Fire

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DELAYED PRESCRIBED BURNING IN A SEEDLING AND SAPLING LONGLEAF PINE PLANTATION IN LOUISIANA

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Abstract—To examine the effects of delaying prescribed burning for several years, I initiated five treatments in a 5- to 6-year-old longleaf pine stand: a check of no control; biennial hardwood control by directed chemical application; and biennial burning in either early March, May, or July. After the initial burns, longleaf pine survival decreased from 82 percent in February 1999 to 67 percent in November 2000. Mortality was highest among the smallest pine trees. Total pine heights in November 2000, adjusted for initial heights in February 1999, averaged 11.9, 11.5, 10.9, 11.4, and 11.3 ft on the five treatments, respectively. Total height was significantly greater on the check treatment than the average of the other four treatments, and March burning had the most adverse effect on height growth.

INTRODUCTION

Longleaf pine (*Pinus palustris* Mill.) forests once constituted a major ecosystem in the Southern United States stretching from southeastern Virginia to central Florida and west into east Texas (Outcalt and Sheffield 1996). These forests covered a wide range of site conditions from wet pine flatwoods to dry mountain slopes, but intensive exploitation reduced the extent of old-growth longleaf forests to only 3.2 million ac by 1993.

The continued loss of longleaf pine forests has endangered or threatened nearly 200 associated taxa of vascular plants and several vertebrate species (Brockway and others 1998). Protecting the remaining longleaf pine forests and restoring longleaf pine plant communities within their historical ranges are paramount in saving these threatened species from extinction. The reintroduction of longleaf pine generally involves the use of fire for preparing sites for regeneration, and prescribed burning usually continues from seedling establishment through stand maturity (Boyer 1993, Croker and Boyer 1975, Haywood and Grelen 2000, Wahlenberg 1946).

Newly established longleaf seedlings may develop little aboveground for several years as the root system develops (Harlow and Harrar 1969). The bunch of needles at the surface resembles a clump of grass, hence the term grass stage describes the juvenile period of growth. Once the seedlings have developed a root collar of about 1 in., they are able to emerge from the grass stage.

Because aboveground growth of longleaf seedlings is slow in newly established stands, a burning program helps keep competing woody vegetation from overtopping and crowding the longleaf pine regeneration, removes dead grass that smothers young seedlings, and reduces the occurrence of brown-spot needle blight caused by *Mycosphaerella dearnessii* Barr. (Croker and Boyer 1975, Wahlenberg 1946).

However, prescribed burns are not always executed on schedule because of adverse weather conditions and lack of resources. A delay of several years can allow fine fuels to accumulate, and this accumulation increases the likelihood of more intense burns when the burning program begins. Delayed burning is, therefore, more likely to destroy seedling and sapling longleaf pines than if fuel loads are kept in check. If fire is not used or is delayed too long, competing woody plants [especially loblolly pine (*P. taeda* L.)] have to be controlled by cutting or directed applications of herbicides on many sites (Haywood 2000). If not, a mixed overstory will eventually develop of loblolly, longleaf, and hardwoods, with a midstory of trees and shrubs that shades out most of the understory vegetation (Haywood and Grelen 2000). To examine the effects of delaying prescribed burning for several years, I initiated this study in a seedling and sapling-size stand of planted longleaf pine.

STUDY AREA

The study area is on the Longleaf Tract, Palustris Experimental Forest, Kisatchie National Forest, in central Louisiana about 19 mi south-southwest of Alexandria (approximate longitude 92°30' W., latitude 31° N.) at an average elevation of 170 ft. Harms (1996) classes the naturally infertile Beauregard-Malbis silt-loam soil complex as a wet pine site because it is seasonally wet during winter although often droughty during summer. Haywood (2000) describes the soils and subtropical climate.

The original forest stand was clearcut harvested in the mid-1980s. The unmerchantable stems and new growth were sheared and windrowed in 1991. A low cover of herbaceous and scattered woody vegetation developed after windrowing, and it was rotary mowed in July and August 1992.

