Impacts of Six Different, Complex Fire Regimes in a Longleaf Pine Ecosystem: Results Over 25 Years

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Abstract—Studies on frequent fire return intervals often span a few years and historically it has been presumed that this is sufficient to assess fire effects in different seasons and/or frequencies. However, long-term data increasingly challenges this assumption. Our research targets an ecosystem dominated by the fire-dependent longleaf pine (*Pinus palustris*). Longleaf pine forests once dominated Southeastern United States uplands and it is well-accepted that the ecosystem was maintained by frequent fire. Nevertheless, important questions remain, including how frequent is frequent enough and how critical is season of burn. Results were evaluated in seven sampling periods spanning 25 years on the Escambia Experimental Forest (Forest Service, U.S. Department of Agriculture) in south-central Alabama. Treatments were six different complex fire regimes: fire every 2, 3, or 5 years in winter or late spring plus a no-burn treatment in each of 3 blocks. Data were collected on longleaf plus hardwood stems > 2.5 cm at breast height. By Year 25 there was little difference in longleaf growth or survivorship, but there were significant treatment-dependent differences in number and size of hardwood stems. Fire return intervals of 2-3 years were important but frequent growing-season burns appear to be critical for managing encroaching native hardwoods and maintaining habitat structure over long time periods.

Keywords: fire regime, season of burn, fire frequency, longleaf pine, hardwood stems

INTRODUCTION

Worldwide there is an increasing need to develop a better understanding of complex fire regimes in many different ecosystems over long time periods and this may be especially true in North America (e.g., Freeman et al 2017). Our paper describes results of long-term research initiated in 1984 and designed to evaluate effects of complex fire regimes on longleaf pine (*Pinus palustris*) and its habitat. The data evaluated cover 25 years and six different fire regimes plus an unburned treatment.

Six decades earlier, Aldo Leopold (1924) noted that fire should be considered as a natural component of the landscape. Since then, there have been many long-term studies established to consider ecological effects of disturbances. However, when fire is considered, often it is in the context of ecosystems with extended fire return intervals and associated research usually documents succession over time (e.g. Rogers 1996).

Currently there is growing interest and need in determining what constituted natural disturbance regimes (e.g., Turner et al. 2003). In the United States, there has been a focus on understanding habitat conditions related to fire prior to European settlement (e.g., Frost 1998, 2006). Using witness tree data and environmental variables, Predmore et al. (2007) determined that prior to European settlement, fire-dependent longleaf communities dominated southern

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areas and Stambaugh et al. (2011) assessed cross-sections of 19 remnant old pines in southern Louisiana and found that the mean fire return interval for the period 1650-1905 was 2.2 years. Recently developed models suggest that large areas of the United States once burned multiple times a decade (Guyette et al. 2012), with some sites igniting more frequently than previously suggested. While these efforts provide better understanding fire return intervals, there have not been many efforts to consider this major component of a burn regime (frequency) while also including seasonality as a potential critical fire regime component.

There have been groundbreaking studies that targeted rapid fire-return intervals with burn treatments applied every one or two years (e.g., Glitzenstein et al. 1995). However, such efforts were rare and, like many other efforts, were often based on data collected over a decade or less. Although past research has provided important information, it is not clear whether frequent burn regimes studied over short time periods reveal ultimate fire effects. What may appear as slight differences among treatments over short time periods may not reveal fire effects based on small shifts over longer time periods. Also, many past fire regime studies often assess only effects on pines. However, in recent years there is a growing interest in fire effects on hardwood species, especially shrubs (Drewa et al. 2006; Kush et al. 1999; Thaxton and Platt 2006). If burning is ineffective over the long-term, hardwood species are likely to increase in dominance, slowly decrease light at the ground level, and so degrade native habitat structure. Appropriate habitat structure maintained by fire effects on hardwood species may be critical for maintaining the high diversity of ground cover plants (e.g., Kush et al. 1999) and vertebrates (e.g., Hermann et al. 2007). Both groups, herbaceous plants and vertebrates, have multiple species of conservation concern in longleaf pine habitat.

Long-term studies of fire regimes that include both frequency and season are needed to better understand effects that might appear to be minor or subtle over the short term. We report on results spanning 25 years, based on a fire effects study initiated in 1984. Results are based on prescribed fire regimes with three different, short-term frequencies (2, 3, or 5 years) plus no fire. In addition, inclusion of two seasons (winter and late spring) permits a comparison of complex regimes that has not commonly been available.

