WHAT FIRE FREQUENCY IS APPROPRIATE FOR SHORTLEAF PINE REGENERATION AND SURVIVAL?

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ABSTRACT.—Shortleaf pine community restoration requires an answer to the question, "What fire frequency is appropriate for shortleaf pine regeneration and survival?" The answer to this question is one of the most critical to successful restoration through fire management. We used three sources of information from Missouri to determine appropriate burning frequencies: a 400-yr historic shortleaf pine growth and fire-scar database, fire effects data from prescribed burning sites, and a vegetation dynamics prediction model that is widely used for characterizing fire regimes. The historic shortleaf pine and fire scar database provides actual past scenarios of regeneration dates, growth, survival, and associated fire events. Shortleaf pine regeneration established most commonly during the 4 years following fire events and generally decreased in abundance with years since fire. Surviving seedlings were those that were not fire scarred the year following establishment, and the mean number of years to a subsequent fire was about 7 years. Fire effects data from prescribed burn sites revealed that both hardwood and pine regeneration showed substantially increased mortality after four consecutive dormant season burns, but oak and hickory species were more likely to survive frequent fire. Mortality of advance regeneration was generally low in all hardwood species after one burn, while shortleaf pine seedlings had high mortality rates. The model showed 8 to 15 yr intervals are likely best for balancing both continual regeneration and recruitment. Model prediction runs for 500 years showed a significantly decreased pine component in the absence of burning. Conversely, long-term frequent burning (1- to 3-yr intervals) resulted in abundant regeneration, but poor survival and ultimately decreased abundance in mid- and late-successional forests. In summary, all three sources support the efficacy of frequent burning (1 to 4 yrs) in promoting pine regeneration, but survival and continued recruitment require longer fire intervals (8 to 15 yrs). Fire management prescriptions that incorporate both frequent burning and longer intervals will likely provide for the most long-term regeneration and recruitment success.

INTRODUCTION

It is widely recognized that fire is critical to shortleaf pine forest ecosystems (Cooper 1989, Bukenhofer and others 1994, Masters and others 1996, Stanturf and others 2002, Rimer 2003, USDA 2003). However, shortleaf pine restoration through fire management begs the answers to questions such as "What fire frequency is appropriate for shortleaf pine regeneration and survival?" Much of the information about shortleaf pine and fire comes from field trials and lies with experienced individuals while relatively little is published about experimental findings. Because of the dynamic conditions of fire events (due to fuels, weather and climate, vegetation, topography, burning technique, etc.), it is difficult to relate single experimental results to the management of large and different forested landscapes.

The historic role of fire within shortleaf pine communities of the Ozark Highlands has been well established and described (Guyette and others 2002, Guyette and others 2006) (Fig. 1). The pre-Euro-American dominance of shortleaf pine in the region was negatively related to historic mean fire intervals (Batek and others 1999). Wildfires likely maintained many of the presettlement shortleaf pine communities and, though at times severe, were predominantly non-stand-replacing surface fires resulting from anthropogenic ignitions. Mixed severity fires resulting in small stand-replacement events likely occurred within the region about every 20 years (Guyette and others 2006). Today, wildfires typically consist of small-scale, low severity surface fires (Westin 1992, Stambaugh and others in press) that are rarely stand-replacing events.

METHODS

In an attempt to provide regionally derived information on fire regime and shortleaf pine dynamics, we chose to summarize results of fire events and shortleaf pine regeneration and survival from many locations and time

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periods within the natural range of shortleaf pine in the Ozark Highlands of Missouri and Arkansas. We used three approaches to determine appropriate burning frequencies for promoting shortleaf pine regeneration and recruitment. The approaches were: analysis using a 400-yr historic shortleaf pine growth and fire scar database (Stambaugh and Guyette 2004), a summary of fire effects data from prescribed burning sites (Dey and Hartman 2005), and model simulations using the Vegetation Dynamics Development Tool (VDDT) (Essa Technologies Ltd. 2005).

