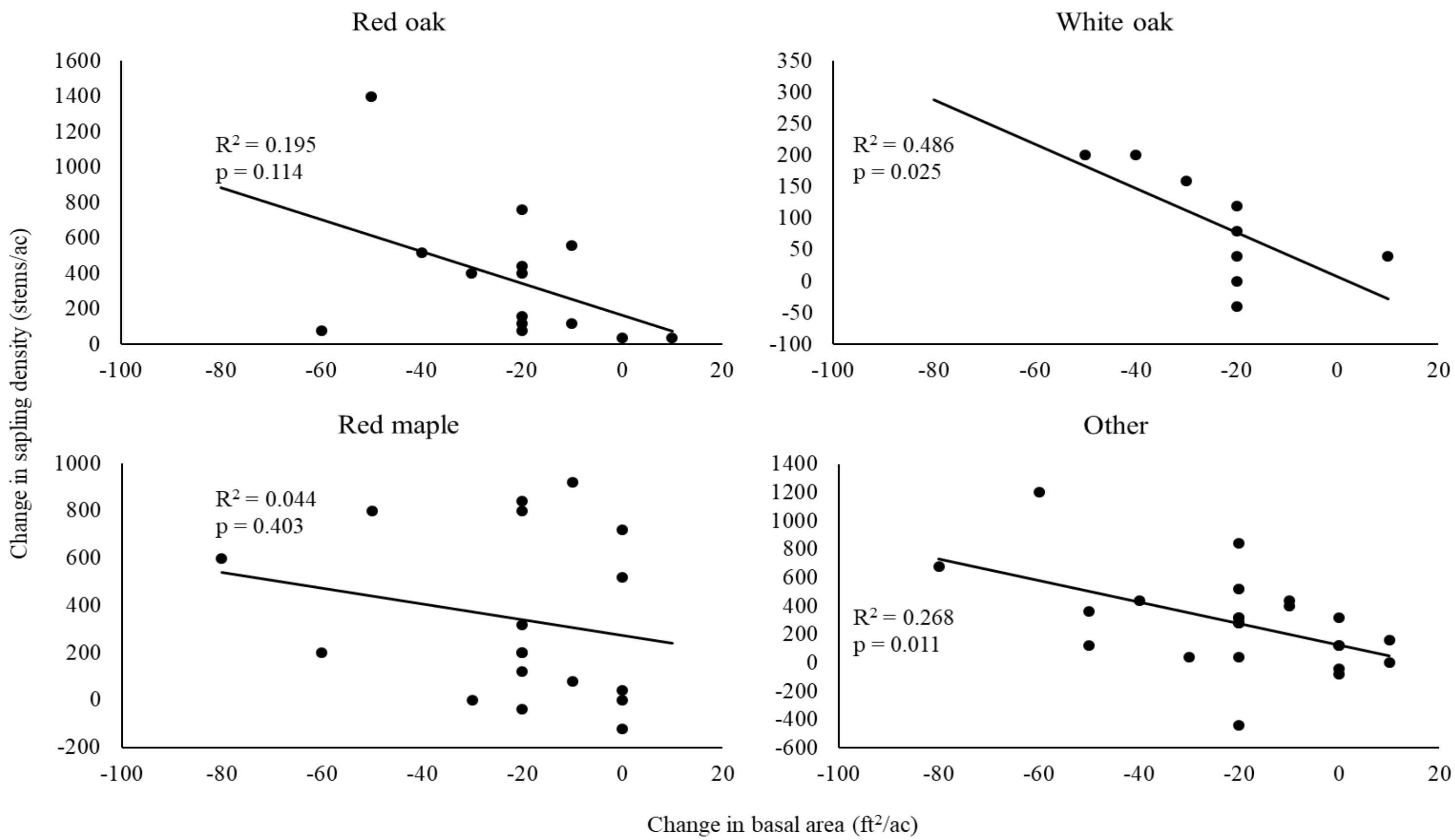

Figure 18. Cumulative change in basal area (ft^2/ac) of overstory (dbh ≥ 4.5 in.) compared to change in sapling (dbh ≥ 0.6 in. to < 4.5 in.) density (stems/ac) twelve years (post12 minus pre1) for all species groups (red oak: northern red oak, black oak; white oak: post oak, white oak; hickory; and other: red maple, blackgum, black cherry, etc.) by plot for dormant treatment across Falling Water, Meadows Knob, and Pilot Knob sites in Ozark-St. Francis National Forest, AR.

Height

Prior to treatment, height was not significantly different among species groups (Table 3). Initially, red maple had the greatest mean height while red oak was the shortest in the control. In the dormant treatment prior to prescribed fire implementation, red and white oak had numerically greater heights than red maple and other species, two years later the same trends were observed in both treatments. Red oak, white oak, and other species heights increased two years following prescribed fire in the dormant treatment, while white oak had a reduction of mean height. In the no-burn control after two years, shorter heights were observed for white oak and red maple groups while height for other species increased and red oak remained similar to pre-treatment heights.

Twelve years following treatment height was significantly different among species groups in the control ($p = 0.009$) and dormant ($p = 0.001$) treatments (Table 3). Red oak was significantly shorter than white oak, red maple, and other species in the no-burn control twelve years following treatment. In the dormant treatment, white oak was significantly shorter when compared to red oak, red maple, and other species. Although there was no significance, red oak did have sharp reduction in height with the increase of basal area in the control, and white oak had increases in height with the increases in basal area in the dormant treatment (Figures 19 and 20).

Table 3. Mean and standard deviation sapling (dbh ≥ 0.6 and < 4.5 in.) height (ft.) for species groups (red oak: northern red oak, black oak; white oak: post oak, white oak; red maple; and other: blackgum, black cherry, etc.) prior to (pre1) and two (post2) and twelve (post12) years following implementation of a single dormant season prescribed fire and no-burn control treatment across Falling Water, Meadows Knob, and Pilot Knob sites in Ozark-St. Francis National Forest, AR. Different letters among species groups within each treatment and column indicate significance (α = 0.05) based on Kruskal-Wallis and Bonferroni Procedure post-hoc tests.

		Height (ft.)		
Treatment	**Species**	Pre1	Post2	Post12
Control	Red oak	11.5[a] (3.0)	11.5[a] (3.0)	10.9[b] (3.3)
	White oak	17.5[a] (6.8)	14.0[a] (5.0)	16.1[a] (5.9)
	Red maple	22.8[a] (12.1)	20.8[a] (10.0)	15.1[a] (6.9)
	Other	16.4[a] (8.8)	17.0[a] (9.4)	16.3[a] (8.7)
Dormant	Red oak	18.2[a] (10.9)	18.6[a] (15.3)	16.8[a] (6.9)
	White oak	18.1[a] (10.2)	17.7[a] (10.3)	13.0[b] (4.3)
	Red maple	17.8[a] (7.9)	23.1[a] (15.2)	18.0[a] (7.7)
	Other	14.7[a] (6.4)	17.0[a] (7.4)	16.9[a] (7.7)

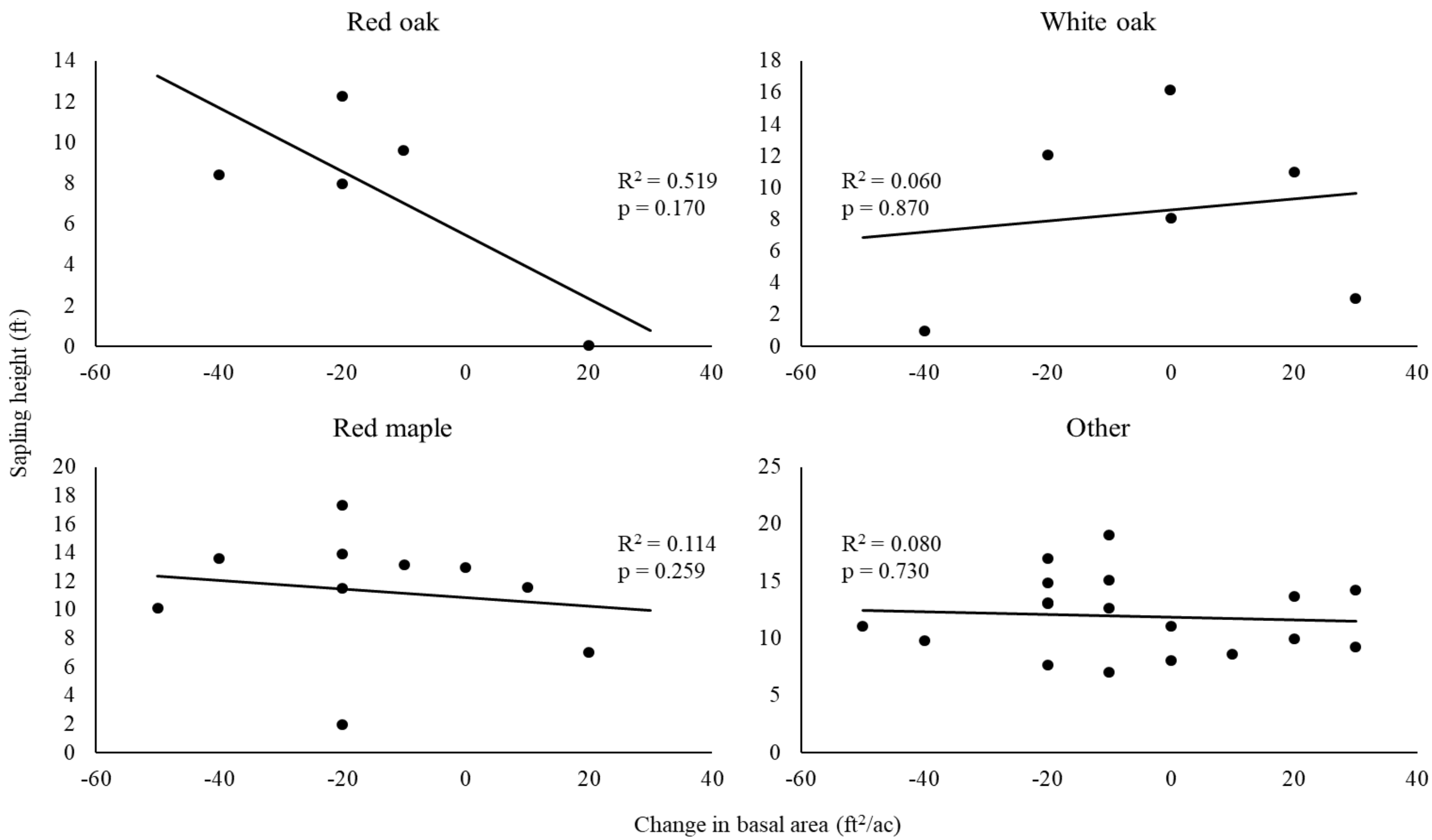

Figure 19. Cumulative change in basal area (ft^2/ac) of overstory (dbh ≥ 4.5 in.) compared to mean sapling (dbh ≥ 0.6 in. to < 4.5 in.) height (ft.) twelve years (post12 minus pre1) for all species groups (red oak: northern red oak, black oak; white oak: post oak, white oak; hickory; and other: red maple, blackgum, black cherry, etc.) by plot for control treatment across Falling Water, Meadows Knob, and Pilot Knob sites in Ozark-St. Francis National Forest, AR.

