# FUEL LOADING AND FIRE INTENSITY—EFFECTS ON LONGLEAF PINE SEEDLING SURVIVAL

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Abstract—Modeling silvicultural practices after natural disturbance, with a particular focus on the use of fire and small canopy openings, may be particularly appropriate in longleaf pine (*Pinus palustris* Mill.) woodlands managed for multiple age classes and over long time scales. However, information about the effects of litter accumulation and fire temperatures on longleaf seedlings is inconsistent. This study examined the effects of season of burn, pine litter loading, and subsequent fire intensity on survival and growth of longleaf seedlings. For both fire seasons, mortality increased over time and was highest for the smallest grass stage seedlings and in the high litter treatment. Litter levels affected fire intensity but had relatively minor effects on subsequent growth of surviving seedlings, but season of burn did affect seedling mortality. The grass and herbaceous fuels of the low litter treatment did not burn during either season, indicating the importance of pine needles for fuel.

## INTRODUCTION

Modeling silviculture after natural disturbance has become a popular concept in forest management. With the resurgence of interest in restoring and managing longleaf pine (*Pinus palustris* Mill.) ecosystems in the Southeast, the natural disturbance model may be particularly applicable. Historically, frequent small-scale natural disturbances have played a significant role in maintaining the longleaf forest structure and composition, resulting in a heterogeneous canopy structure and subsequent variation in pine litter deposition (Mitchell and others 2006). Initial restoration efforts have focused both on establishing longleaf pine regeneration and reintroducing fire, the dominant historic disturbance, into these systems. However, results from studies comparing the effects of litter accumulation on fire temperature and the subsequent effects on seedling growth and survival are inconsistent, and generally do not consider different levels of needle litter accumulation in conjunction with groundcover.

We know that longleaf pine seedlings are extremely tolerant of fire once they are well established and have achieved a minimum size (Croker and Boyer 1975). They are not, however, fireproof and the use of prescribed fire can affect longleaf seedling survival and growth. Several factors can affect seedling response to fire, including growth stage (both within the annual cycle and long-term), vigor and competitive status, and the fuel loading around the seedlings. The relative importance of these individual factors is not easy to determine, however, due to the number of interactions between them. For instance, natural longleaf pine regeneration is typically found in larger openings away from adult trees due to the overstory competition with seedlings as well as the interaction of seedlings with fire. The overstory affects resources such as light availability and has a direct effect on seedling growth (Battaglia and others 2003, McGuire and others 2001, Palik and others 1997). Survival, however, is often related to the fire resistance of grass stage seedlings, and increased litterfall near mature trees leads to higher fire temperatures (Glitzenstein and others 1995, Williamson and Black 1981) such that a greater seedling size is needed to survive fire when close to adults (Boyer 1974, Bruce 1950). Further, seedling response is rarely evaluated in response to operational prescribed fire due to the lack of controls and the high variability. Yet, it is the response of longleaf regeneration to operational fires that is important for long-term sustainable management in these forests.

Our objective for this study was to examine the survival and growth response of longleaf pine seedlings to operational prescribed fire conducted in both the dormant and growing seasons. Specifically, we: 1) examined the correlation between fuel loading and fire temperature; 2) quantified the variation in fire temperature with height; 3) examined interactions between seedling size and fuel loading on survival and growth; and 4) evaluated the effectiveness of grass fuels in the absence of pine litter.

## METHODS

### Study Site

The research was conducted at the Joseph W. Jones Ecological Research Center at Ichauway, an 11 600 ha reserve in southwest GA. The climate is subtropical with mean daily temperature ranging from 5 to 17 °C in the winter and 21 to 34 °C in the summer (Goebel and others 2001). Annual precipitation averages 132 cm, evenly distributed throughout the year. Over 7 000 ha of the site have an overstory of 75 to 95 year-old naturally regenerated second-growth longleaf pine and a species-rich groundcover, including wiregrass (*Aristida stricta* Michx.) (Kirkman and others 2001).

