A COMPARISON OF THE ECOLOGICAL EFFECTS OF HERBICIDE AND PRESCRIBED FIRE IN A MATURE LONGLEAF PINE FOREST: RESPONSE OF JUVENILE AND OVERSTORY PINE

Jennifer L. Gagnon and Steven B. Jack[1]

Abstract—Prescribed fire may be removed as a forest management tool by regulatory agencies concerned about air quality issues. Herbicides have been proposed as substitutes for prescribed fires in southern pine forests, but we are aware of no studies that examine the effects of herbicide application in mature, fire-maintained longleaf pine (*Pinus palustris* Mill.) forests. We compared the effects of prescribed fire (F), herbicide application (Velpar®L) (H), and a combination treatment (F+H) in a mature longleaf pine forest with a 60+ year history of prescribed fire. The responses of naturally regenerated juvenile longleaf pine and overstory trees were monitored for 3 years. Juveniles receiving the F+H treatment had the highest mortality; juveniles in the H treatment were the largest, with the highest percentage (134) growing into the sapling class. Growth response of the mature trees was not consistent among years. Overstory hardwood mortality was over 60 percent in the F+H and H treatments.

INTRODUCTION

Historically, fire was a frequent natural disturbance in longleaf pine (*Pinus palustris* Mill.) ecosystems in the Southeastern United States (Glitzenstein and others 1995, Landers and others 1995, Wahlenberg 1946). Disturbances from frequent, low intensity fires are essential to maintain the structure, diversity, and function of this forest type. Specifically, fire: (1) reduces fuels, minimizing wildfire incidence (Brockway and Lewis 1997, Brockway and Outcalt 2000, Wahlenberg 1946, Lemon 1949); (2) exposes a bare mineral soil seedbed necessary for longleaf pine regeneration (Brockway and Lewis 1997, Brockway and Outcalt 2000, Hodgkins 1958, Lemon 1949, Provencher and others 2001, Rebertus and others 1989, Wahlenberg 1946); (3) prevents hardwood encroachment (Brockway and Lewis 1997, Brockway and Outcalt 2000, Brockway and others 1998, Heyward 1939, Lemon 1949, Rebertus and others 1989, Wahlenberg 1946); (4) promotes diversity of understory species and flowering of certain species (such as wiregrass [*Aristida beyrichiana* Trin. & Rupr.); Mulligan and others 2002]; (5) provides habitat for wildlife, including rare and endangered species (Brockway and Lewis 1997, Brockway and Outcalt 2000); and (6) controls brown spot needle blight infection (Brockway and Lewis 1997, Brockway and Outcalt 2000, Lemon 1949, Rebertus and others 1989, Wahlenberg 1946).

Given the historical and ecological importance of fire in the region, prescribed fire has become an important tool for managing longleaf pine forests (Glitzenstein and others 1995, Landers and others 1995). However, potential restrictions on the use of prescribed fire, due to health and safety concerns regarding particulate and smoke production, have emphasized the need to look at alternatives. One such alternative may be herbicides. Herbicides have been widely used in forestry over the past 2 to 3 decades in intensively managed forests, where the primary management objective is fiber production (Haywood 1994, Haywood and Tiarks 1990). Herbicides have been shown to: (1) increase tree growth by controlling non-crop vegetation (Haywood 1994, Haywood and Tiarks 1990); improve habitat for certain wildlife species (McComb and Hurst 1987); (2) control hardwood competition (Haywood and Tiarks 1990, McComb and Hurst 1987); and (3) release seedlings from competing vegetation (Haywood and Tiarks 1990, McComb and Hurst 1987).

To date, little or no research has addressed the ecological impacts of herbicide treatment in mature mesic longleaf pine forests, and we are aware of only one study (Chen and others 1977) that directly compares the effects of herbicides and prescribed fire in mature or semi-mature forests. We initiated this study to evaluate the relative effects of herbicide application, as compared to prescribed fire, on the control of vegetative competition, impacts on native flora and fauna, and on the ecological function of mature longleaf pine forests. This study was not designed to examine the efficacy of herbicide in controlling hardwoods or maximizing growth rates but rather to compare the effects of herbicide relative to prescribed fire.