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METHODS

Study Establishment

Initially, I established research plots in a randomized complete block split-plot design and remowed them in December 1992 (Haywood 2000). Each of the 15 whole plots (5 blocks by 3 main plot treatments) measured 84 by 84 ft (0.16 ac) and contained 14 rows of 14 seedlings arranged in 6-by-6 ft spacing. I divided the center 100 seedlings equally into 2 subplots, and randomly assigned year-of-planting to each of the 50-seedling subplots. One subplot was planted in February 1993 and the other subplot was planted in January 1994. For each year-of-planting, I used the same Mississippi seed source. My crew hand planted the 42-week-old container longleaf seedlings with a punch of the correct size for the root plug. In both years the soil was wet, and we encountered no planting problems.

To determine the effects of herbaceous vegetation management practices on growth of newly planted longleaf pine seedlings, I assigned 3 treatments to the 15 whole plots (Haywood 2000). These treatments were (1) no herbaceous plant control after planting, (2) two annual applications of hexazinone herbicide [3-cyclohexyl-6-(dimethylamino)-1-methyl-1,3,5-triazine-2,4(1H,3H)-dione], and (3) mulching. Despite treatment, on all plots hardwood and loblolly pine brush overtopped and crowded the planted longleaf seedlings. We manually severed the brush in 1997 and sprayed the new growth with triclopyr (3,5,6-trichloro-2-pyridinyloxyacetic acid) herbicide in 1998. The most commonly treated plant was waxmyrtle (Myrica cerifera L.).

New Study Design

After completing the initial vegetation management research and reporting the findings (Haywood 2000), I initiated this new phase of research to address delayed prescribed burning. This shift was possible because in the original design, the block, seedling age (subplot), and treatment-by-age interaction effects were not significant (a = 0.05). Therefore, I reconfigured the design, and the three original treatments—check, herbicide application, and mulching—became the blocks. Blocking was justified because of significant differences in longleaf pine total height among the original treatments (Haywood 2000).

I randomly assigned five treatments within the three blocks, or replicates (Steel and Torrie 1980). In the first (check) there was no more woody plant control after 1998. In the second (herbicide) beginning in 1999 there was biennial control of woody vegetation over 2 ft tall with a directed application of herbicide (triclopyr) in May; we did not treat blackberry (*Rubus* spp.) and woody vines. In the third, fourth, and fifth treatments, I conducted biennial burning in early March, May, or July, respectively.

Confirmation of the New Study Design

I analyzed pretreatment survival and tree height data taken in February 1999 using the original analysis of variance for a split-plot randomized complete block design model (Steel and Torrie 1980). However, this time I used the new treatments (check, herbicide, March burn, May burn, and July burn) as the main plot effects (table 1). I included tree age and treatment-by-age interaction terms in the analysis, and there were no significant age effects or treatment-by-age interactions in the pretreatment analyses (a = 0.05). Thus, the plots were sufficiently uniform to continue with the new research, and I ignored the age of seedlings in future analyses.

Burning Samples and Technique

Before setting fires, I collected a combustible fine fuel sample on five randomly located 2.4-ft^2 fuel-monitoring plots. I again collected fuel samples 1 week after the burns to determine fuel consumption on a dry-weight basis. I calculated Byram's fire intensity for each burn (Haywood 1995).

All burns were strip-head fires set with drip torches and were monitored to determine their intensity (Haywood 1995). First, we set a backfire along the downwind side of the plot. After the line was secure, we lit the strips about 24 ft apart and allowed them to burn together.

Measurements

Before initiating new treatments, I measured longleaf pine total height in February 1999 to use as a covariate in future analyses. I measured posttreatment total height and diameter at breast height in October 1999 and November 2000, 4 to 7 and 17 to 20 months after the initial set of treatments, respectively.

Data Analysis

The model was a randomized complete block design with three blocks as replicates (Steel and Torrie 1980), and I analyzed two groups of longleaf pine—all pine trees or just those out of the grass stage (pines over 0.4 ft tall). In this first analysis, dependent variables were pretreatment pine survival and total height measured in February 1999 and pretreatment survival and heights adjusted for mortality through November 2000. If I found significant treatment differences (a = 0.05), I used Duncan's Multiple Range Tests to determine mean separations.

In subsequent analyses of posttreatment total height and diameter measurements, I used the pretreatment heights as a covariate in the study design (Steel and Torrie 1980). I did not use pretreatment diameters as covariates because not all trees were at least 4.5 ft tall in February 1999.