Historic Shortleaf Pine Growth and Fire Scar Database

This database consists of approximately 600 cross sections cut from the base of shortleaf pine remnant trees, live trees, and existing stumps that were collected from throughout the Ozark Highlands region during the past 20 years (Guyette 1994, Guyette and others 2002, Guyette and Spetich 2003) (Fig. 1). This database represents trees that survived fire events and does not contain those that were killed and have since decomposed. Tree-ring data from cross sections span the past four centuries and the database was queried for those trees that had both pith dates (stem ages) and fire event dates. The query resulted in 96 trees with pith dates ranging from 1585 to 1896 (Fig. 2). Of these, 64 trees had information about the number of years since fire as derived from fire history studies at their respective sites. Ninety-one trees contained information about the number of years from the pith to the first fire scar on that tree and 95 had information about the number of years from the pith to the first fire event that occurred within the vicinity (less than 1 km^2). It is important to note that pith dates reflect the first year of growth of the stem and that it is not known whether stems initiated from a seedling or a sprout.

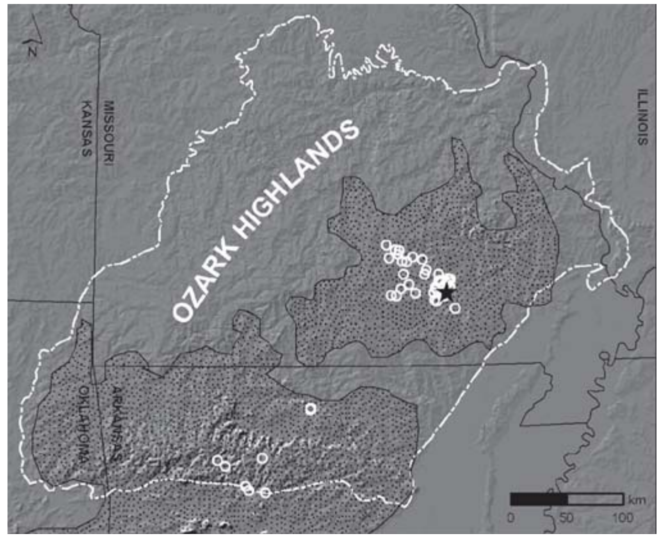

Figure 1.—Locations of shortleaf pine fire history sites (white circles), the Chilton Creek Preserve (black star), the boundary Ozark Highlands ecoregion (white line) (Bailey 1998), and the approximate range of shortleaf pine (stippled area). Fire history sites are where shortleaf pine specimens used in the growth and fire scar analysis were collected. The Chilton Creek Preserve is the location from which fire effects data were summarized.

Fire Effects

Fire effects data for shortleaf pine were summarized from the Chilton Creek Preserve, a 2289 ha site located along the Current River in Shannon and Carter Counties, Missouri. The preserve has been divided into five management units of approximately 200 ha each. All units were burned in the spring of 1998 and then burned during the dormant