Specifically the objectives of this paper were to: (1) compare the growth and survival of longleaf pine juveniles to prescribed fire and herbicide application; and (2) compare the growth and survival of overstory trees (including both pine and hardwood) to prescribed fire and herbicide application. Our hypothesis was that growth and survival of both the juveniles and overstory would be similar among the treatments. Other ecological responses (e.g., biomass accumulation, canopy openness, species richness, nitrogen cycling, litter decomposition, and wildlife) were also monitored, but these data are not presented.

METHODS

Study Site

The study was conducted at the Joseph W. Jones Ecological Research Center, at Ichauway, located in southwestern Georgia, U.S.A. in the lower Gulf Coastal

[1]Lead Research Technician and Conservation Ecologist, Joseph W. Jones Ecological Research Center, Route 2 Box 2324, Newton, GA 39870, respectively.

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Plain (31° 13'N, 84° 29'W). The 11,600 ha property contains approximately 7,500 ha of longleaf pine. The study plots were located on old-field mesic sites (areas with little or no wiregrass) dominated by naturally regenerated second growth longleaf pine, approximately 70+ years old. Historically, frequent prescribed surface fires have been used to manage the sites. Dominant soil types range from somewhat poorly drained to somewhat excessively drained Ultisols.

Study Design

The study used a randomized complete block design with four replications of three treatments: 1. F = fire (applied June, 2000); 2. H = herbicide (hexazinone; Velpar® L spot applied on a 1.2- x 1.8-m grid at a rate of 2.5 L ha^{-1}, February, 2000). This particular herbicide treatment was chosen to minimize impact on groundcover plants and diversity, not to maximize hardwood control; and 3. F+H = fire + herbicide. Blocks were a minimum of 8 ha, and each treatment was represented once within each block. Ten 0.10-ha circular subplots were established within each treatment plot (n = 40 subplots per treatment) to monitor ecological effects. In 1999, pretreatment data were collected. All plots were burned in the summer (July-August) of 2002. Final juvenile and overstory measurements were made in the fall of 2002, following the prescribed fire.

Measurements

Juveniles—Within each treatment plot, 8 subplots with advanced natural longleaf pine regeneration were identified as regeneration subplots (n = 24 regeneration subplots total). Within each regeneration subplot, 20 seedlings were tagged for repeated measurements. The seedlings were selected so that the number of trees in each of three height classes was approximately equal (height class 1 = grass stage, less than 1 m tall; height class 2 = rocket stage, greater than 1 m but less than 2 m tall; height class 3 = saplings, greater than 2 m tall and diameter at breast height (d.b.h.) less than 10 cm. All regeneration was assumed to be from the 1987 seed crop (age 12 years at study establishment). End of growing season measurements were made in 1999 (pretreatment) and annually thereafter. Measurements included height (to tip of bud) using a height pole and either root collar diameter (for seedlings in height classes 1 and 2) or d.b.h. (for seedlings in height class 3). In 1999 and 2000, only one diameter measurement was taken for each juvenile tree; in 2001 and 2002, two diameter measurements, perpendicular to one another, were taken for each tree and averaged. The two measurement method takes into account the irregular shape of seedling stems and therefore may provide a more accurate estimate of diameter.

Overstory—Prior to treatment application (1999) and in 2001 and 2002, end of growing season height, d.b.h., species and status (living/dead) of all trees (d.b.h. > 6 cm) were recorded in each of the 0.10-ha circular subplots. Ingrowth (into the 6-cm diameter class) was also recorded in 2001 and 2002.

Data Analysis

SAS® software [V (9) of the SAS System for Windows] was used to analyze the data. Growth data were examined using a repeated measures design (Proc GLM). Pretreatment measurements were included as covariates in the analyses because there were strong correlations between pretreatment and post-treatment measurements as well as significant differences among pretreatment measurements. Survival data were examined using the Chi Square test for independence. Significance for all analyses was determined at $\alpha = 0.05$.