STUDY SITE

The study was conducted on the Escambia Experimental Forest (EEF) in Escambia County near Brewton, Alabama. The property is owned by T.R. Miller Mill Company; the Forest Service, in cooperation with the company, has maintained the site for research purposes since 1947. EEF is located on the Gulf Coastal Plain and encompasses approximately 1,200 ha. The predominant soil series is Troup, defined by low fertility and low organic matter content. The uplands are dominated by naturally occurring longleaf pine, with some small areas still supporting old individual trees. Much of the acreage of the site supports native ground cover with no indication of past agriculture activities. Additional information on EEF is found in Boyer (1987, 1995, 1999), Kush et al. (1999, 2000), and Barlow et al. (2010).

Over many years, a wide-range of long-term study plots, including the ones described in the current work, have been established on EEF using a shelterwood management system to study a variety of young longleaf pine stands (e.g., Croker 1956). Boyer (1984) describes establishment of the research plots and indicates that the parent, overstory trees in the plots used for the current project were removed in the winter of 1976. The juvenile "grass-stage" longleaf pine trees that remained were assumed to have established during the 1973 mast year.

METHODS

Study Design and Experimental Treatments

Seven treatments were replicated in each of three blocks, six burn treatments, and one unburned. The burn treatments were defined by two seasons and three fire return intervals (burn frequencies). Seasons were winter (mid-January through February) and late spring (mid-April through May); burn frequencies were every 2, 3, or 5 years. Each combination of treatments (season x burn frequency) was applied to one plot in each block. This resulted in treatment codes: Winter 2 (W2), Winter 3 (W3), Winter 5 (W5), Spring 2 (S2), Spring 3 (S3), and Spring 5 (S5). In addition, there was a plot in each block that remained unburned since 1979, 5 years prior to initiation of the first sampling efforts. Plots containing the No Burn treatment were coded as UB.

Areas sampled in each treatment plot are 20.1 x 20.1 m (0.04 ha). Prior to initiation of study treatments, research areas were thinned leaving 40 permanently marked study trees in each measurement plot. In Year 0, dominant longleaf trees averaged 3 to 4.3 m in height (Boyer 1984). All study areas, including those later assigned to a no fire treatment, were burned in the spring of 1979 to create an initial standardized time-since-last fire. Justification for the project and additional information on establishment of plots is found in Boyer (1984) and Barlow (2010).

Barlow et al. (2010) describes some aspects of conditions during the experimental fires, including ignition pattern (generally flank or strip head fires) and day-of-burn weather. Day-of-burn weather usually included fine fuel moisture of 7-10 percent, 35-55 percent relative humidity, and generally steady wind of 4.8-8.0 km/hr (3-5 mi/hr). Experimental burns usually followed rain and were executed in ways that were expected to minimize crown scorch of the pines.

Measurements

Beginning in 1984 and subsequently every 3 to 5 years, all measurement plots, including unburned ones, were assessed. Data were collected in late fall and early winter, after woody species had generally ceased growth but before any upcoming fire treatments. During each assessment year, all 40 longleaf pine individuals were tallied as alive or dead. Diameter at breast height (d.b.h.) was measured for all live trees and this value was used to calculate basal area (BA). Also, during each assessment year, all hardwood stems at least ~2.5 cm (1.0 in) in diameter at ~1.4 m (4.5 ft) height were counted and d.b.h. measured. Unlike longleaf pine trees, individual hardwood stems were not marked, and so individual stems could not be tracked over time. Also, unlike longleaf pines, the number of hardwood stems was not standardized at the initiation of treatments (see below). Although hardwood stems were identified to species during each sampling period, in the current paper we have pooled species and targeted the overall treatment effects on habitat structure.

Data were first collected in 1984 (Year 0) and the first experimental burn treatments were applied in 1985 (Year 1). Results spanning the first 25 years are reported below.

Statistical Analyses

Plots were evaluated for longleaf pine (1) tree survivorship and (2) mean BA of individual trees surviving until Year 25 and these assessments required multiple statistical approaches. A chi-square analysis was applied to assess survivorship of individual trees and repeated measure (ANOVA) using GLM Proc was used to assess mean BA. UB plots were not included in analyses because, although replicated among plots, this treatment is not based on two factors (season and frequency). However, as a basis for comparison we present results for the UB treatment in all graphs.