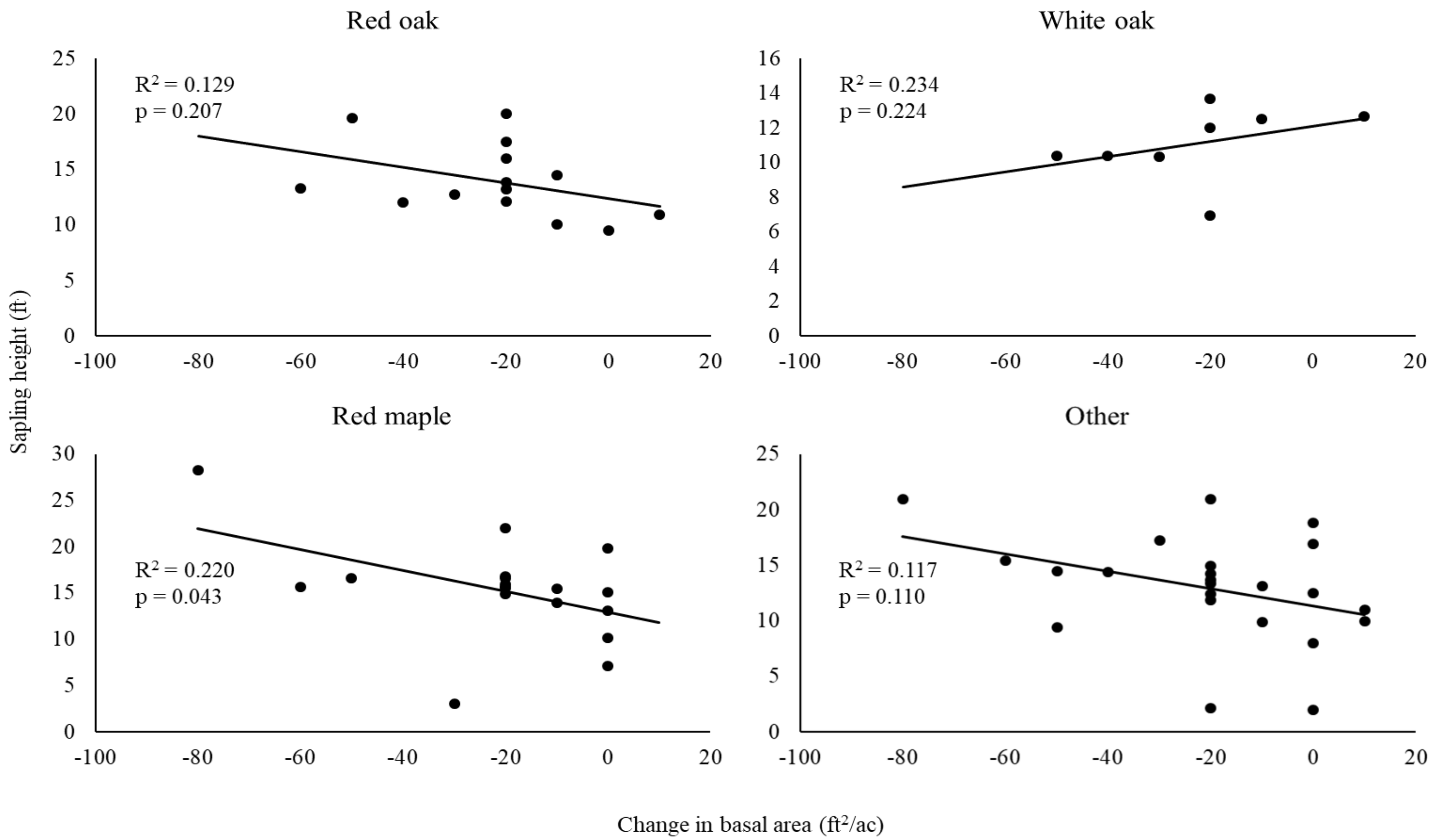

Figure 20. Cumulative change in basal area (ft^2/ac) of overstory (dbh ≥ 4.5 in.) compared to mean sapling (dbh ≥ 0.6 in. to < 4.5 in.) height (ft.) twelve years (post12 minus pre1) for all species groups (red oak: northern red oak, black oak; white oak: post oak, white oak; hickory; and other: red maple, blackgum, black cherry, etc.) by plot for dormant treatment across Falling Water, Meadows Knob, and Pilot Knob sites in Ozark-St. Francis National Forest, AR.

Diameter

Prior to the treatment and two years following, dbh did not significantly differ among species groups in the no-burn control. After twelve years in the control ($p = 0.001$) dbh significantly differed among species (Table 4). In the dormant treatment prior to the prescribed fire, dbh among species was significantly different ($p = 0.041$), but Bonferroni post-hoc comparisons test failed to reveal any significant differences among species. Two years after prescribed fire, dbh significantly differed ($p = 0.004$) among species. Red oak had greater dbh than other species. Twelve years after the burn, dbh was similar among species ($p = 0.349$) with dbh ranging from 1.2 to 1.3 in. (Table 4).

Prior to and two years following in the control, there were no significant differences in basal area among species. Twelve years following treatment, in the no-burn control ($p = 0.001$) white oak had a greater basal area than red maple and other had greater basal area than red maple. In the dormant treatment, prior to the burn, basal area significantly differed ($p = 0.045$), but post-hoc test did not have significant values. Two years following prescribed fire in the dormant treatment basal area, significantly differed ($p = 0.004$) among species with red oak having greater basal area than other ($p = 0.015$). Twelve years after treatment did not have significantly different basal area among species (Table 5).

Table 4. Mean and standard deviation for sapling (dbh ≥ 0.6 to < 4.5 in) dbh (in.) for species groups (red oak: northern red oak, black oak; white oak: post oak, white oak; red maple; and other: blackgum, black cherry, etc.) prior to (pre1) and two (post2) and twelve years (post12) following implementation of a single dormant season prescribed fire and no-burn control treatment across Falling Water, Meadows Knob, and Pilot Knob sites in Ozark-St. Francis National Forest, AR. Different letters among species groups within treatment in columns indicate significance ($\alpha = 0.05$) based on Kruskal-Wallis and Bonferroni Procedure post-hoc tests.

		DBH (in.)		
Treatment	**Species**	Pre1	Post2	Post12
Control	Red oak	0.9^{a} (0.2)	1.0^{a} (0.2)	1.0^{ab}(0.5)
	White oak	2.4^{a} (1.2)	2.3^{a} (1.0)	2.2^{a} (1.6)
	Red maple	2.2^{a} (1.4)	2.3^{a} (1.5)	1.2^{b} (0.8)
	Other	1.8^{a} (1.0)	1.7^{a} (1.0)	1.5^{a} (0.9)
Dormant	Red oak	2.0^{a} (1.1)	2.1^{a} (0.9)	1.3^{a} (0.7)
	White oak	2.2^{a} (1.3)	2.3^{ab}(1.3)	1.3^{a} (0.7)
	Red maple	1.8^{a} (1.0)	1.7^{ab}(1.1)	1.2^{a} (1.1)
	Other	1.5^{a} (0.9)	1.5^{b} (0.9)	1.3^{a} (0.8)

Table 5. Mean sapling (dbh ≥ 0.6 to < 4.5 in.) basal area (ft^2/ac) for species groups (red oak: northern red oak, black oak; white oak: post oak, white oak; red maple; and other: blackgum, black cherry, etc.) prior to (pre1) and two (post2) and twelve years (post12) following implementation of a single dormant season prescribed fire and no-burn control treatment across Falling Water, Meadows Knob, and Pilot Knob sites in Ozark-St. Francis National Forest, AR. Different letters among species groups within treatment in columns indicate significance (α = 0.05) based on Kruskal-Wallis and Bonferroni Procedure post-hoc tests.

		Basal area (ft^2/ac)		
Treatment	**Species**	Pre1	Post2	Post12
Control	Red oak	0.00^{a}	0.01^{a}	0.01^{ab}
	White oak	0.04^{a}	0.03^{a}	0.04^{a}
	Red maple	0.04^{a}	0.04^{a}	0.01^{b}
	Other	0.02^{a}	0.02^{a}	0.02^{b}
Dormant	Red oak	0.03^{a}	0.03^{a}	0.01^{a}
	White oak	0.03^{a}	0.04^{ab}	0.01^{a}
	Red maple	0.02^{a}	0.02^{ab}	0.01^{a}
	Other	0.02^{a}	0.02^{b}	0.01^{a}

Topkill & Sprouting Response

To compare the differences among species in percent topkill, percent resprout, and sprouts per rootstock, a Kruskal-Wallis and Bonferroni post-hoc tests were conducted. Percent topkill and resprout among the species groups were not significantly different in the dormant treatment two years after treatment. Although there were no significant differences, red oak (93%) had a numerically greater occurrence of topkill, while white oak (63%) had a lower percentage of topkill, and red maple and other species (~74%) were similar. Nearly all (> 99 %) of red oak rootstocks resprouted when topkilled by the fire two years following treatment. Two years ($p = 0.001$) following treatment, red oak had a greater number of sprouts per rootstock than other species. Red maple also had a greater number of sprouts per rootstock than other species two years after prescribed fire in the dormant treatment. At year twelve ($p < 0.001$) the distribution of sprouts per rootstock was also differed among species groups. Red maple number of sprouts per rootstock was significant compared to other species with a greater mean of sprouts. White oak also had a greater number of sprouts per rootstock than other species at year twelve in the dormant treatment (Table 6).

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Table 6. Mean sapling (dbh ≥ 0.6 to < 4.5 in.) percent topkill and resprout two years (post2) following treatments and sprout density (sprouts/rootstock) two (post2) and twelve (post12) years for species groups (red oak: northern red oak, black oak; white oak: post oak, white oak; red maple; and other: blackgum, black cherry, etc.) across Falling Water, Meadows Knob, and Pilot Knob in Ozark-St. Francis National Forest, AR. Different letters indicate significance (α = 0.05) among species groups in dormant treatment in columns based on Kruskal-Wallis and Bonferroni Procedure post-hoc tests.