RESULTS

Juvenile Response

Growth—Mean seedling diameter decreased between 2000 and 2001. This decrease probably resulted from differences in measurement techniques (as described above) rather than from treatment effects. No significant differences in seedling diameter were observed in 2001 (fig. 1a). In 2002, however, seedling diameters in the H treatment were significantly larger than in the F and F+H treatments (F = 4.3 cm, F+H = 4.2 cm, and H = 4.5 cm; $p = 0.0171$). No significant height differences were observed in 2000 (fig. 1b); however, in 2001 and 2002, seedlings in the F and F+H treatments were significantly shorter than seedlings in the H treatment (e.g., 2002: F = 3.1 m, F+H = 3.0 m, and H = 3.5 m; $p < 0.0001$).

Survival and ingrowth—Low seedling mortality was observed in 2000 (fig. 1c). By 2001, however, the Chi-Square test for independence indicated that seedling survival was highly dependent upon treatment ($p = 0.0147$). The highest survival rates were in the F and the H treatments (94 and 96 percent, respectively) and lowest in the F+H treatment (87 percent). The differences were further evident in 2002 (F = 92 percent, F+H = 82 percent and F+H = 92 percent; $p = 0.0043$). The percentage of seedlings leaving the grass stage (height class 1) and initiating height growth (height class 2) was inconsistent over the course of the study (data not shown); in 2002, the percentage of juveniles leaving the grass stage was highest for the F+H and H treatments (F = 72 percent, F+H = 82 percent and H = 82 percent). The increase in percentage of juveniles in the sapling stage (height class 3) was consistently highest for the H treatment, and consistently lowest for the F+H treatment (e.g., in 2002, F = 121 percent, F+H = 79 percent, and H = 134 percent).

Overstory Response

Growth—Longleaf pine was the dominant pine species in the overstory. The most dominant hardwood species were southern red oak (*Quercus falcata* Michaux), laurel oak (Q. *hemisphaerica* Bartram ex Wild.), and water oak (Q. *nigra* L.). Pine diameters were not significantly different among the treatments (fig. 2a). In contrast, 2001 mean hardwood diameters in the F+H treatment were significantly smaller (F = 26.4 cm, F+H = 25.3 cm and H = 26.1 cm; $p = 0.0006$); however, by 2002 these differences were no longer significant.

Pine total height varied significantly, but inconsistently, among the treatments in both 2001 (F = 22.9 m, F+H = 23.1 m and H = 23.3 m; $p = 0.0034$) and 2002 (F = 23.3 m, F+H = 23.6 m and H = 23.5 m; $p = 0.0239$); (fig. 2b). The shortest trees were consistently in the F treatment.