For hardwood stem data, ANOVA was also used to evaluate potential differences among sample years. Comparisons were made among treatments for (1) number of hardwood stems and (2) total BA of all hardwood stems within treatment type over 25 years.

RESULTS

Longleaf Pine Trees

Longleaf pine mortality was generally low; however, there was some loss of individuals over time. Over the entire sample period, there was a statistical difference related to year (chi-sq < 0.001; fig. 1). However, there was no significant difference based on longleaf pine mortality among the two seasons of burn (chi-sq $= 0.9322$) or three frequencies (chi-sq $= 0.9751$). Visual comparison between UB and all other treatments (fig. 1) suggests that mortality of trees in UB plots is similar to that experienced in burn treatments. Although treatments over time do not appear to have significantly influenced tree survivorship, data collected in Year 25 revealed differences in survivorship compared to earlier assessments. There was a substantial decline in number of live trees independent of treatment (fig. 1). Future observations will be required to better understand this result.

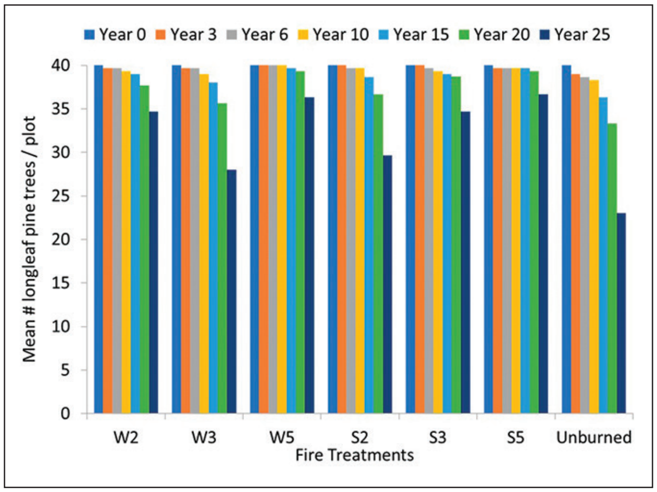

Figure 1—Mean number of longleaf pines per plot alive during each of seven sampling events spanning 25 years. Trees were 11 years old at Year 0.

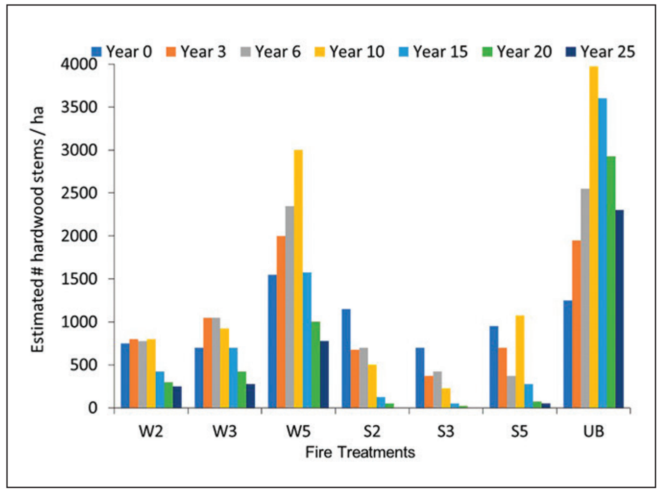

Figure 3—Estimated number of hardwood stems per hectare pooled over size classes. Hardwood stems below breast height (1.4 m) were not considered.

BA of longleaf pine trees alive in Year 25 did not differ significantly throughout the study, among season of burn ($p = 0.26$), fire frequency ($p = 0.80$), or season x frequency ($p = 0.13$) (fig. 2). In Year 25, the range of the average BA per tree, over all treatments and unburned plots, varied between 310 cm^2 to 344 cm^2.