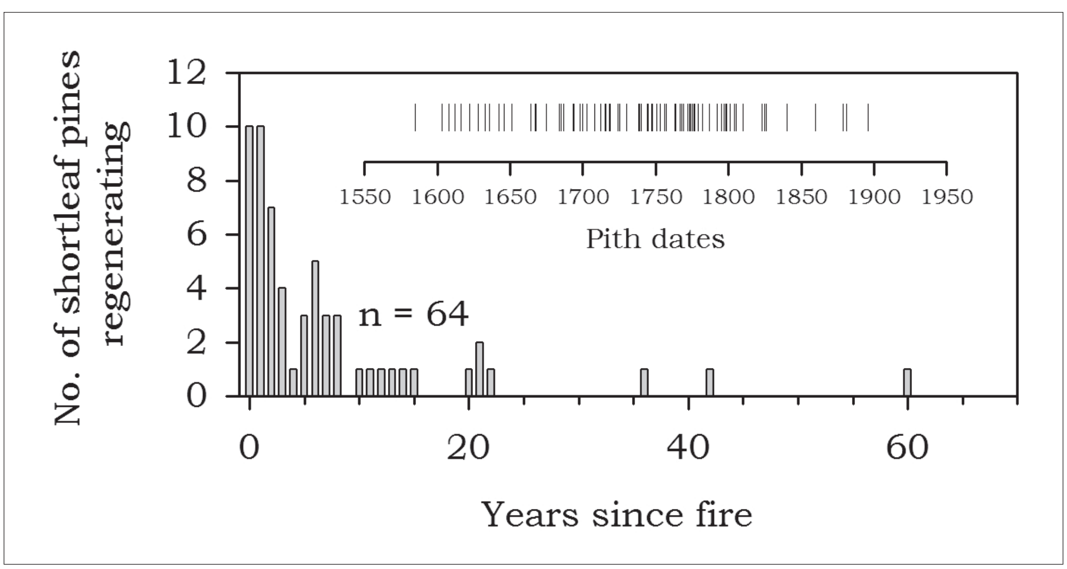

Figure 2.—Bar graph of the number of shortleaf pines regenerating during the years following fire events. Data were generated from a historic shortleaf pine specimen database (see methods). Years of regeneration of these trees are shown as pith dates (upper right of graph).

season on a randomly determined 1- to 4-yr return interval basis. One management unit (Kelly North) has been burned annually. Pre- and post-burn information is available for fuels and fire behavior, and fire effects information is available for herbaceous, seedling, and sapling vegetation layers (Sasseen 2003, Dey and Hartman 2005). Here, we summarize the fire effects findings of Dey and Hartman (2005) as they relate to the survival of shortleaf pine regeneration and compare their findings to those generated from the historic shortleaf pine database and VDDT modeling approaches.

VDDT Model

VDDT is a model developed for examining the influence of various disturbance and management actions on vegetation development (Essa Technologies Ltd. 2005). The model is a state and transition model that was developed for use in the Landfire project, a federally funded project producing consistent and comprehensive maps and data describing vegetation, wildland fuel, and fire regimes across the United States (Rollins and others 2003). VDDT has a suite of reference models that have been developed for many different vegetation types, including oak-hickory-pine forests, based on information from published literature, expert input, and peer review. We used a five-box model developed for oak-pine forests to explore the effects of different fire frequencies on the regeneration and survival of shortleaf pine communities, particularly over extended time periods (e.g., 500+ years). Details of this model can be found in Guyette and others (2004) and Shlisky and others (2005). In general, the model simulates the survivorship and transition of oak-hickory-pine forests as a result of fire disturbances (and other disturbances if chosen) which can be changed by the user. The model contains five forest seral states (Table 1). In subsequent model runs we decreased the fire frequency to understand the effects of fire on various forest states, particularly the maintenance of two states: an early seral mixed forest (i.e. regeneration) and late-seral forest with greater than 2 percent shortleaf pine (i.e., survivorship of shortleaf pine) (Table 1). Model simulations were generated using fire frequencies of annual burning, 2-yr, 4-yr, 8-yr, 15-yr, and 40-yr fire intervals, and no fire disturbance. For each scenario the model was run for 500 timesteps using 10 simulations. Initial model conditions began with equal area (20 percent of landscape) represented by each seral stage. VDDT calculates the percentage of area occupied by each seral state, and model results were produced for the 100 and 500 timesteps. No model modifications were made other than fire disturbance frequencies.

RESULTS

Historic Shortleaf Pine Growth and Fire Scar Database

The mean number of years from a pith date to a fire event was 6.8 years. The abundance of shortleaf pine regenerating fell sharply with time since fire; the majority occurred within the first 8 years from a fire event (Fig. 2). Much of the regeneration that survived underwent another fire within the first 12 years of regenerating (Fig. 3). The mean number of years from regeneration to the first fire scar was 45.5 years and the majority of trees survived at least one fire in the first 20 years of growth. No trees were represented as having survived a fire injury during the first year of growth.