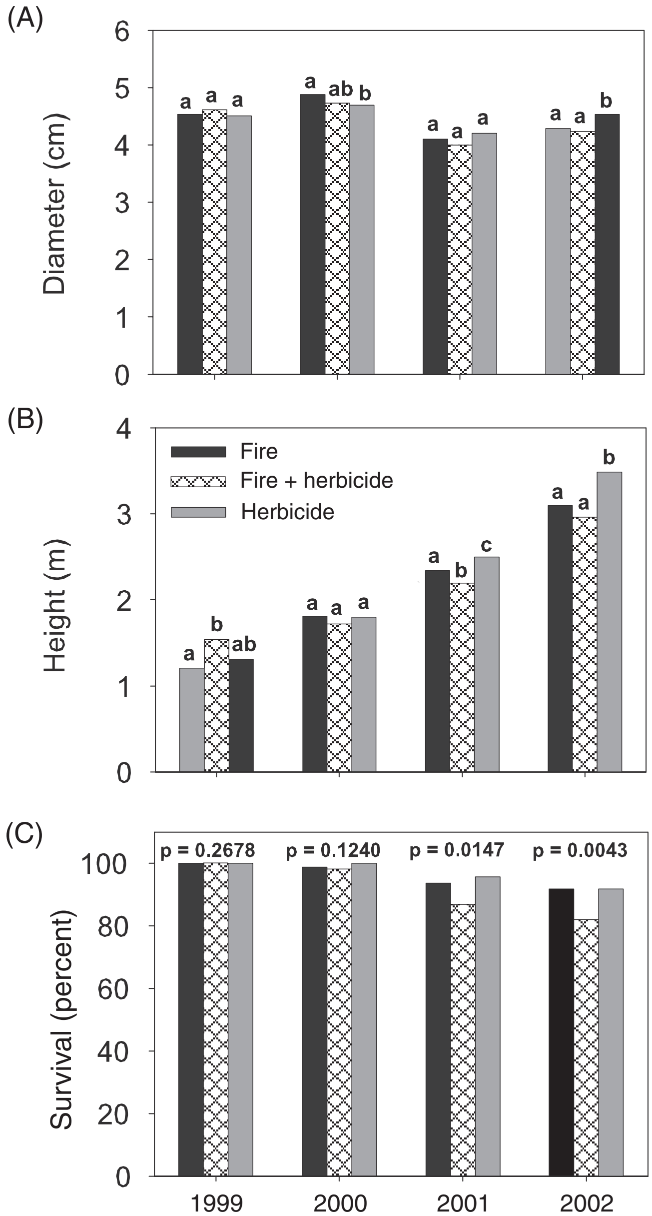

Figure 1—Longleaf pine seedling (a) diameters (b) heights, and (c) survival by year and treatment. Different letters denote significant differences among treatments at $\alpha = 0.05$. P-values are from the Chi-Square test for independence.

Hardwood total heights were not significantly different among treatments.

Pine live crown ratio (LCR) was significantly different in both 2001 (F = 43.2 percent, F+H = 43.6 percent and H = 44.7 percent; $p = 0.0401$) and 2002 (F = 44.4 percent, F+H = 46.1 percent and H = 45.8 percent; $p = 0.0069$) (fig. 2c). Pine LCR was consistently significantly lower in the F treatment compared to the F+H and H treatments. Hardwood LCR was also significantly different among the treatments in both 2001 (F = 68 percent, F+H = 53 percent and H = 66 percent; $p < 0.0001$) and 2002 (F = 61 percent, F+H = 49 percent and H = 65 percent; $p < 0.0001$), but unlike the pines, was significantly lower in the F+H treatment.