The operational prescribed fires were conducted at two different times of the year in similar burn units. Both units had 1-year rough and had been managed with frequent fire for over 50 years. Soils were moderately-well to well-drained Ultisols. The growing season burn unit was 17 ha in size while the dormant season burn unit was 160 ha. Treatment plots in both burn units were located in canopy gaps with abundant natural regeneration. Average basal area of the overstory for the treatment plots was 1 $m^2$/ha. Groundcover in the plots was dominated either by wiregrass or by slender bluestem (*Schizachyrium tenerum* Nees).

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**Experimental Design and Sampling**

Operational prescribed fires were conducted in both the growing season (July 2004) and the dormant season (January 2005) using strip headfire ignition techniques. Within the burn units for each season of burn we established 3 replications of 3 fuel treatments (i.e., n=9 plots per season). The treatment plots were 7 by 14 m (approximately 0.01 ha) and were located to include a size range of naturally regenerated longleaf pine seedlings. The three plots in each replicate were constrained as to location (they needed to be relatively close together) to facilitate the use of data recorders for the thermocouple set-up (see details below). However, treatments were assigned randomly to the three plots within a replicate.

The three fuel treatments were 1) low litter treatment where the pine straw was raked from the plots, 2) control or ambient pine litter where the existing litter was left intact, and 3) high litter treatment where additional pine straw was added to the plot. The raked pine litter from the low litter treatments was added to the high litter plots to roughly double the amount of pine straw in the high litter treatment, resulting in approximately 0, 1x and 2x levels of pine litter in the treatments.

Fire temperatures were monitored in the treatment plots using thermocouple arrays. Fire temperatures were estimated at three heights (ground or 0, 1, and 2 m) at 2 locations within each plot using K-type thermocouples (6 thermocouples per height and treatment combination, 54 total) attached to galvanized conduits placed 3.5 m from plot edges. Thermocouples were attached to multiplexors using type K AWG 20 thermocouple wire (maximum temperature 900 °C). Multiplexors were attached to Campbell dataloggers and installed in heavy-duty toolboxes which were buried at the center of each replicate block under approximately 30 cm of soil just prior to burning. Thermocouples were sampled at 3 second intervals, and residence times above a threshold temperature of 70 °C calculated.

All seedlings within the plots were mapped and tagged prior to the fire treatments. In addition, each seedling was measured for root collar diameter (RCD) and height to the base of the terminal bud, and a height class group assigned based upon this height measurement. Height classes were assigned to seedlings as follows: 1 = small grass stage (< 0.2 m); 2 = grass stage (< 1 m); 3 = rocket stage (in active height growth, < 2m); and 4 = sapling (> 2 m tall with RCD < 15 cm). Initial seedling mortality was assessed two weeks after the fire application. Seedling growth (basal diameter and height) were measured along with survival at the end of the first growing season following the fire (October 2004 and 2005 for growing season and dormant season, respectively) and at the end of the 2006 growing season.

Data were analyzed in SAS (v. 9.1 for Windows, SAS Institute, Inc., Cary, NC) using SAS/STAT. Seedling growth data were analyzed using Proc GLM, while categorical data (survival, residence time) were analyzed using Chi-square tests for independence. Statistical significance was assessed at $\alpha = 0.05$ level.

## RESULTS AND DISCUSSION

The fuel treatments did result in different fire characteristics during the operational prescribed fire. Most striking was that the low litter treatments (with pine straw removed) essentially did not burn for either season – the flame front burned up to the plot boundaries on all sides but did not burn at all into the plots. This result was not completely surprising for the growing season fire as the groundcover vegetation was green and succulent. In the dormant season fire, however, the groundcover vegetation was dry and brown yet still did not burn even though wiregrass was the dominant species in these plots. In contrast, the control and high litter treatments had complete fuel removal as the fire front burned through the plots.