Fire Effects

First year burning effects resulted in shortleaf pine having the highest seedling and sapling layer percent mortality (38 percent) of any species recorded (see Table 3 in Dey and Hartman 2005). Despite high initial mortality, shortleaf pine had only 1 percent additional mortality in subsequent fires, while all other species sustained higher mortality rates. Following 3+ burns (annual burning frequency), shortleaf pine showed the lowest percent total damage calculated as the sum of the percent mortality and percent shoot dieback. The probability of shortleaf pine seedlings and saplings (advance reproduction) in the understory of a mature oak-pine forest surviving a spring surface fire was significantly related to initial stem size (i.e., basal diameter and height). Small-diameter shortleaf pine advance reproduction had the

Table 1.—Forest developmental states of coarse (south central U.S.) and empirically-driven (Current River Hills, MO) oak-hickory-pine VDDT models developed by Guyette and others (2004) and validated by Shlisky and others (2005). The effects of different fire disturbance frequencies on the development and success of each seral state are shown in Figure 4.

Seral State	Age range (yrs)	Code
Early seral mixed forest	0-12	A
Mid-seral mixed forest; canopy cover >55%	13-70	B
Mid-seral mixed forest; canopy cover <55%	13-70	C
Late-seral forest; >55% canopy cover; <2% shortleaf pine	>70	D
Late-seral forest; >55% canopy cover; >2% shortleaf pine	>70	E

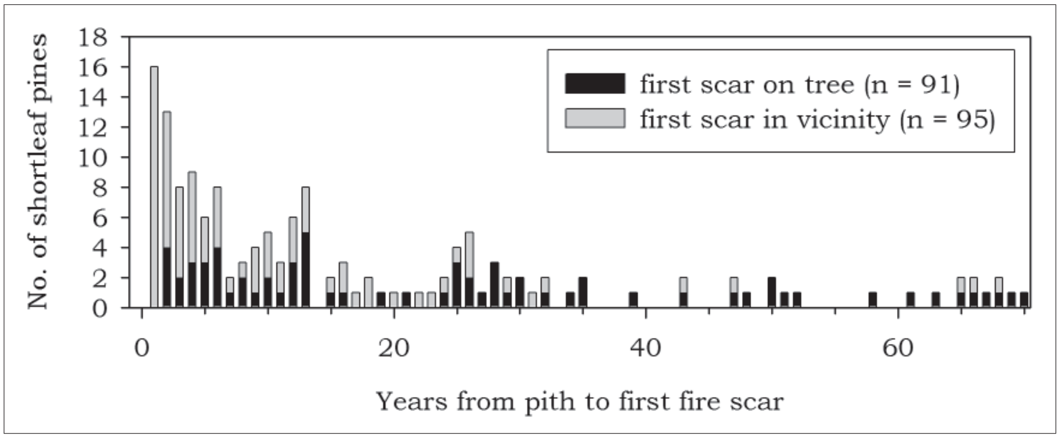

Figure 3.—Bar graph showing the historic shortleaf pine specimen trees and the number of years to the first fire they survived as documented by a scarring injury. Two types of fires are shown: fires that were recorded on that individual tree and fires that scarred other trees in the vicinity (within about 1 km) of where the tree grew.

lowest survival probabilities compared to similarly sized hardwood seedlings. Shortleaf pines that were less than 2 cm in basal diameter had less than 40 percent chance of surviving a single spring surface fire. In contrast, pines that were greater than or equal to 10 cm in basal diameter had a 90 percent or greater probability of surviving burning. Large diameter (greater than 5-cm basal diameter) pines that survived one fire had high probabilities of surviving repeated dormant-season surface fires. Overall, repeated burning in the dormant season reduced the height of understory trees and favored oak reproduction. Fire effects data from Chilton Creek demonstrated that the success of fire treatments may be better assessed after conducting multiple burns as high mortality may occur in the initial burn and not be representative of long-term repeated burning.