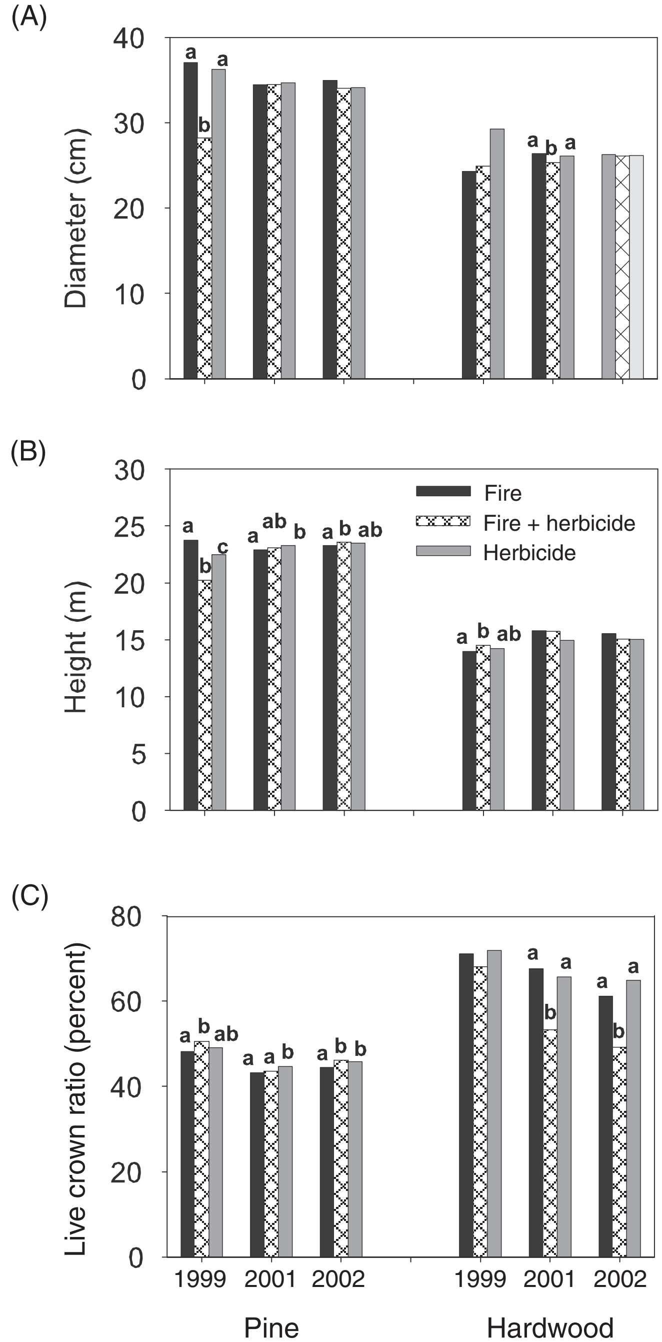

Figure 2—Overstory (a) diameters (b) heights, and (c) live crown ratios by year, treatment, and species group. Different letters denote significant difference at $\alpha = 0.05$. P-values are from the Chi-Square test for independence.

Survival and ingrowth—None of the treatments had a detrimental effect on overstory pine survival (in 2002, mortality was less than 3 percent for each of the treatments) (fig. 3a). In contrast, hardwood mortality was high in the F+H and H treatments (F = 2 percent, F+H = 63 percent and H = 70 percent). Pine ingrowth into the 6 cm diameter class was greatest for the F+H treatment and lowest for the H treatment (F = 70 trees per ha (TPH), F+H = 130 TPH and H = 10 TPH) (fig. 3b). Hardwood ingrowth was greatest in the F treatment and lowest in the H treatment (F = 110 TPH, F+H = 40 TPH and H = 20 TPH).

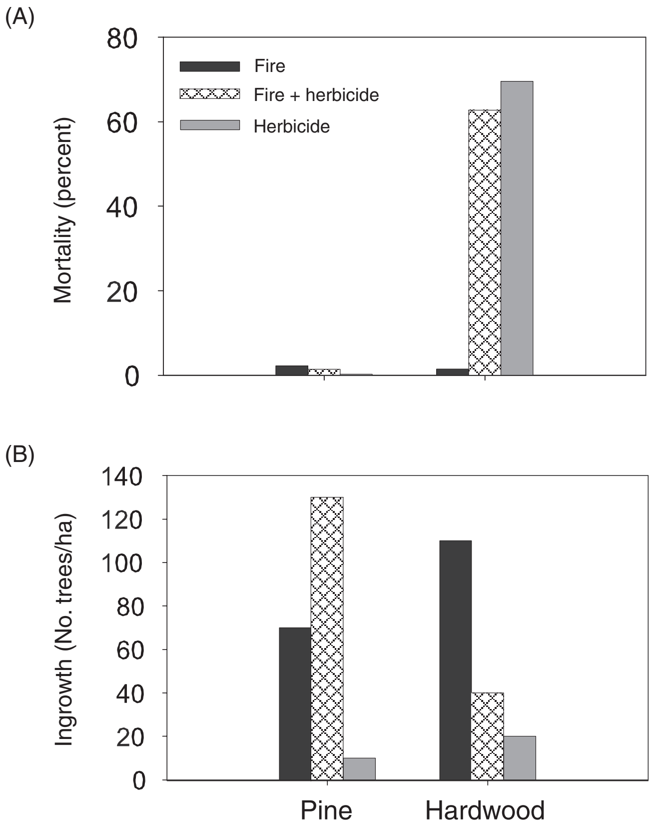

Figure 3—Pine and hardwood (a) overstory mortality and (b) ingrowth into the 6 cm diameter class, by treatment, in 2002. P-values are from the Chi-Square test for independence.