Fire intensities, as indicated by maximum recorded temperatures, were in general positively correlated with fuel loadings (fig. 1). Growing season fires were on average hotter than the dormant season fires but there were no statistical differences in maximum observed temperatures between seasons. The patterns of maximum temperature with sensor height followed expected trends, especially when averaged across fuel treatments (fig. 1), but the patterns for the dormant season fire with height were more variable.

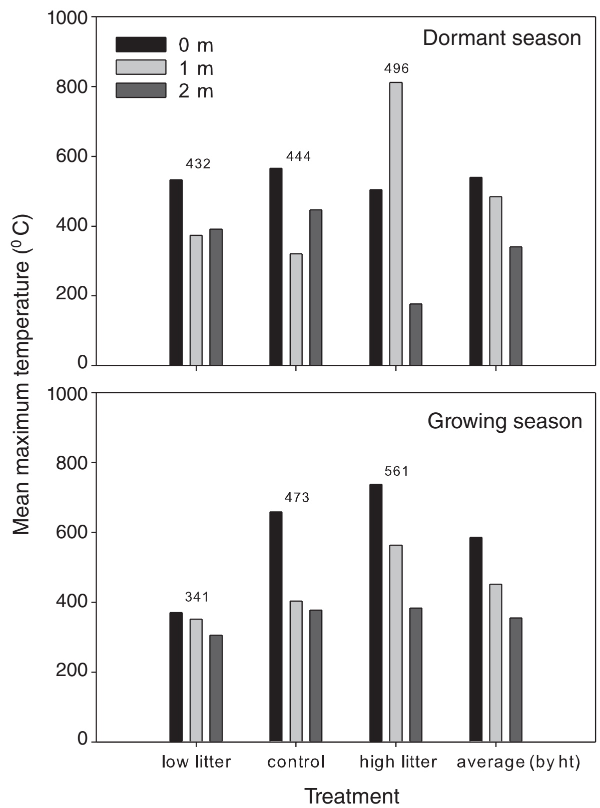


Figure 1—Mean maximum temperature measured at each sensor height for each fuel loading treatment and averaged across treatments. Numbers over bar groups represent the maximum temperature measured across heights. Upper graph is for dormant season burn; lower graph is for growing season burn. Although some patterns are apparent with increasing fuel loads and sensor height, no statistical differences were detected.

For plant tissue death, it is not only the temperature to which the tissue is exposed that is important, but also the length of that exposure, also known as the residence time. The threshold temperature for instantaneous (i.e., less than 1 second) plant tissue death is generally thought to be 60 °C (Wright 1970), but this value varies somewhat by species with the value for longleaf pine being slightly higher (Wade and Johansen 1986). We calculated the residence time for temperatures above 70 °C as this will certainly result in tissue death. The results in figure 2 illustrate the variability in residence times with sensor height and fuel treatment. The most obvious result is that the growing season fire had much longer residence times above 70 °C than was measured for the dormant season fire. This result is not surprising given the much higher air temperatures during the growing season and the reduced heating required to reach the threshold temperature. A pattern of increasing residence time with increasing fuel loading only holds true for the ground-level sensor in both seasons (fig. 2). The more variable pattern at the 1 and 2 m heights is possibly due to eddy currents moving heat in variable patterns above the flame front (Clements and others 2006), where it is detected by the thermocouples. Although there were not consistent patterns of increasing residence time with increasing fuel loading across the sensor heights for either season, the residence times were statistically different between heights as indicated by a Chi-square test ($p<0.0001$ for both seasons).

Seedling survival was reduced by higher fuel loading, both at the end of the first growing season and at the end of the 2006 growing season (fig. 3); the survival rates for the low litter and control treatments were not statistically different, but both were statistically greater ($p<0.001$ by $\chi^2$ test) from the high litter survival rate when data were pooled between growing seasons for both measurement times (fig. 3a). In comparing the survival by season of burn (fig. 3b) the survival rate from the growing season was significantly lower ($p<0.0001$ by $\chi^2$ test). Examining the data more closely indicated that most of the mortality was concentrated on the smallest seedlings (those in height class 1), and that the mortality tended to increase with fuel loading at both measurement times (fig. 4a). This result is similar to that found by Grace and Platt (1995) for very small longleaf pine seedlings experiencing different levels of pine needle loading due to canopy density. Perhaps more interesting is that mortality increased with time for all fuel treatments (fig. 4a), even though the low litter treatment plots did not burn. This result indicates that direct fire effects are not the only cause of mortality detected in this study, though we do not know specifically what those other causes might be. Similar to the results for fuel treatment, the growing season fire had a lower survival rate in comparison to the dormant season fire at both measurements (fig. 4b).