VDDT Model

Model simulations demonstrated that forest developmental states are highly sensitive to small changes in burning frequency. Simulations of annual burning allowed for the greatest proportion (nearly 60 percent) of the landscape to be in an early seral state (Fig. 4). The effect of decreasing the burning frequency from annual burning to 40-year fire intervals was a transition in the amount and types of seral states occupying the landscape. For example, the percent of area in early seral states decreased dramatically (60 to 4 percent) while mid-seral closed canopy developmental states slightly increased (Fig. 4). Forest developmental states that likely represent shortleaf pine success (i.e., classes C and E) showed different responses. Mid-seral open canopy states slightly decreased in percent area from 2-year to 40-year burning intervals. Percentage area of late-seral open canopy states with > 2 percent shortleaf pine (i.e., class E) increased from 2-yr to 8-yr burning intervals. The percent area of this late-seral state decreased as fire intervals increased beyond 15 years. The “no fire disturbance” scenario resulted in a dominance of the late-seral state with no shortleaf pine component on nearly 80 percent of the area at timestep 500 (Fig. 4).

DISCUSSION

Shortleaf Pine Regeneration and Survival

In this study the regeneration success of shortleaf pine appeared to be related to time since fire. Much of the regeneration summarized from the historic shortleaf pine database showed that regeneration following fire occurred within the first 10 to 15 years. This time period is likely related to many of the factors essential to regeneration establishment such as available light, nutrient release, and litter cover, as well as ability to resprout. In the Ozarks, litter and duff are important barriers to shortleaf regeneration (Grano 1949, Shelton and Wittwer 1992) and time since fire and shortleaf pine regeneration are inversely related (Ferguson 1958). Stambaugh and others (2006) estimated litter in Ozark forests accumulates to a maximum equilibrium within about 12 years post-fire. It is common for current Ozark oak-pine forests to have undergone decades of fire exclusion resulting in maximum litter accumulation levels, the development of a substantial duff layer, and ultimately large scale preclusion of shortleaf pine seedling establishment.

Although shortleaf pine regeneration showed a positive response to fire events, shortleaf pine’s survival following regeneration appeared to necessitate recurring fire (Fig. 3). The results suggest that following regeneration, immediate burning and repeated frequent burning (annual to 2-yr frequency) do not support shortleaf pine survivorship. Although shortleaf pine seedlings can resprout vigorously following topkill (Walker and Wiant 1966, Keeley and