	Topkill (%)	**Resprout (%)**	**Sprouts/ rootstock**	
Species	Post2	Post2	Post2	Post12
Red oak	93[a]	100[a]	8[a]	1[ab]
White oak	63[a]	75[a]	7[ab]	2[a]
Red maple	74[a]	79[a]	7[a]	2[a]
Other	73[a]	82[a]	3[b]	1[b]

Seedlings

Density & Composition

Initially, the majority of stems in the seedling strata was composed of other and red maple, with oak species having lower densities in the control (red maple and other: 1,940 stems/ac; oak: 405 stems/ac) and dormant (red maple and other: 1,206 stems/ac; oak: 545 stems/ac) treatment (Figure 21). Two years after prescribed fire, other species ($p = 0.021$) were significantly different between control and dormant treatment (Figure 22). At year twelve, other species (1,438 stems/ac) comprised the majority of seedlings in the control, and although red and white oak (1,360 stems/ac) had increases in the changes in density those groups still had lesser values than other species. Oak (1,093 stems/ac) density was reduced by year twelve and red maple and other (3,822 stems/ac) species were the majority of composition in the dormant treatment. Twelve years following treatment there was no significant difference between the no burn control and the dormant treatment for red oak despite numerically large increases. Other ($p = 0.001$) species was the only group that prescribed fire had a significant effect on between the no burn control and the dormant treatment at year twelve, despite increases of red maple and white oak (Figure 23). Oak seedling changes in density at year twelve increased with the increase in overstory basal area, while red maple and other had slight reductions in the control (Figure 24). Red maple was the only species group to experience reductions in density with the increase of overstory basal area in the dormant treatment (Figure 25).

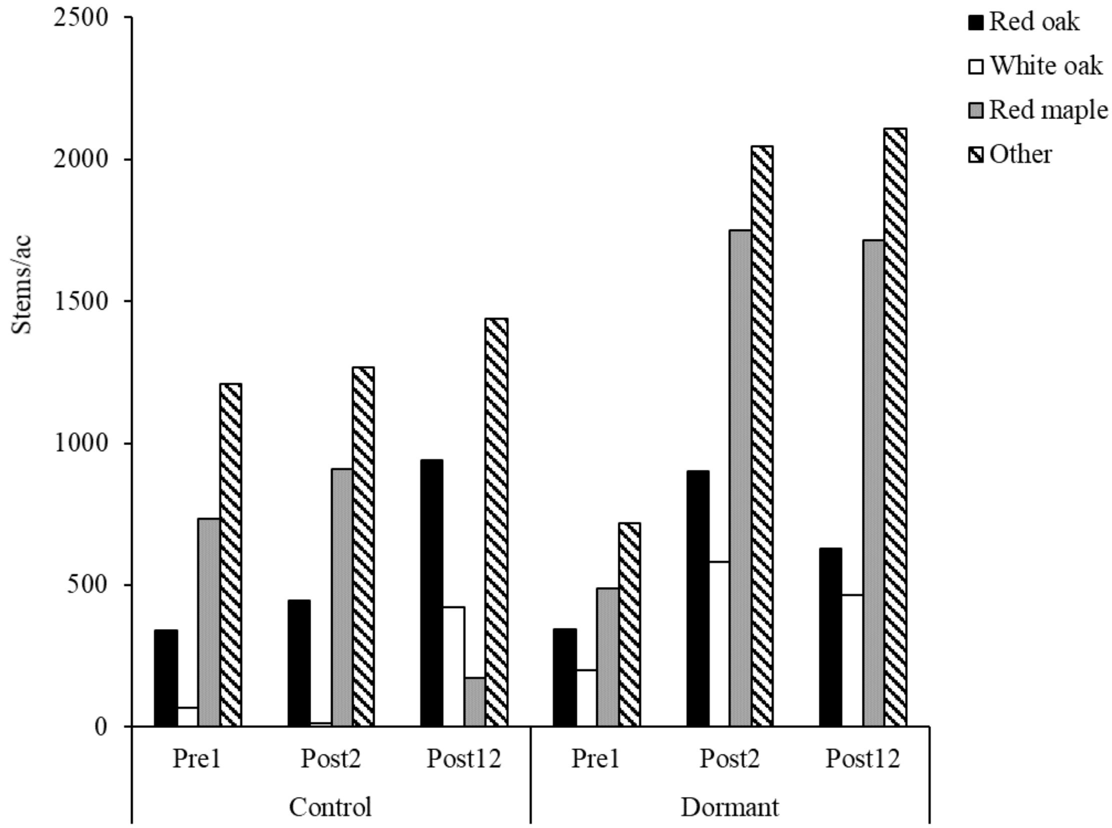

Figure 21. Mean density (stems/ac) of seedlings (dbh < 0.6 in. and ≥ 2 ft.) for species groups (red oak: northern red oak, black oak; white oak: post oak, white oak; red maple; and other: blackgum, black cherry, etc.) prior to (pre1) and two (post2) and 12 years (post12) following implementation of dormant season prescribed fire and a no-burn control treatments at the Falling Water, Meadows Knob, and Pilot Knob sites in Ozark-St. Francis National Forest, AR.

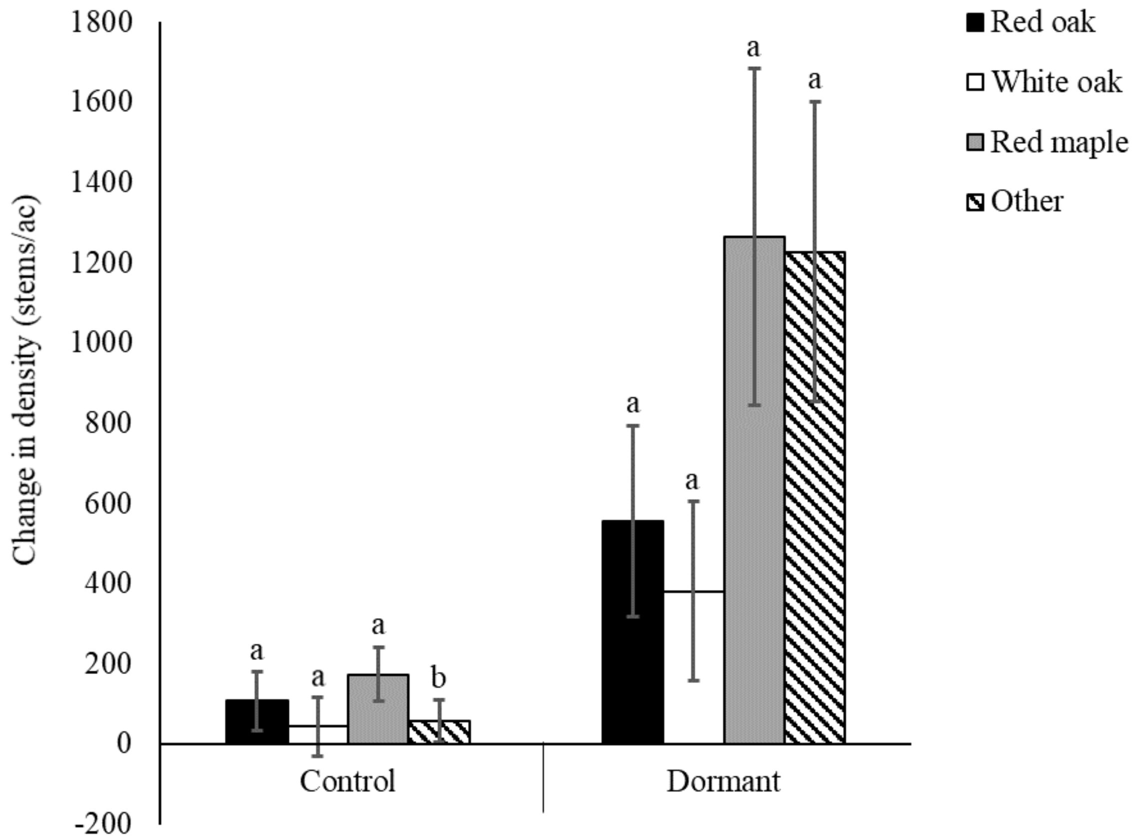

Figure 22. Mean two-year change (post2 minus pre1) (error bars indicate +/- SE) in seedling (dbh < 0.6 in. and ≥ 2.0 ft.) density (stems/ac) for species groups (red oak: northern red oak, black oak; white oak: post oak white oak; hickory; and other: red maple, blackgum, black cherry, etc.) following implementation of a single dormant season prescribed fire and no-burn control treatment across Falling Water, Meadows Knob, and Pilot Knob sites in Ozark-St. Francis National Forest, AR. Different letter indicate significant difference (α = 0.05) for species group between treatments based on a Mann-Whitney test.

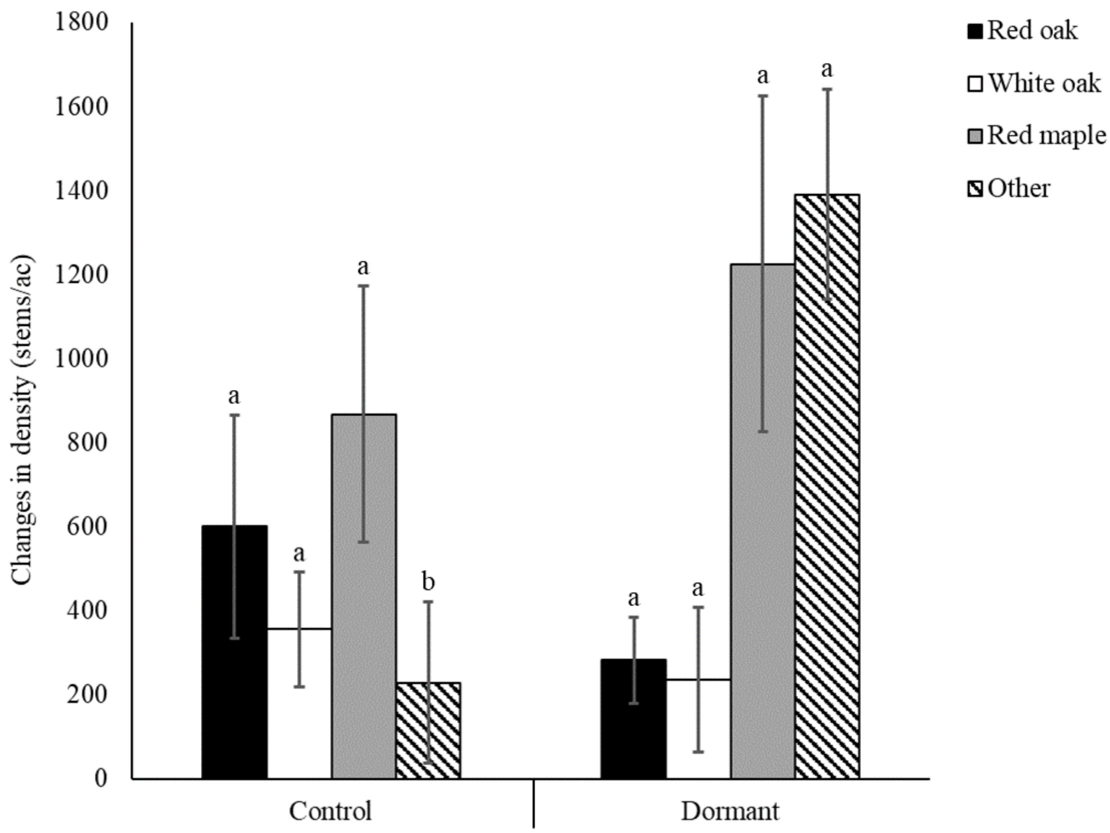

Figure 23. Mean twelve-year change (post12 minus pre1) (error bars indicate +/- SE) in seedling (dbh < 0.6 in. and ≥ 2.0 ft.) density (stems/ac) for species groups (red oak: northern red oak, black oak; white oak: post oak white oak; hickory; and other: red maple, blackgum, black cherry, etc.) following implementation of a single dormant season prescribed fire and no-burn control treatment across Falling Water, Meadows Knob, and Pilot Knob sites in Ozark-St. Francis National Forest, AR. Different letter indicate significant difference (α = 0.05) for species group between treatments based on a Mann-Whitney test.