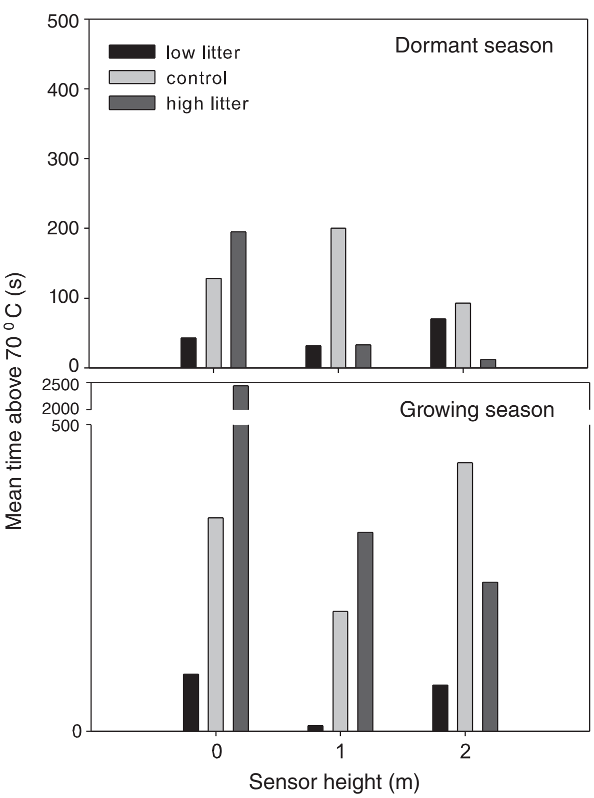


Figure 2—Average residence time above 70 °C by fuel loading treatment and sensor height. Note scale differences between upper (dormant season) and lower (growing season) graphs. Residence time was statistically different between sensor heights ($\chi^2$ $p<0.0001$) for both seasons but was not statistically different between fuel treatments.