Hardwood Stems

Density of all hardwood stems ≥ 2.5 cm d.b.h. (fig. 3) was significantly influenced by ($p = 0.02$) season of burn; however, there was no significant ($p = 0.07$) association with fire frequency. In addition, there was no significant difference related to the interaction of season x fire frequency ($p = 0.17$). Although UB plots could not be included in the analysis, observations indicated a common pattern in relationship of density of hardwood stems (pooled overall size classes) and change over time. Visual examination of figure 3 reveals that, beginning in Year 15, there were consistent declines in number of hardwood stems over all treatments. It is visually apparent that the magnitude of change differs among treatments (fig. 3) and appears to be especially true for all spring burn treatments. By Year 25, there are well-defined defined differences in treatment effect on number of hardwood stems, ranging from a mean of ~2,300 hardwood stems per hectare in UB plots to no hardwood stems observed in any of the S2 plots (fig. 3).

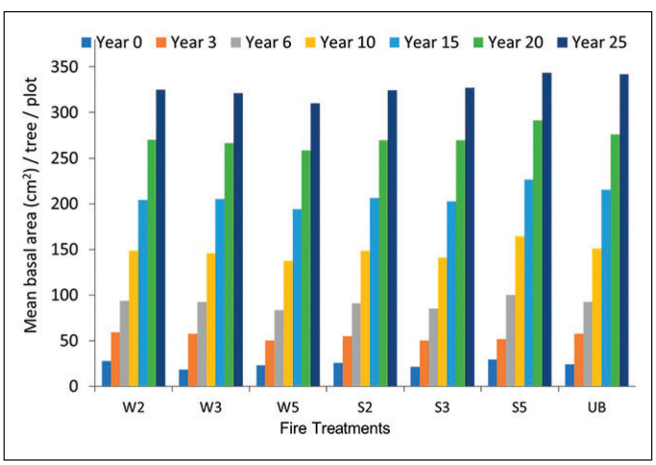

Figure 2—Mean basal area of individual longleaf pines per plot, alive in Year 25 of the study. Trees were 36 years old in Year 25.

When hardwood basal area was pooled over all stems, statistical comparison among fire treatments indicates a significant difference in hardwood stem BA associated with season of burn (fig. 4, $p = 0.02$). A visual comparison across all treatments reveals, after Year 15, there were consistent declines of BA in spring burn plots. Winter burn plots show less consistent patterns although all three fire return intervals supported higher BA in Year 25 compared to Year 0 (fig. 4). In addition, the mean BA of hardwood stems in UB plots steadily increased over all years (fig. 4).

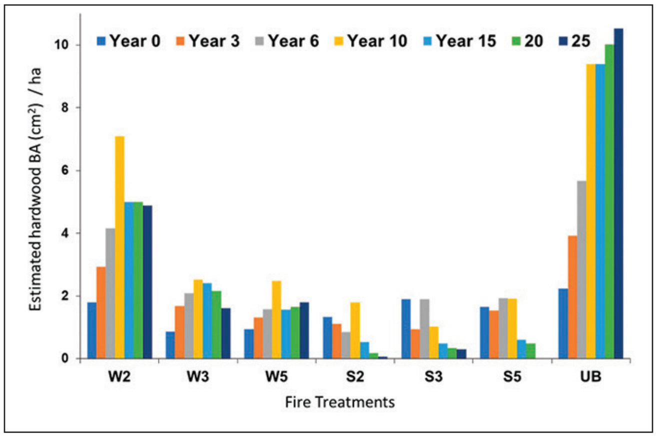

Figure 4—Estimated total basal area per hectare of all hardwood stems. Note that hardwood stems below breast height (1.4 m) were not included.

SUMMARY

In the current paper, we summarized results of a long-term research project on Escambia Experimental Forest. The data spans 25 years and is part of an ongoing, replicated project that compares six complex treatments based on two seasons (winter and late spring) and three different fire frequencies (every 2, 3, or 5 years). A seventh treatment remains unburned and serves as a comparison to burned plot treatments. The treatments were designed to cover some of the common categories of prescribed fire applied to this habitat type.

Summary of Longleaf Pine Results

An unexpected result was that during most of the 25-year study period, there was almost no effect of any treatment, including unburned, on survivorship or growth of longleaf pines. This was especially evident early in the research. Longleaf individuals were 11 years old at Year 0 of the project and this may have contributed to the high degree of early survivorship over all treatments. However, assessment of data collected in Year 25 revealed a potential shift in that pattern. Up until that time, all treatments averaged a total of 3 percent loss or less of trees. Although in Year 25, longleaf trees in plots that experienced any of the burn treatments during that time were more likely to survive compared to those in the UB plots. In addition, within the burn treatments during this last sample period, the Year 5 plots (regardless of season of burn) experienced less mortality compared to trees in Year 2 and Year 3 plots. However, there may be a confounding factor: During Year 25, plots assigned to Year 2 and Year 3 treatments were burned, but Year 5 plots were not scheduled for fire during that same period. Additional years of burn treatments and data collection will be required to fully understand this result and to determine if the pattern continues.