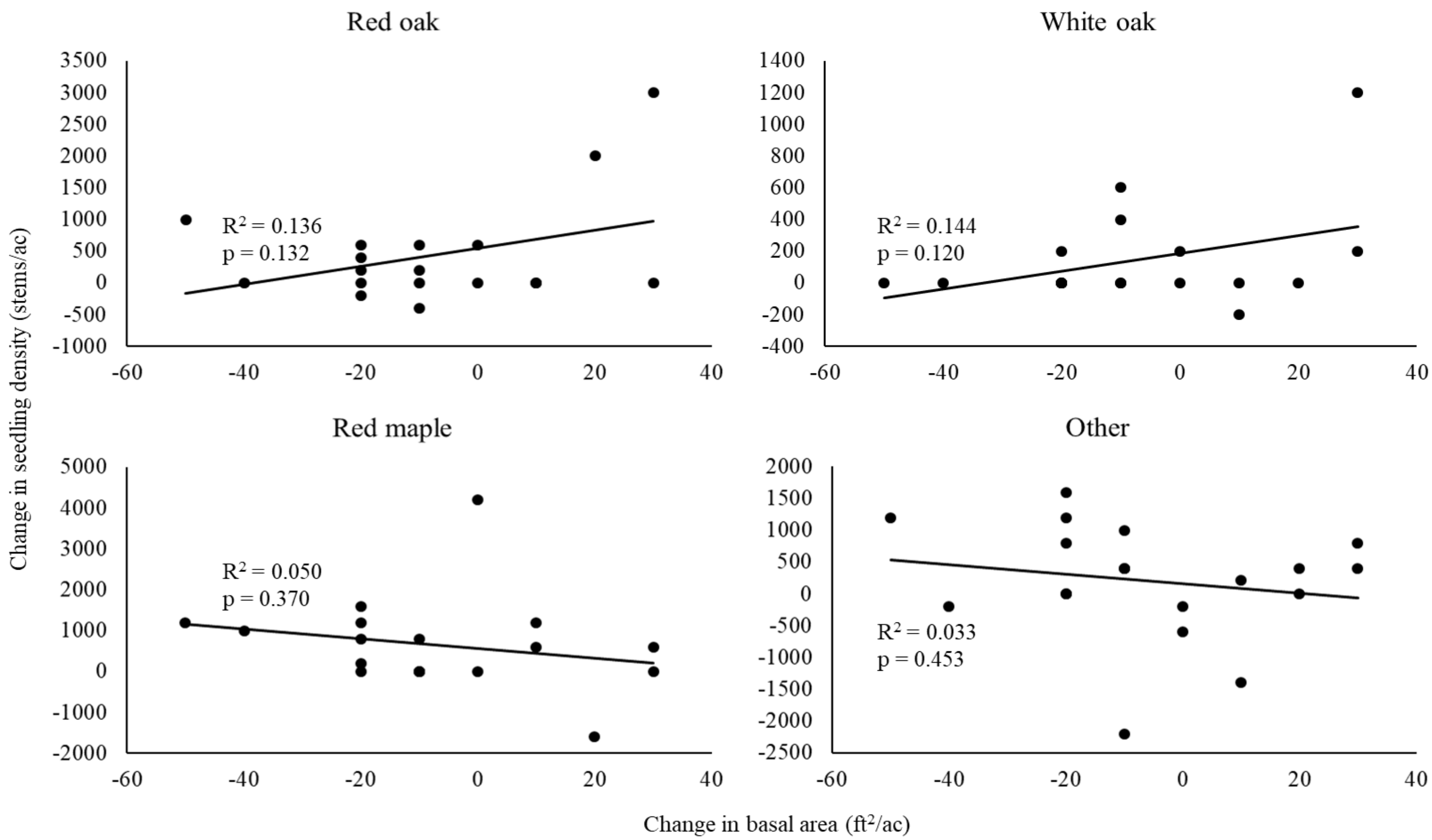

Figure 24. Cumulative change in basal area (ft^2/ac) of overstory (dbh ≥ 4.5 in.) compared to changes in seedling (dbh < 0.6 in. and ≥ 2.0 ft.) density (stems/ac) twelve years (post12 minus pre1) for all species groups (red oak: northern red oak, black oak; white oak: post oak, white oak; hickory; and other: red maple, blackgum, black cherry, etc.) by plot for control treatment across Falling Water, Meadows Knob, and Pilot Knob sites in Ozark-St. Francis National Forest, AR.

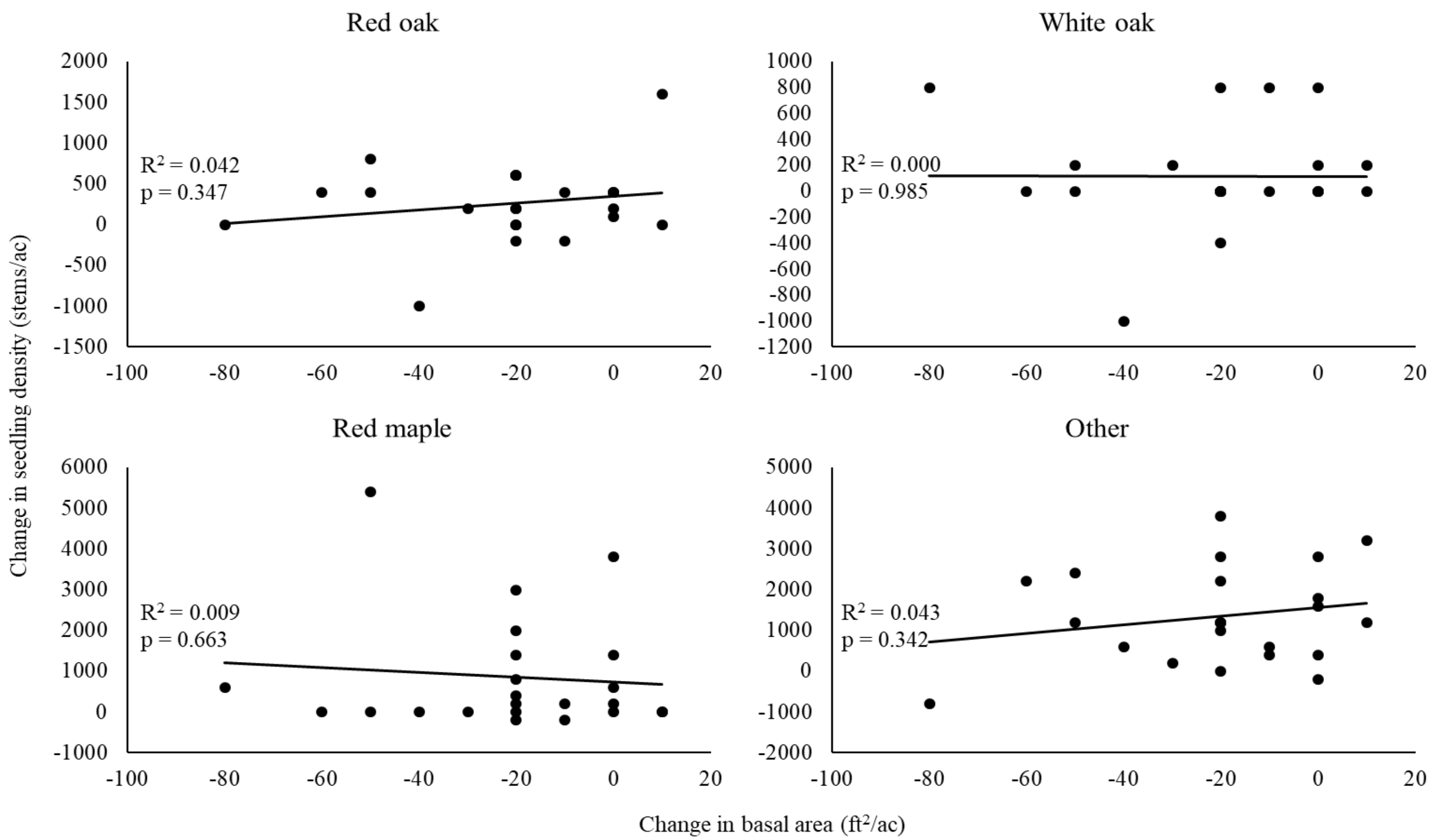

Figure 25. Cumulative change in basal area (ft^2/ac) of overstory (dbh ≥ 4.5 in.) compared to changes in seedling (dbh < 0.6 in. and ≥ 2.0 ft.) density (stems/ac) twelve years (post12 minus pre1) for all species groups (red oak: northern red oak, black oak; white oak: post oak, white oak; hickory; and other: red maple, blackgum, black cherry, etc.) by plot for dormant treatment across Falling Water, Meadows Knob, and Pilot Knob sites in Ozark-St. Francis National Forest, AR.

Height

Prior to the prescribed fire treatment, seedling height was significantly different among species groups in the control ($p < 0.001$) and the dormant ($p = 0.014$) treatment. Other species (3.4 ft.) had significantly greater heights prior to treatment in the control, while white oak (0.6 ft.) had the lowest (Table 7). In the no-burn control there was significant differences in height both two ($p < 0.001$) and twelve ($p = 0.004$) years following treatment. Two and twelve years after prescribed fire, red maple (3.4 ft.; 4.0 ft.) and other (3.5 ft.; 4.0 ft.) had greater heights than white oak (0.9 ft.; 2.3 ft.). In the dormant treatment ($p = 0.014$) prior to prescribed fire implementation, other (3.1 ft.) species had greater heights than that of red oak (1.4 ft.). Two years after the burn in the dormant treatment ($p = 0.012$) other (3.3 ft.) species had greater height than red oak (1.7 ft.). At year twelve mean height had no significant difference among species groups in the dormant ($p = 0.104$) treatment. Red maple (4.6 ft.) and other (4.1 ft.) did have numerically greater heights, but red oak did have height growth of 135% from year two to year twelve, allowing an increase of competitiveness (Table 7). A simple linear regression was used to significantly predict if changes in basal area had an effect on mean seedling height. Although there was no significance, all species groups observed had increases in height with the increase of overstory basal area in the control twelve years after treatment (Figure 26). In the dormant treatment, red maple had an increase in height with the increase in overstory basal area, while other and white oak had decreases (Figure 27).

Table 7. Mean and standard deviation seedling (< 0.6 in and ≥ 2 ft.) height (ft.) prior to (pre1) two years (post2) and twelve years (post12) for species groups (red oak: northern red oak, black oak; white oak: post oak, white oak; red maple; and other: blackgum, black cherry, etc.) following implementation of a single dormant season prescribed fire and no-burn control treatment across Falling Water, Meadows Knob, and Pilot Knob sites in Ozark-St. Francis National Forest, AR. Different letters among species groups within treatment indicate significance (α = 0.05) in columns based on Kruskal-Wallis and Bonferroni Procedure post-hoc tests.