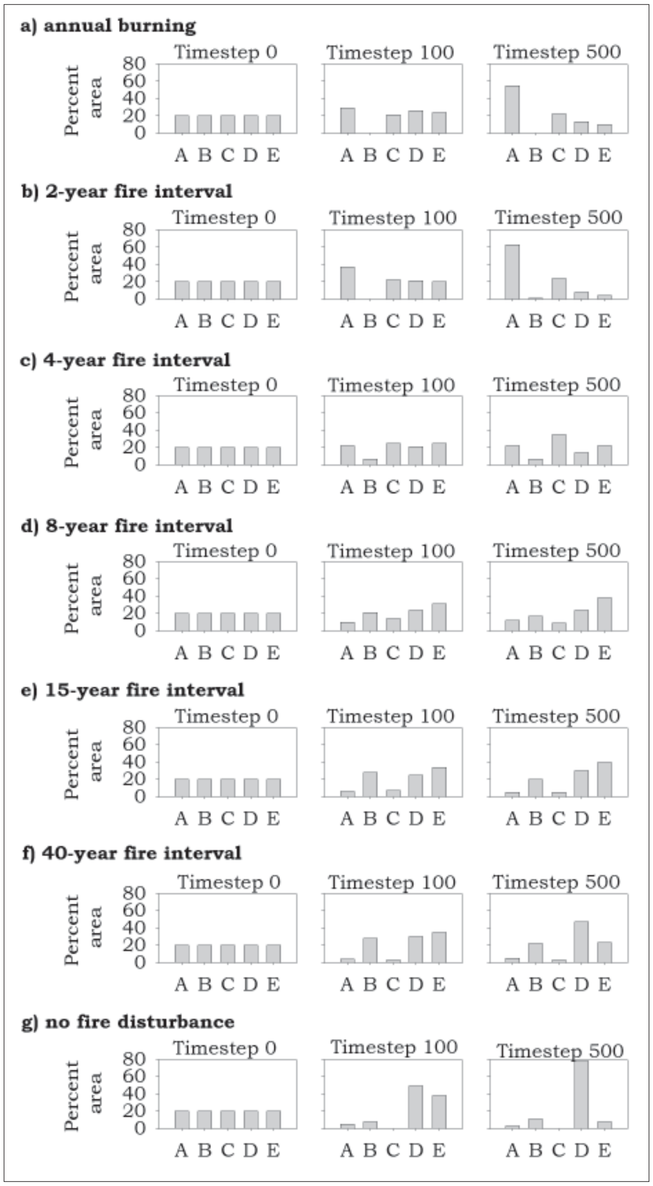

Figure 4.—Bar graphs of percent area of landscape (VDDT model simulated) that is comprised in five forest seral states (coded A through E, Table 1). The percent area in each seral state is shown for seven different fire frequency scenarios. Initial forest conditions (timestep 0) contain equal amounts of each seral state, and results are shown for 100 yr and 500 yr timesteps. Class codes are: A = Early seral mixed forest, B = Mid-seral mixed forest; canopy cover >55%, C = Mid-seral mixed forest; canopy cover <55%, D = Late-seral forest; >55% canopy cover; <2% shortleaf pine, E = Late-seral forest; >55% canopy cover; >2% shortleaf pine.

Zedler 1998), it is not known how many successive resprouting events can occur from the same root stock during a frequent burning regime; therefore, repeated frequent fire may prohibit survival of seedlings. In a study that compared a remnant stand of shortleaf pine with the existing stand at the same site, Guyette and Dey (1997) concluded that 100 years of burning with a mean fire return interval of 3.1 years contributed to the elimination and reduction of advanced pine regeneration.

A recurring question is "what amount time of does it take for a pine to gain some degree of fire resistance?" It appears from our analysis that this is within a range of 8 to 15 years, depending on stand and environmental conditions. Wade and others (2000) reported a range of 6 to 15 years for drier, nutrient poor sites and a 2- to 6-yr range on more fertile sites. Walker and Wiant (1966) showed comparable results based on tree size and Baker (1992) reported supporting results based on tree height. Respectively, they reported that shortleaf trees larger than about 2 to 10 cm diameter at breast height (DBH) and 4 to 5 m in height are somewhat resistant to surface fires. The range in tree height and size likely varies based on fire environment and behavior. Brinkman and Smith (1968) reported that "free growing" trees in Missouri within this fire-resistant size class were about 7 years old. Similarly, shortleaf growing in different regions (e.g., Arkansas and Oklahoma Ozarks and Ouachita Mountains) may reach resistance earlier than more northerly populations because of increased growth rates. Denser overstory stockings that cause decreased pine growth would also increase the age to resistance. Suppressed understory trees may be particularly problematic as they may be 30 years old or greater and still within a size range susceptible to fire kill (Brinkman and Smith 1968, Stambaugh 2001).