Summary of Hardwood Stem Results

Results of effects of different fire regimes on hardwood stem dominance provide information with significance for conservation concerns. Season of burn (winter versus late spring) may play a more significant role than the frequency of burn (2, 3, or 5 year) when hardwood control is considered. As suggested by Barlow et al (2015), frequency of growing season fire appears to be important but may play a smaller role compared to season of burn, at least during the 25-year period.

Although the assessments are complex, they reveal that both regime factors (season and frequency) may play important roles in managing for hardwood control. For example, by Year 25, spring fires demonstrated significantly better control of the number of hardwood stems compared to winter burns. This was also the case for managing total BA of hardwood stems. Not only did it appear as if spring fires were more effective in controlling hardwoods, burns every 2 or 3 years were more likely to reduce BA compared to burns every 5 years. Over the 25 years of the study, controlling midstory hardwood stem numbers to meet conservation goals appears most likely to have benefit from frequent burns in the growing season compared to other fire regimes and fires every 2 or 3 years appear to be the most productive. Because burns every 5 years may result in highly ineffective control of hardwood stems, especially those stems above breast height, we suggest caution against management plans that rely not only on burns based on that frequency but also that plan to apply fire every 4 years. However, management needs may be met with longer fire return intervals if there are little or no conservation interests of concern or if the site undergoes periodic herbicide treatment fires every 4-5 years.

Final Thoughts

Our results appear to support estimations of historical fire return intervals suggested by Frost (1998, 2006) and models developed by Guyette et al. (2012). Frost (1998, 2006) places the location of the Escambia Experimental Forest study site as being on the border between areas that burned, on average, every 1-3 years and 4-6 years. Work by Guyette et al. (2012) indicates that the site averaged fires every 2-4 years.

Unfortunately, neither body of research (Frost 1998, 2006; Guyette et al. 2012) addresses the fire regime component of seasonality, nor is there a large body of literature that addresses that topic. However, it is generally assumed that most lightning strikes in the Southeast United States often occurred in the middle of the summer (e.g., Komarek 1964, 1974), with some burns happening during that period, but with fires ignited as early as late spring and not ceasing until early fall (e.g., Duncan et al. 2010). Long-term research on this topic is generally lacking.

Over much of the 25-year study period, all burn treatments supported hardwood stems at densities that apparently did not exist historically in longleaf pine ecosystems in south Alabama. Bartram (1791) described what are now understood to be longleaf pine ecosystems as open, park-like grassland. Over two centuries later, many researchers working on patches of what are thought to be healthy longleaf ecosystems describe similar habitat (c.f. Hanberry et al. 2018). Once hardwoods are widely established, it requires significant effort to effectively prescribe fire to eliminate them from the system. The size and number of hardwood stems in the spring 5-year treatment could not support natural regeneration of longleaf pine; competition is too severe to allow establishment of seedlings. If plots in the spring 2- and 3-year treatments were to go another year of two without fire, it would be difficult to effectively manage for longleaf pine, native ground cover, and other aspects of conservation concern. Historically longleaf pine ecosystems supported a minor hardwood component on the upland sandy sites that are prevalent on Escambia Experimental Forest. Lack of frequent growing season fire allows high densities of hardwood stems to establish in the understory of longleaf ecosystems. This outcome is a major factor contributing to the high number of threatened and endangered species in the Southeast. Proactive use of prescribed fire is needed to effectively limit hardwoods in longleaf pine forests. Difficulty and expense of removing hardwoods from these systems is time-consuming and costly, and often dangerous the longer fire is not applied or is done so ineffectively.

ACKNOWLEDGMENTS

This paper is in memory of Dr. William Boyer who envisioned the research project over 40 years ago: he understood, when few others did, the importance of fire to the management of longleaf pine ecosystems. He was promoting the use of frequent fire in the growing season when most were content to burn every 3 years in the dormant season. He was studying what was happening when most were just looking.

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