DISCUSSION

Prescribed fire is the main management tool in mesic longleaf pine ecosystems in the Southeastern United States. Recently, concern over the safety of using prescribed fire, particularly near urban areas, has indicated the need to explore alternative management tools. One such tool is herbicide application. Chen and others (1977) compared the effects of fire to the effects of herbicide application in loblolly-shortleaf pine (*Pinus taeda* L., *P. echinata* Mill.) forests; however the effects of these treatments on mature mesic longleaf pine forests have not been directly compared. This paper presents a portion of a larger study designed to compare the ecological effects of the treatments. The F treatment served as the control because repeated prescribed fires have been the standard management tool in this forest for over 60 years. As such, the discussion of the results will compare effects of the F+H and H treatments relative to the F treatment.

Results of this study suggested that if maximizing pine tree growth and survival and top-killing overstory hardwoods were the main management objectives, then herbicide application alone was an effective management tool. The H treatment increased seedling height and diameter growth, while maintaining seedling survival at levels comparable to the F treatment. In addition, the H treatment did not have a negative effect on overstory pine growth or survival but effectively top-killed overstory hardwoods. In mature longleaf pine forests, however, the management objectives are numerous, and maintenance of biodiversity, ecosystem function, wildlife habitat (particularly for rare and endangered species), and forest structure (i.e., open canopy, little or no midstory) may take precedence over maximizing pine growth.

Preliminary results from other aspects of this study indicated other management objectives were not being met when herbicide was used in place of prescribed fire. One problem was related to the method of herbicide application. The spot application was effective in top-killing overstory hardwoods with large root systems, which ensured contact with the herbicide. However, understory hardwoods with smaller root systems did not necessarily make contact with the herbicide. The death of the large trees released the smaller stems, including stems of resistant species, such as sassafras [*Sassafras albidum* (Nutt.) Nees]. Although this trend was not apparent in the ingrowth data presented in this paper, standing biomass data (not presented) showed an increase in woody midstory biomass in the H treatment (F = 163 g m^{-2} and H = 360 g m^{-2}). Even if a broadcast herbicide application is used, in the absence of prescribed fire, repeated herbicide treatments would be needed on a regular basis to maintain control of hardwoods.

Another problem associated with the H treatment was a significant increase in debris biomass (F = 3316 g m^{-2}, F+H = 3418 g m^{-2}, and H = 4217 g m^{-2}) and total biomass (F = 3741 g m^{-2}, F+H = 3743 g m^{-2} and H = 4817 g m^{-2}) in these plots compared to the F and F+H plots. In the absence of prescribed fire, biomass would continue to accumulate, thereby increasing fuel loads and potential for wildfire and eventually rendering the use of prescribed fire difficult and dangerous.

Brockway and Outcalt (2000) and Provencher and others (2001) demonstrated that rapid restoration on xeric sandhill sites could be achieved by using a combination of hexazinone application and prescribed fire. Our results suggested that the F+H treatment was useful in restoring mesic longleaf pine forests. Although there were some detrimental effects of this treatment on juveniles, survival remained above 80 percent 2 years after treatment. The F+H treatment could be used to effectively remove overstory hardwoods (a single application top-killed greater than 60 percent of the overstory hardwoods), while preventing smaller hardwood stems from growing into the midstory. Hexazinone resistant species, such as sassafras, would also be controlled. Repeated prescribed fire could be used to maintain the forest after a single herbicide application.

CONCLUSION

The results of this study, when examined apart from other ecosystem effects, suggested that herbicide application was a beneficial and perhaps suitable substitute for fire in mature longleaf pine ecosystems, at least for encouraging juvenile growth and removing hardwoods from the overstory. However, the ecological effects on the entire ecosystem need to be considered when making management decisions. Other data from this study, which were not presented here, showed an increase in woody midstory biomass as well as significant increases in debris and total biomass; biomass would continue to accumulate in the absence of fire. Over time, these changes would increase fire risk and result in larger scale changes in the longleaf pine ecosystem. The F+H treatment may be the most effective in rapidly restoring degraded sites, when followed by a prescription of regular prescribed fire.

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