Along the lines of Dey and Hartman (2005), more information is needed to determine the different probabilities of survivorship by tree characteristics (e.g., tree size, growth, age) that exist between shortleaf pine and hardwood competitors. It is likely that shortleaf pine has a higher probability of surviving repeated fires compared to hardwood competitors, particularly over long periods of time and within a smaller diameter range (e.g., 4 to 20 cm basal diameter). Identifying the period of development in which shortleaf has a higher probability of surviving fires compared to hardwoods would help to develop prescribed fire management guidelines for shortleaf pine restoration. From the results of this and other studies mentioned above, it appears that shortleaf is tolerant of low-intensity surface fires within a specific diameter-height window (e.g., 4- to 20-cm basal diameter, 4 to 5 m in height) (Walker and Wiant 1966, Baker 1992) that corresponds to a specific range of tree ages and fire frequencies (8 to 15 yrs).

Long-term effects (e.g., 50+ years) of repeated burning on oak-pine forest dynamics are not well understood partly because few locations have been monitored for this length of time. However, much of this pine growth and fire information already exists in the historic record and can be gleaned from pine remnants that date to presettlement time periods (prior to 1820). Pieces of remnant wood are relatively common throughout the entire Ozark region and beyond and indicate locations of previous pine sites. The success and dominance of pine at time of settlement in the Ozarks (e.g., 2 to 6 million acres in Missouri) resulted from fire disturbances that favored shortleaf pine regeneration and survival. It is for these reasons that the historic information is relevant and perhaps critical to understanding present day shortleaf pine community restoration. It should be noted that results from the historic shortleaf pine database used in this study are based on wildfire events. More information is needed that compares fire effects resulting from prescribed fires versus wildfires (see Gnehm and Hadley, this proceedings).

Survivorship of shortleaf pine is not only reduced by short time lags to the next fire and repeated frequent burning, but also long-term suppression of fire. VDDT model simulations illustrated that long fire intervals (e.g., 40+ years) do not promote seral states containing shortleaf pine. VDDT estimates that long-term suppression of fire promotes the dominance (>80 percemt, Fig. 4) of hardwoods over shortleaf pine. In late-successional forests in the Ozarks little shortleaf pine regeneration is allowed by small-scale disturbances (Shelton and Cain 1999, Stambaugh 2001, Stambaugh and Muzika, this proceedings).

Fire Management

Fire management implications of these results pertain to burning frequencies and generalized effects on shortleaf pine. One important point is that burning frequencies represent mean fire intervals that are a result of variation in years between subsequent fires. Burning that incorporates variability in years between fires more closely mimics the historic fire regime and the results presented in this study. Initial burn effects from decades of litter accumulation may not represent those following repeated fires.

In young oak-pine forests in the Ozarks, conditions of fire suppression commonly result in pine being overtopped by hardwoods. This situation may be less common further south in the region, where the species attains greater height growth rates. In Missouri underplanting of pine prior to overstory removal has been used to enhance shortleaf's competitive ability. However, even under this condition, additional hardwood control may be required, further emphasizing the species' need for repeated disturbance.

Along with frequency, the timing of burning treatments is likely a critical consideration for promoting shortleaf pine. Regional fire scar histories show that fire events occurred almost exclusively during the dormant season (i.e., approximately October to March). Timing of burns should precede the timing of seed dissemination (late October, November) and seedling development (early spring season) to maximize regeneration survival. Information or monitoring of the timing of critical life stages and the fire environment would be of particular value towards understanding the appropriate season of fire for shortleaf pine restoration.

CONCLUSION

The three methods used to determine the appropriate burning frequencies for promoting shortleaf pine regeneration and survival all resulted in similar conclusions. Frequent burning (1- to 4-yr frequency) likely promotes regeneration, but a lowered frequency (8 to 15 yrs) promotes survival and recruitment into the overstory. We hypothesize that an 8- to 15-yr fire frequency may be a range where shortleaf has a higher probability of recruitment than many hardwood competitors, especially after longer periods of continuous burning. Additional information on fire effects (both prescribed fire and wildfire) specific to oak-pine forests and historic pine growth with corresponding fire information would aid in further defining appropriate fire frequencies.

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