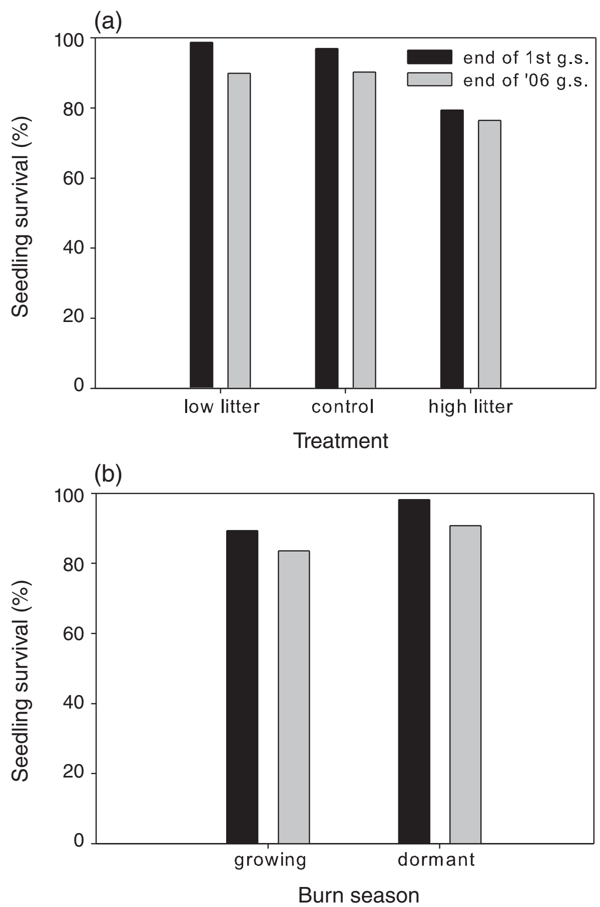


Figure 3—Percent survival for all seedling size classes, measured at the end of the first growing season post-fire and the end of the 2006 growing season, by (a) fuel loading treatment and (b) season of burn. Chi Square tests showed significant differences between fuel treatments ($p<0.001$) and burn seasons ($p<0.0001$) at both time periods.

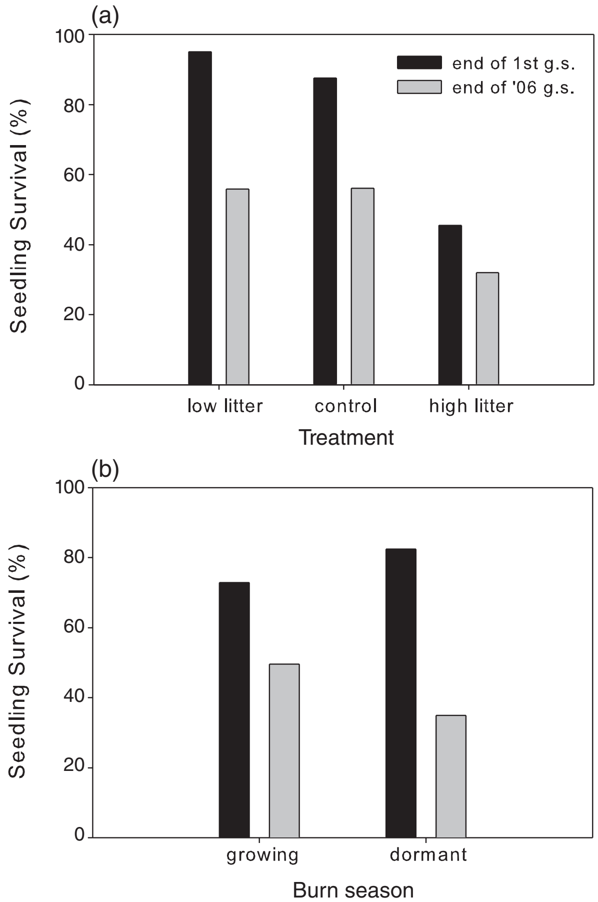


Figure 4—Percent survival for smallest seedling size class (small grass stage, height class 1, <0.2 m), measured at the end of the first growing season post-fire and the end of the 2006 growing season, by (a) fuel loading treatment and (b) season of burn. Chi Square tests indicated significant differences for the fuel loading (p<0.0001) and fire season (p<0.01) at both time periods.