		Height (ft.)		
Treatment	**Species**	Pre1	Post2	Post12
Control	Red oak	2.1^{ab} (1.9)	2.8^{ab} (1.7)	3.6^{ab}(1.8)
	White oak	0.6^{b} (1.1)	0.9^{b} (1.4)	2.3^{b} (1.8)
	Red maple	2.3^{ab} (1.7)	3.4^{b} (1.5)	4.0^{a} (1.0)
	Other	3.4^{a} (1.0)	3.5^{a} (1.1)	4.0^{a} (1.0)
Dormant	Red oak	1.4^{b} (1.9)	1.7^{b} (1.6)	4.0^{a} (1.8)
	White oak	1.4^{ab} (1.7)	1.9^{ab} (1.9)	3.3^{a} (1.6)
	Red maple	1.9^{ab} (2.0)	3.1^{ab} (1.9)	4.1^{a} (2.2)
	Other	3.1^{a} (1.4)	3.3^{a} (1.3)	4.6^{a} (1.1)

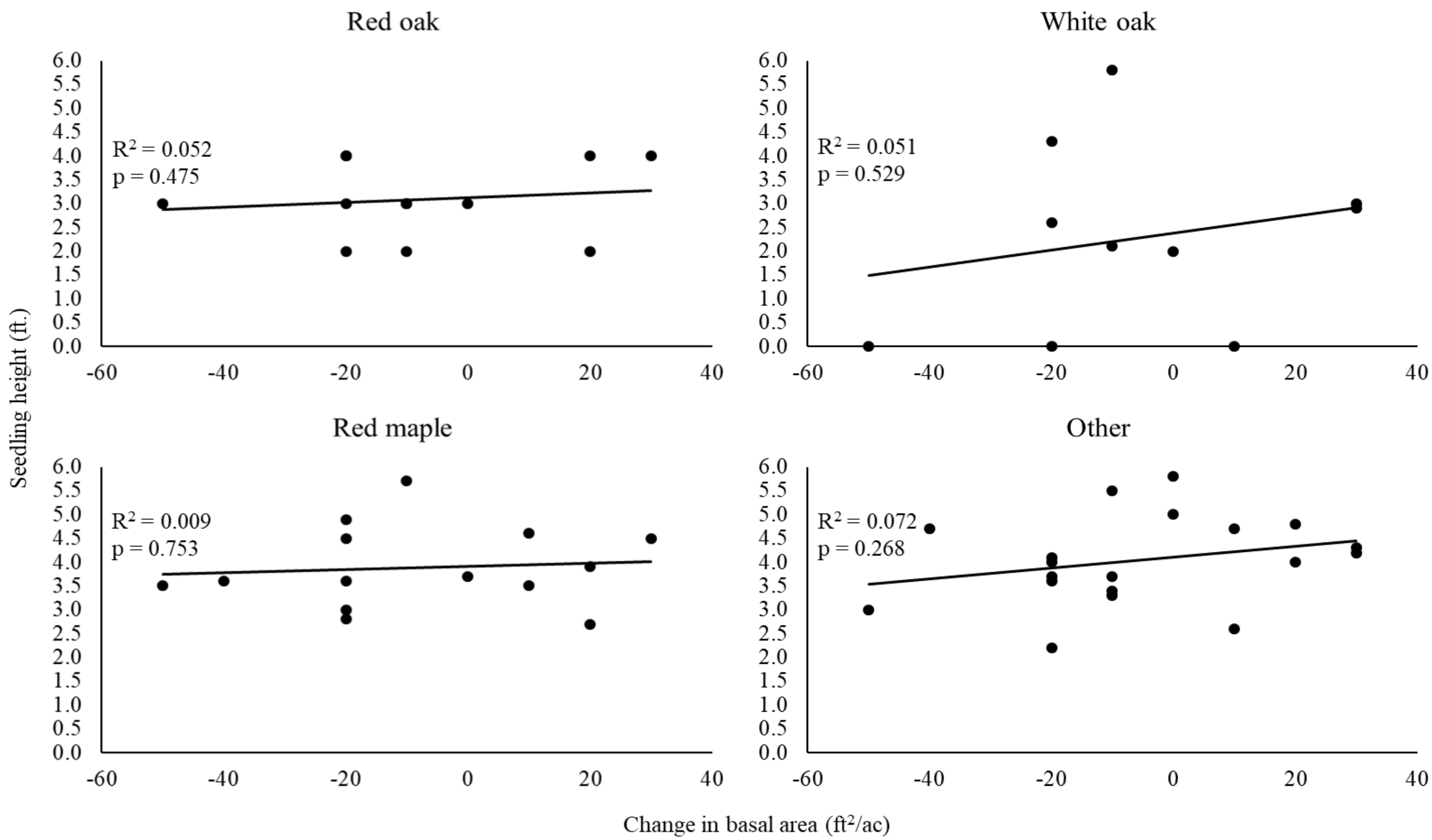

Figure 26. Cumulative change in basal area (ft^2/ac) of overstory (dbh ≥ 4.5 in.) compared to mean seedling (dbh < 0.6 to ≥ 2.0 ft.) height (ft.) twelve years for all species groups (red oak: northern red oak, black oak; white oak: post oak, white oak; hickory; and other: red maple, blackgum, black cherry, etc.) by plot for control treatment across Falling Water, Meadows Knob and Pilot Knob sites in Ozark-St. Francis National Forest, AR.

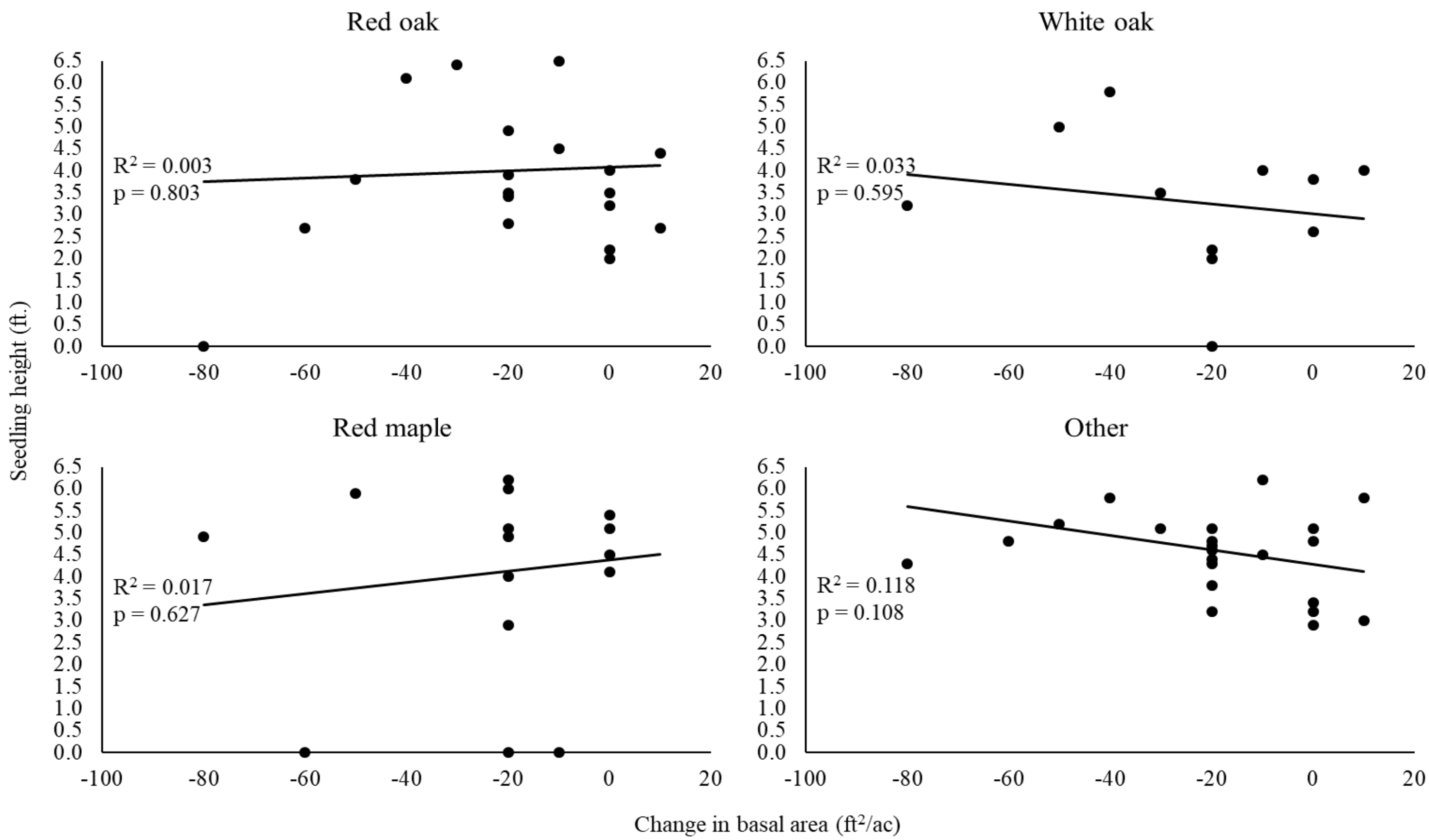

Figure 27. Cumulative change in basal area (ft^2/ac) of overstory (dbh ≥ 4.5 in.) compared to mean seedling (dbh < 0.6 to ≥ 2.0 ft.) height (ft.) twelve years for all species groups (red oak: northern red oak, black oak; white oak: post oak, white oak; hickory; and other: red maple, blackgum, black cherry, etc.) by plot for dormant treatment across Falling Water, Meadows Knob and Pilot Knob sites in Ozark-St. Francis National Forest, AR.

Basal Diameter

Prior to the implementation of the dormant season prescribed fire, there was a significant difference ($p = 0.003$) among species groups in the no burn control. White oak basal diameter was significantly less ($p = 0.002$) than that of the other group (0.4 in) in the control. The post-hoc test once again found significant ($p = 0.021$) basal diameters among white oak (0.1 in.) and other (0.4 in.) in the control. Basal diameter did not significantly differ among species groups twelve years following treatment ($p = 0.295$).

In the dormant treatment, no significant differences ($p = 0.270$) were found among any of the species groups for basal diameter, prior to treatment (Table 8). Two ($p = 0.530$) and twelve ($p = 0.579$) years after the burn, in the dormant treatment, there was no basal diameter significance was found. Although there was a lack of significance at year twelve in the dormant treatment, red oak did have numerically larger mean basal diameter growth to red maple and was similar to the basal diameters of the other species group (Table 8). Simple linear regression analysis found no significant results in both the no-burn control and dormant treatments for a change in overstory basal area effect on mean seedling basal diameter. In the no-burn control twelve years after treatment, white oak had a sharp increase of basal diameter when the change in overstory basal area was greater than -30 ft^2/ac (Figure 28). In the dormant treatment all species groups experienced reductions in basal diameter with the increase of overstory basal area (Figure 29).