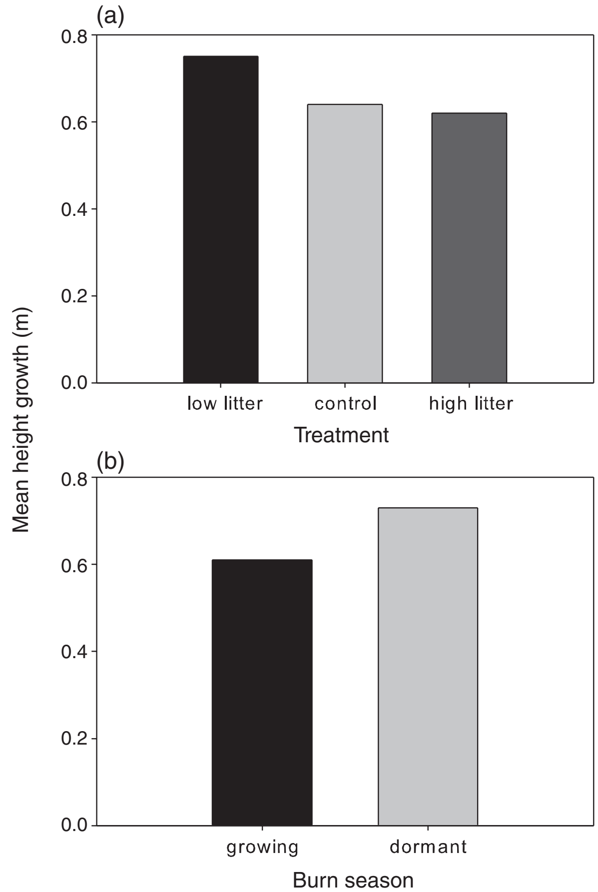


Figure 5—Mean height growth response for all seedling sizes by (a) fuel loading treatment and (b) season of burn. No statistical differences were found between treatments or seasons using ANOVA procedures.

Growth responses to fuel treatment and fire season were mixed. There were no significant differences ($\alpha = 0.05$) in height growth at the end of the 2006 growing season either by fuel loading or season of burn, though there appears to be a trend of decreasing height growth with increased fuel (fig. 5a), and height growth following the dormant season burn was slightly greater (fig. 5b). Given the very small RCD values recorded for many of the smallest seedlings it was difficult to calculate directly positive RCD growth; instead, we compared initial and final RCD to assess if the treatments led to any differences in RCD. With this data limitation, there was no statistical or apparent response in RCD growth with fuel loading (fig. 6). The effect of burn season on RCD could not be assessed in this instance because the growing season and dormant season populations had significantly different average RCDs at both the initial measurement and the final measurements (data not shown). The analysis of both the height and RCD data was complicated by the large range of seedlings sizes measured in the study and the resulting high variability.

The results from this study present a case study examining the effects of operational prescribed fire on seedling mortality and growth with varying levels of fuel loading. The results should not be extrapolated broadly to all prescribed fire in longleaf pine forests, but they do begin to address gaps in our knowledge of fire and longleaf seedling response. Of particular interest is the fine-scale variability in fuel loading found under a natural longleaf pine canopy and the potential influence of this fuel variability on seedling demography (Mitchell and others 2006).

## SUMMARY

1. Pine fuels (needles) are necessary for fires to carry well in these forests, particularly in natural gaps and even with the presence of wiregrass and in the dormant season when vegetation is cured.
2. Prescribed fire did have an effect on longleaf seedling and sapling mortality and growth, but fire was not the only influence and many factors interact to determine the response to fire.
3. Higher levels of pine fuel loading generally led to more intense fires and higher seedling mortality.

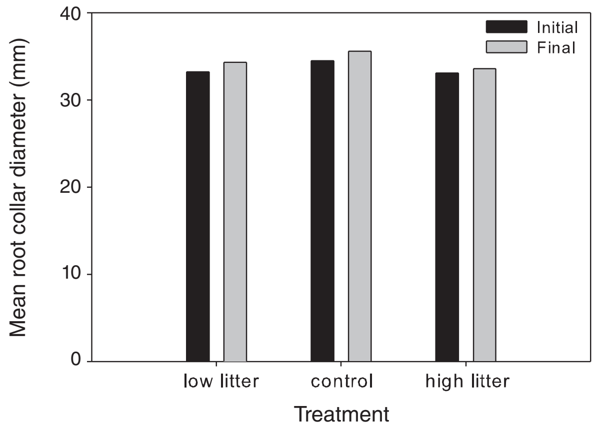


Figure 6—Average root collar diameter (RCD) by fuel loading treatment at beginning of study and at the end of the 2006 growing season. ANOVA tests found no statistical differences between treatments at either measurement time.

4. Contrary to our initial assumption we did not detect any significant seasonal differences in seedling response to prescribed fire.
5. Small seedlings are much more likely to die following the application of prescribed fire, but fire is not the only cause of this mortality as delayed mortality occurred in low litter plots that did not carry fire.
6. More controlled experiments are necessary to determine the relationships between fuel loading and fuel bed characteristics and seedling growth response and demography.

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