Table 8. Mean and standard deviation seedling (dbh < 0.6 in. and ≥ 2 ft.) basal diameter (in.) prior to (pre1) two years (post2) and twelve years (post12) for species groups (red oak: northern red oak, black oak; white oak: post oak, white oak; red maple; and other: blackgum, black cherry, etc.) following implementation of a single dormant season prescribed fire and no-burn control treatment across Falling Water, Meadows Knob, and Pilot Knob sites in Ozark-St. Francis National Forest, AR. Different letters among species groups within treatment indicate significance (α=0.05) in columns based on Kruskal-Wallis and Bonferroni Procedure post-hoc tests.

		Basal Diameter (in)		
Treatment	**Species**	Pre1	Post2	Post12
Control	Red oak	0.3^{ab}(0.2)	0.4^{ab}(0.2)	0.4^{a} (0.2)
	White oak	0.1^{b} (0.1)	0.1^{b} (0.1)	0.3^{a} (0.2)
	Red maple	0.3^{ab}(0.2)	0.3^{ab}(0.2)	0.4^{a} (0.2)
	Other	0.4^{a} (0.2)	0.4^{a} (0.2)	0.4^{a} (0.2)
Dormant	Red oak	0.3^{a} (0.2)	0.2^{a} (0.2)	0.5^{a} (0.2)
	White oak	0.3^{a} (0.3)	0.3^{a} (0.2)	0.4^{a} (0.2)
	Red maple	0.2^{a} (0.2)	0.3^{a} (0.2)	0.4^{a} (0.2)
	Other	0.4^{a} (0.2)	0.3^{a} (0.2)	0.5^{a} (0.2)

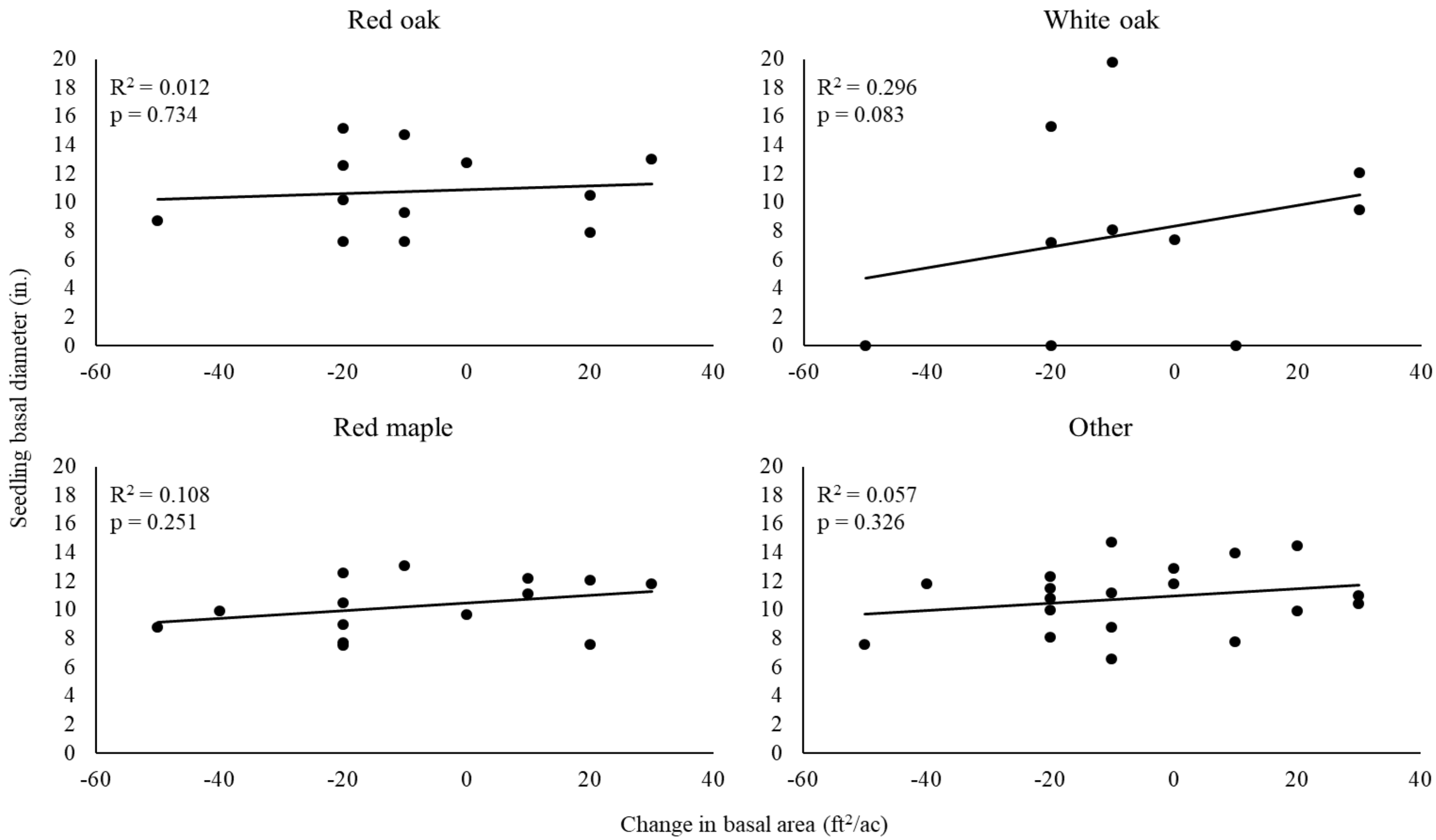

Figure 28. Cumulative change in basal area (ft^2/ac) of overstory (dbh ≥ 4.5 in.) compared to mean seedling (dbh < 0.6 and ≥ 2.0 ft.) basal diameter (in.) twelve years for all species groups (red oak: northern red oak, black oak; white oak: post oak, white oak; hickory; and other: red maple, blackgum, black cherry, etc.) by plot for control treatment across Falling Water, Meadows Knob and Pilot Knob sites in Ozark-St. Francis National Forest, AR.

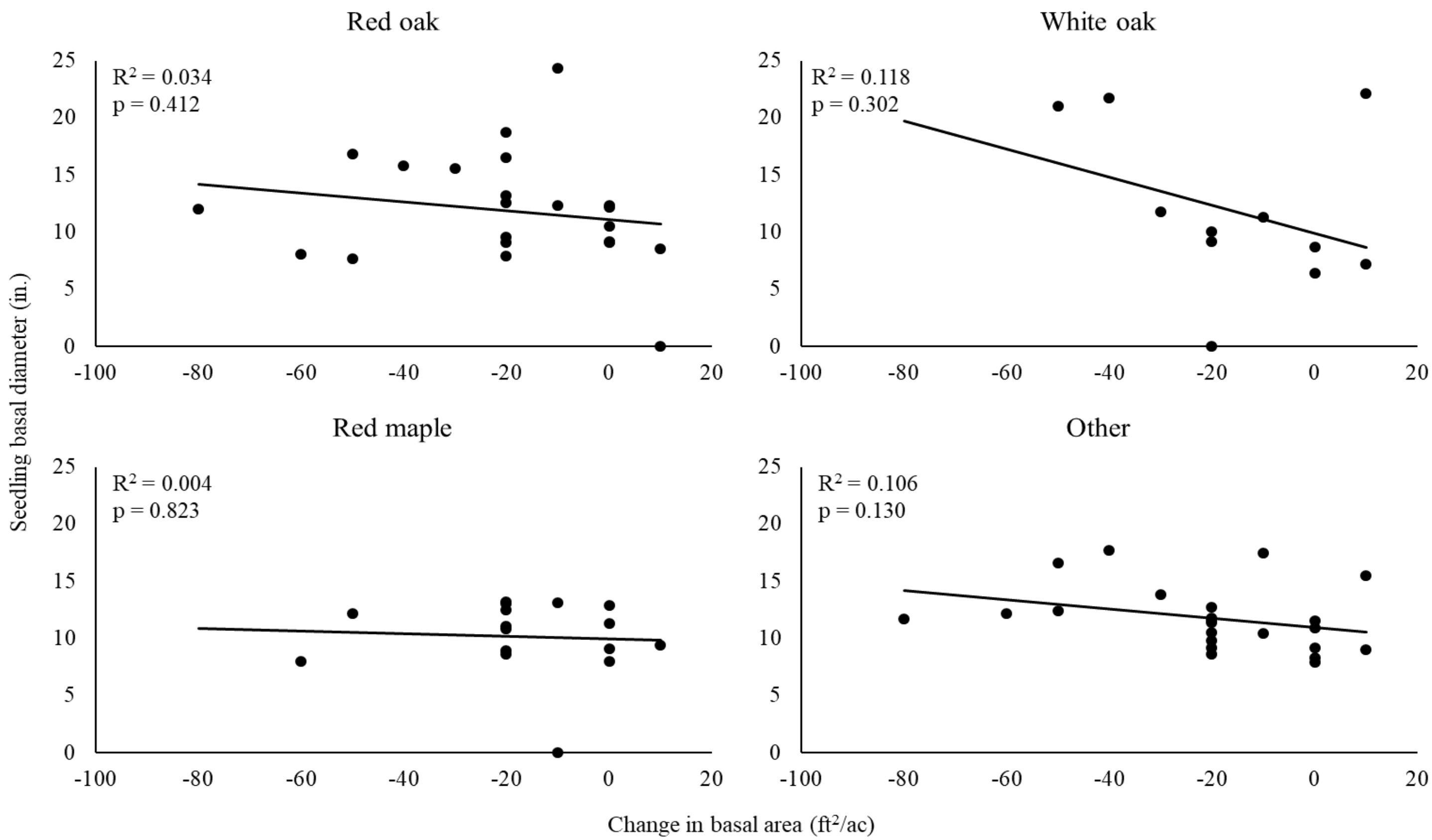

Figure 29. Cumulative change in basal area (ft^2/ac) of overstory (dbh ≥ 4.5 in.) compared to mean seedling (dbh < 0.6 and ≥ 2.0 ft.) basal diameter (in.) twelve years for all species groups (red oak: northern red oak, black oak; white oak: post oak, white oak; hickory; and other: red maple, blackgum, black cherry, etc.) by plot for dormant treatment across Falling Water, Meadows Knob and Pilot Knob sites in Ozark-St. Francis National Forest, AR.

Topkill & Sprouting Response

Tagged seedling variables including percent topkill, percent resprout, sprouts per rootstock, and dominant sprout basal diameter and height two years after prescribed fire in the dormant treatment was used. All species groups experienced ~100% topkill two years after treatment. Red oak (84%) had a greater percentage of resprout ($p = 0.030$) than red maple (65%) in the dormant treatment (Table 9). Two years after the implementation of the dormant season prescribed fire, white oak had greater sprouts per root stock than other ($p = 0.012$), while there was a significant difference among red maple and other species ($p = 0.012$). In the dormant treatment at year twelve red maple had greater sprouts per rootstock than red oak ($p < 0.001$) and other ($p < 0.001$) species groups (Table 9).

Two years following treatment no significance was found among species groups for basal diameter ($p = 0.163$). Twelve years after the burn basal diameter among species groups did not significantly differ ($p = 0.498$) with basal diameters ranging from 1.1 to 1.3 inches (Table 10). Two ($p = 0.147$) and twelve ($p = 0.187$) years after the burn there was no differences among species groups in the dormant treatment for dominant sprout height (Table 11). Two years following treatment, red oak (3.1 ft.) and white oak (3.0 ft.) had similar mean heights to that of red maple (4.0 ft.) and blackgum (3.1 ft.). Although not significant, red maple and red oak had a mean difference of 1.0 ft. in height two years following treatment. At year twelve red maple dominant sprout height was almost 2.0 ft. taller in the dormant treatment but was not significant ($\alpha > 0.05$).

Table 9. Mean tagged seedling (< 0.6 in and ≥2.0 ft.) topkill percentage two years (post2) following treatments, resprout percentage two years (post2) following treatment and sprout density (sprouts/rootstock) two (post2) and twelve (post12) years by species group (red oak: northern red oak, black oak; white oak: post oak, white oak; red maple; and blackgum) following a single dormant season prescribed fire and no-burn control treatment across Falling Water, Meadows Knob, and Pilot Knob sites in Ozark-St. Francis National Forest, AR. Different letters among species groups within the dormant treatment indicate significance ($\alpha = 0.05$) among columns based on Kruskal-Wallis and Bonferroni post-hoc tests.

	Topkill (%)	**Resprout (%)**	**Sprouts/rootstock**	
Species	Post2	Post2	Post2	Post12
Red oak	100^{a}	84^{a}	2^{b}	1^{ab}
White oak	100^{a}	83^{ab}	3^{a}	2^{ab}
Red maple	100^{a}	65^{b}	2^{b}	2^{a}
Blackgum	100^{a}	85^{ab}	2^{b}	1^{b}

Table 10. Mean and standard deviation basal diameter (in.) of dominant sprout from tagged seedling (dbh < 0.6 in. and ≥ 2 ft.) two years (post2) and 12 years (post12) following treatment by species group (red oak: northern red oak, black oak; white oak: post oak, white oak; red maple; and blackgum) following a single dormant season prescribed fire and no-burn control treatment across Falling Water, Meadows Knob and Pilot Knob sites in Ozark-St. Francis National Forest, AR. No significant (α = 0.05) differences found among species groups within dormant treatment among columns based on Kruskal-Wallis and Bonferroni Procedure post-hoc tests.

	Basal Diameter (in.)	
Species	Post2	Post12
Red oak	0.4[a](0.2)	1.3[a](0.7)
White oak	0.4[a](0.3)	1.2[a](0.6)
Red maple	0.2[a](0.1)	1.1[a](0.5)
Blackgum	0.3[a](0.2)	1.0[a](0.4)

Table 11. Mean and standard deviation height (ft.) of dominant tagged seedling sprout (dbh < 0.6 in. and ≥ 2 ft.), two years (post2) and 12 years (post12) sites by species group (red oak: northern red oak, black oak; white oak: post oak, white oak; red maple; and blackgum,) following a single dormant season prescribed fire and no-burn control treatment across Falling Water, Meadows Knob and Pilot Knob in Ozark- St. Francis National Forest, AR. No significant (α = 0.05) differences found among species groups within dormant treatment among columns based on Kruskal-Wallis and Bonferroni Procedure post-hoc tests.

	Height (ft.)	
Species	Post2	Post12
Red oak	3.1[a](1.4)	10.6[a](6.7)
White oak	3.0[a](1.8)	10.5[a](6.7)
Red maple	4.0[a](1.2)	12.3[a](6.2)
Blackgum	3.1[a](1.2)	8.1[a](6.1)

DISCUSSION

Overstory

In stands that were impacted by oak decline associated events (e.g., drought, red oak borer, etc.), white oak and red oak were affected by prescribed fire events to a greater degree than hickory and other species groups by year twelve. Oaks demonstrated more instances of dead/dying crown dieback classification in both the control (red oak: 20%; white oak: 7%; hickory: 7%; other: 3%) and dormant (red oak: 24%; white oak: 2%; hickory: 10%; other: 0%) treatment prior to prescribed fire. Other regional studies conducted in stands impacted by oak decline events reported upwards of 40 to 70% of red oak basal area and 13 to 14% of white oak basal area as dead/dying (Heitzman et al., 2007). Haavik et al. (2012) reported mortality levels for red oak (~20%) that were similar to this study. The greater mortality levels reported by Heitzman et al. (2007) may be related to a bias in evaluating sites that were targeted as a result of greater red oak borer damage.

Red and white oak had the largest mortality percent values in the dormant treatment at year twelve, and red oak had lower grow-in basal area while white oak, hickory, and other had more grow-in in the dormant treatment. Species in the overstory that demonstrated poor to dying crown classification prior to treatment had greater mortality than those that had healthy crowns in both the treatments. When dbh was greater than 16 inches, white oaks had a greater mortality percentage, while red oaks experienced mortality regardless of dbh. Oak mortality in the Ozarks has been found to increase with the increases in crown dieback (Fan et al., 2008). Fan et al., (2008) found mortality increased dramatically when dbh was less than 8 in., which was not the case in this study. In northwestern Arkansas, oaks with dbh greater than 10 in. and crown dieback > 95% at pre1 measurements experienced the greatest mortality.

Although upland oaks maintained their dominance in these stands, compositional shifts were observed. Prior to treatment red oak (39 ft^2/ac) and white oak (40 ft^2/ac) dominated, and still do at year twelve, but there has been a continuing shift of more white oak (38 ft^2/ac) with that species group being the most dominant, as well as, grow-in stems from other species (8 ft^2/ac) and hickory (7 ft^2/ac) by year twelve. Reduction in red oak and the continuing shift to more white oak, hickory and other species may be related to increased ages of red oak as well as being shorter lived than white oak (Burns and Honkala, 1990; Heitzman et al., 2007).

Saplings

Overall, non-oak competitor species such as red maple, blackgum, and black cherry consistently had density values greater than oak initially, and both two and twelve years following treatments. Similar results were reported in Ohio, in which areas that had been burned three to five times that had greater initial densities of non-oak competitors (e.g., red maple and blackgum) still had greater densities of these mesophytic competitors than red oak 13 years after treatment (Hutchinson et al., 2012). Regardless of the majority of the composition being non-oak competitors, red and white oak sapling densities still increased following treatment, especially on sites where greater densities of oak were observed prior to treatment. For instance, in the dormant treatment at Pilot Knob the initial density of red oak was 193 stems/ac and white oak was 153 stems/ac, both greater than the density of red maple (40 stems/ac) and other (207 stems/ac) species groups (Table B1). Twelve years following the dormant season burn at Pilot Knob, red oak (780 stems/ac) and white oak (273 stems/ac) density increased to a greater degree than for red maple (140 stems/ac) and other (473 stems/ac) species groups. In the Cumberland Plateau of Kentucky after repeated burns, sites with abundant oak sapling densities prior to treatment demonstrated a greater increase in oak density (Keyser et al., 2017). In this study red and white oak sapling densities increased with overstory basal area reduction while sapling density for red maple and other species groups increased as overstory basal area increased (Figures 17 and 18).

Logistic regression models developed for the Missouri Ozarks illustrated reduced probability of oak advanced reproduction density when the overstory basal area was greater than 22 ft^2/ac (Larsen et al., 1997). There were large values of increased density for oaks with the decrease in overstory basal area, but there were also large increase values for other species as well in the dormant treatment. One cause maybe various stages of mesophication across the sites. Since mesophication continually improves the environment for shade-tolerant, fire sensitive species, the presences of these mesophytic species prior to treatment would allow continued densities following treatment. The other and red maple groups had larger density values at pretreatment measurements at Falling Water and Meadows Knob, which may be the cause of continued increases even with the reduction in overstory basal area (Table B1). The loss of hickory was also observed, but there was so few hickory it was removed as a variable for analysis by year twelve.

Height was reduced for red and white oak by year twelve, while height for red maple and other increased in the dormant treatment. In Missouri, similar decreased height was reported for black oak and white oak ten years after burns (Fan et al., 2012). In this study, reduction in oak height could be attributed to the high percentage of topkill followed by smaller sprouts, which eventually grew into the sapling layer twelve years following treatment. With the increases in the overstory basal area in the no-burn control, red oak height was reduced, while white oak increased; the same was observed in the dormant treatment but to a lesser degree for red oak. Red maple and other species also had reductions in height with the increases in overstory basal area in the dormant treatment by year twelve (Figure 20). On sites in the Missouri Ozarks where harvesting practices were implemented on exposed and protected backslopes, red and white oak had larger annual height increments when the residual basal area was less than 22 ft^2/ac (Vickers et al., 2014).

Oak sapling dbh and basal area were greater than non-oak competitors prior to and two years following treatment; however, by year twelve diameter was similar in the dormant treatment, while white oak had the greatest diameter. Reduction in dbh, similar to trends in height, has been found to be related to the decrease in saplings and the resulting formation of sprouting clumps (Brose et al., 2014). This was observed in this study with red oak having a numerically greater percent of resprout and a significantly great number of sprouts per rootstock two years following the implementation of a single dormant season prescribed fire.

Seedlings

Similar to the sapling strata, non-oak competitors made up the majority of the seedling composition and although there were increases in oak density two years following treatment, red maple and other species groups remained dominant through year twelve. In this study, height and basal diameter increased for oak seedlings in the dormant treatment. In other Central Hardwoods region studies effects on oak and non-oak seedlings have varied. Prescribed fire had no significant effect on oak and red maple seedling height on Ohio (McQuattie et al., 2004; Brose et al., 2005). Results from this study found other species having greater heights than red oak two years following treatment. Apsley and McCarthy (2004) found red maple seedlings were taller than chestnut oak on burned compared to unburned sites, which was also observed here, although not significantly different. Overall, oak seedling density, height, and basal diameter was improved by year twelve, which has also been observed in Kentucky, with height and diameter growth of white oak and increases in oak density following prescribed fire (Kuddes-Fischer and Arthur, 2002).

All red oak, white oak, red maple, and blackgum seedlings experienced 100% topkill in the dormant treatment. Red oak had the greatest percent of rootstocks to resprout and white oak had the greatest number of sprouts per rootstock two years following prescribed fire. Dey and Hartman (2005) found that survival probability was greater with larger initial basal diameters and heights, and those larger basal diameters has greater energy reserves in the roots which supports the growth of sprouts following a fire disturbance (Canadell and Rodá, 1991; Kozlowski et al., 1991; Dey and Parker, 1996; Dey and Hartman, 2005). Initial oak basal diameter was less than that of red maple and blackgum, but red oak had a significantly larger percent of resprout percent and white oak had greater numbers of sprouts per rootstock two years following treatment. The larger basal diameter for oak sprouts might increase the probability of survival following another prescribed fire (Dey and Hartman, 2005). On dry sites in Ohio, oak seedling density increased with the reduction of overstory basal area from years six to 13 following a prescribed fire. In the Missouri Ozarks the probability of greater seedling density and height was related to lower overall basal area (Iverson et al., 2017; Larsen et al., 1997).

CONCLUSIONS & MANAGEMENT IMPLICATIONS

A single dormant season prescribed fire improved oak regeneration potential by increasing oak density, height, diameter, and the resulting sprout response. However, non-oak density was not reduced by year twelve, most likely due to its abundant presence prior to the prescribed fires. On sites where there was a larger oak component the resulting densities were larger than the non-oak competitors. Prescribed fire also increased oak competitiveness with oaks that sprouted following treatment, or larger stems that were not topkilled having similar if not greater height and diameter values to non-oak competitors. With the current density, height, and diameters of oaks at year twelve, these species would be more competitive with higher probabilities of survival following an additional prescribed fire. However, a potential concern is that without additional treatment on these stands, the current densities of non-oak competitors will only increase as well as those heights and diameters outcompeting oaks.

To further promote oak regeneration and recruitment into the overstory, the use of multiple fires are needed to increase forest floor light and favoring oaks over competitor mesophytic species (Alexander et al., 2008; Iverson et al., 2017). Other methods that have had success in the Ozarks is the implementation of a shelterwood harvest followed with prescribed fire. The harvest releases overtopped trees while reaching the desired basal area. A waiting period of 3-5 years before implementing prescribed fire allows for fuel bed development and oak root system development, and time for the seedbed to germinate. Spring fires would kill more mesophytic hardwoods, shifting the composition toward oak, and the oaks sprouting in response to fire would improve in growth (Johnson et al., 2002; Lanham et al., 2002; Brose et al., 2014).

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APPENDIX A: OVERSTORY

Table A1. Average overstory basal area (ft2/ac) pre-treatment (pre1) and two treatment (post2), and 12 years following treatments (post12) across Falling Water, Meadows Knob and Pilot Knob sites by species group in Ozark-St. Francis National Forest, AR.

Site	**Treatment**	**Year**	**Red oak (ft^2/ac)**	**White oak (ft^2/ac)**	**Hickory (ft^2/ac)**	**Other (ft^2/ac)**
Falling Water	Control	Pre1	22	73	28	13
		Post2	20	72	27	13
		Post12	18	70	25	12
	Dormant	Pre1	39	44	12	18
		Post2	34	43	11	19
		Post12	24	44	11	18
Meadows Knob	Control	Pre1	47	41	4	17
		Post2	43	40	4	21
		Post12	34	33	10	26
	Dormant	Pre1	52	31	4	8
		Post2	44	31	4	2
		Post12	28	36	2	12
Pilot Knob	Control	Pre1	4	12	30	14
		Post2	0	12	26	12
		Post12	8	12	26	12
	Dormant	Pre1	40	25	0	7
		Post2	35	22	0	7
		Post12	23	20	0	3
	Growing	Pre1	12	50	7	3
		Post2	12	50	7	3
		Post12	12	52	8	5

Table A2. Average basal area (ft2/ac.) of overstory crown conditions (Healthy: 0-25; Fair: 25-50; Poor: 50-75; Dead/Dying: >95) across Falling Water, Meadows Knob and Pilot Knob sites in control and dormant plots in Ozark- St. Francis National Forest, AR.

Treatment	**Year**	**Crown Condition**	**Red oak (ft^2/ac.)**	**White oak (ft^2/ac.)**	**Hickory (ft^2/ac.)**	**Other (ft^2/ac.)**
Control	pre1	Healthy	28	46	30	20
		Fair	5	0	0	0
		Poor	0	0	0	0
		Dead/Dying	9	5	8	2
	Post2	Healthy	30	46	30	20
		Fair	1	3	3	0
		Poor	3	0	0	0
		Dead/Dying	10	1	2	2
	Post12	Healthy	26	37	30	18
		Fair	9	8	0	4
		Poor	0	0	0	0
		Dead/Dying	8	11	3	3
Dormant	pre1	Healthy	36	37	10	32
		Fair	3	2	0	0
		Poor	3	0	0	0
		Dead/Dying	12	5	2	0
	Post2	Healthy	28	33	7	30
		Fair	10	5	3	3
		Poor	2	7	0	0
		Dead/Dying	15	6	2	8
	Post12	Healthy	39	33	10	29
		Fair	2	7	3	3
		Poor	3	0	0	0
		Dead/Dying	5	6	0	5

Table A3. Mean change in basal area based on crown conditions (Healthy: 0-25; Dead/Dying: >95) from two years following treatment to pre-treatment measurement (post2-pre1), and 12 years following treatment to pre-treatment measurement (post12-pre1) across Falling Water, Meadows Knob and Pilot Knob sites in control and dormant plots in Ozark-St. Francis National Forest, AR.

Site	Treatment	Year	Crown Condition	Red oak (ft^2/ac)	White oak (ft^2/ac)	Hickory (ft^2/ac)	Other (ft^2/ac)
Falling Water	Control	post2-pre1	Healthy	0	-5	-5	-3
			Dead/Dying	-5	0	0	0
		post12-pre1	Healthy	-7	-13	-5	0
			Dead/Dying	-10	13	5	0
	Dormant	post2-pre1	Healthy	-3	-3	-2	0
			Dead/Dying	-1	-5	0	0
		post12-pre1	Healthy	-9	-9	0	-8
			Dead/Dying	-4	10	-5	15
Meadows Knob	Control	post2-pre1	Healthy	3	-5	0	-1
			Dead/Dying	-2	6	0	0
		post12-pre1	Healthy	-1	9	0	-1
			Dead/Dying	2	-7	0	0
	Dormant	post2-pre1	Healthy	-6	-6	0	-4
			Dead/Dying	16	0	0	0
		post12-pre1	Healthy	-16	0	0	0
			Dead/Dying	3	0	0	0
Pilot Knob	Control	post2-pre1	Healthy	0	0	0	-13
			Dead/Dying	0	0	0	5
		post12-pre1	Healthy	0	3	-2	-3
			Dead/Dying	0	10	0	10
	Dormant	post2-pre1	Healthy	8	6	0	1
			Dead/Dying	-4	-3	0	0
		post12-pre1	Healthy	2	0	0	0
			Dead/Dying	-4	0	0	0

APPENDIX B: SAPLINGS

Table B1. Mean sapling (dbh ≥ 0.6 to < 4.5 in.) density (stems/ac.) pre-treatment (pre1), two years following treatment (post2) and 12 years following treatment (post12) in control and dormant plots across Falling Water, Meadows Knob and Pilot Knob by species group (red oak: northern red oak, black oak; white oak: post oak, white oak; red maple; and other: blackgum, black cherry, etc.) in Ozark- St. Francis National Forest, AR.

Site	Plot	Year	Red Oak (stems/ac)	White Oak (stems/ac)	Red Maple (stems/ac)	Other (stems/ac)
Falling Water	Control	pre1	13	13	33	127
		post2	13	13	33	147
		post12	27	13	220	207
	Dormant	pre1	4	9	84	187
		post2	0	4	13	31
		post12	173	18	524	364
Meadows Knob	Control	pre1	4	31	44	347
		post2	4	22	40	396
		post12	22	9	93	387
	Dormant	pre1	0	0	150	195
		post2	0	0	50	105
		post12	10	0	405	615
Pilot Knob	Control	pre1	0	88	0	144
		post2	0	64	0	128
		post12	0	64	0	376
	Dormant	pre1	193	153	13	207
		post2	13	40	0	40
		post12	780	273	47	473

Table B2. Mean and standard error of mean sapling (dbh ≥ 0.6 to < 4.5 in.) density (stems/ac.) prior to (pre1), two years following treatment (post2) and 12 years following treatment (post12) across Falling Water, Meadows Knob and Pilot Knob sites by species group (red oak: northern red oak, black oak; white oak: post oak, white oak; red maple; and other: blackgum, black cherry, etc.) in control and dormant plots in Ozark- St. Francis National Forest, AR.

		Red oak (stems/ac)		**White oak (stems/ac)**		**Red maple (stems/ac)**		**Other (stems/ac)**	
Treatment	**Year**	**Mean**	**Std. Err**	**Mean**	**Std.Err**	**Mean**	**Std.Err**	**Mean**	**Std.Err**
Control	Pre1	6	4	44	23	26	13	206	71
	Post2	6	4	33	16	24	12	223	86
	Post12	16	8	29	18	104	64	323	58
Dormant	Pre1	66	63	54	50	83	39	196	6
	Post2	4	4	15	13	21	15	59	23
	Post12	321	234	97	88	325	144	484	72

APPENDIX C: SEEDLINGS

Table C1. Mean seedling (< 0.6 in. dbh and ≥ 2.0 ft.) density (stems/ac.) pre-treatment (pre1), two years following treatment (post2) and 12 years following treatment (post12) in control and dormant plots across Falling Water, Meadows Knob and Pilot Knob by species group (red oak: northern red oak, black oak; white oak: post oak, white oak; red maple; and other: blackgum, black cherry, etc.) in Ozark-St. Francis National Forest, AR.

Site	Treatment	Year	Red oak (stems/ac)	White oak (stems/ac)	Red maple (stems/ac)	Other (stems/ac)
Falling Water	Control	Pre1	267	200	600	1200
		Post2	333	200	900	1286
		Post12	467	400	1467	1400
	Dormant	Pre1	375	0	800	575
		Post2	575	67	2200	925
		Post12	900	800	2650	2100
Meadows Knob	Control	Pre1	400	40	925	1178
		Post2	575	120	1025	1200
		Post12	1325	242	1875	1733
	Dormant	Pre1	0	0	200	1000
		Post2	50	0	971	2450
		Post12	300	500	829	2375
Pilot Knob	Control	Pre1	200	0	0	1280
		Post2	100	0	0	1360
		Post12	100	200	200	960
	Dormant	Pre1	767	367	0	533
		Post2	2467	1033	3600	3000
		Post12	700	233	400	1767

VITA

Mr. Mason Danheim attained his Bachelor of Science in Forestry with a major in Wildlife Management, continuing his passion for the outdoors, in 2016 from Stephen F. Austin State University in Nacogdoches, TX. While attending SFASU, Mason graduated with multiple career certifications including, The Wildlife Society's Associate Wildlife Biologist® and The Association for Fire Ecology Wildland Fire Technician.

During his time at SFA, Mason worked with the United States Forest Service conducting federal fire monitoring research and data collection, as well as, an internship with the Bureau of Land Management collecting and analyzing data on noxious weeds, as well as, implementing treatment. After graduating with his BSF, Mason hiked the entire length of the Appalachian Trail in one season in 2017 and finished in time to pursue his Master of Science in Forestry. Under the guidance of Dr. Rebecca Kidd research was conducted examining the long-term effects of prescribed fire on degraded upland oak-hickory stands in northwestern Arkansas.

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This thesis was typed by Mason Danheim, using Stephen F. Austin State University Graduate School Style Manual.