I used linear contrasts to determine differences among treatments to address several hypotheses associated with delayed burning based partly on Haywood and Grelen (2000). First, suspension of woody plant control will eventually be detrimental to longleaf pine trees: treatment 1 versus treatments 2 through 5. Second, biennial burning and woody plant control with herbicides will have similar effects: treatment 2 versus treatments 3 through 5. Third, burning in May will have similar growth effects as burning in March or July: treatment 4 versus treatments 3 and 5, and fourth, March and July burning will have similar effects: treatment 3 versus treatment 5.

Table 1—Confirmation of the new study design; the 5- and 6-year-old longleaf pine were measured in February 1999 before the initiation of treatments[a]

Treatment effects	All longleaf pine			Longleaf out of the grass stage		
	Survival	Height	Disease	Pines out of grass stage	Height	Disease
	Pct	*Ft*	- - - - - - *Percent*	*- - - - - -*	*Ft*	*Pct*
Treatments						
1. Check	86	6.3	10	82	6.6	10
2. Herbicide	86	5.0	12	79	5.3	11
3. March burn	79	5.5	7	74	5.8	6
4. May burn	83	5.3	11	79	5.6	11
5. July burn	84	4.3	15	76	4.6	16
Prob>F-value	.205	.388	.221	.243	.405	.104
Age						
5-year-old trees	83	4.9	11	77	5.2	10
6-year-old trees	84	5.7	11	79	6.0	11
Prob>F-value	.786	.212	.937	.730	.190	.497
Treatment-by-age interactions						
5-year-old trees						
1. Check	87	5.7	11	83	6.0	10
2. Herbicide	85	4.8	14	79	5.1	12
3. March burn	82	5.1	7	76	5.5	7
4. May burn	82	4.5	10	76	4.8	10
5. July burn	79	4.4	13	74	4.7	12
6-year-old trees						
1. Check	85	7.0	9	81	7.2	9
2. Herbicide	87	5.2	11	80	5.6	9
3. March burn	76	6.0	7	73	6.2	6
4. May burn	85	6.1	12	81	6.3	11
5. July burn	88	4.2	18	79	4.6	20
Prob>F-value	.205	.894	.782	.655	.934	.523

[a] There were no significant treatment or age differences or treatment-by-age interactions before treatments began (a = 0.05).

RESULTS

Burning Effects

I conducted the first set of burns in a 6-year-old grass-dominated rough. Grasses dominated the rough because woody competitors were controlled on all plots before the study began (table 2). Fire intensities ranged from 84 to 199 British thermal units (Btu) per foot, which were well above the recommended maximum intensity of 50 Btus per foot (Haywood 1995).

Treatment Effects

Tree mortality was low on the check and herbicide treated plots, decreasing on average from 86 percent in February 1999 to 81 percent in November 2000 (table 3). The dead longleaf pines averaged < 1 ft tall; so, initial heights of living trees increased from 5.7 to 6.1 ft once I dropped dead trees from the data set.

Prescribed burning, regardless of date, reduced longleaf pine survival, which decreased from an average of 82 percent in February 1999 to an average of 67 percent in November 2000 on the three burned treatments (table 3). The dead trees averaged < 2 ft tall. Thus before burning, the longleaf pines averaged 5.0 ft tall, and after I dropped these dead trees from the data set, the surviving pines averaged 5.9 ft tall in the pretreatment measurement (table 3).

In February 1999, percentage of pines out of the grass stage (pines over 0.4 ft tall) averaged 96 percent and ranged from 94 percent on the March-burn plots to 97 percent on the check and herbicide plots (table 3). Although these were the tallest trees, fire had the same adverse

Table 2—Parameters and intensities for the three 1999 prescribed burns conducted in a 6-year-old grass rough in 1999

Treatments	Burning date	Diurnal temperature range	Wind speed	Average fuel load[a]	Range in fire intensity	Average fire intensity[b]
		°F	*Mph*	*Lbs/ac*	- - - - *Btu per foot* - - - -	
March burn	March 2	56 – 73	4	3,305	92 – 124	111
May burn	May 14	56 – 86	2	5,360	84 – 109	99
July burn	July 8	70 – 91	3	3,908	116 – 199	170

[a] Oven-dried weights.
[b] Average fire intensities were from two to over three times the recommended maximum intensity of 50 Btus per foot (Haywood 1995).

effect on survival as for all pines partly because longleaf pines are still highly vulnerable to fire damage and mortality until the seedlings are 4 to 6 ft tall (Bruce 1951). Longleaf pines out of the grass stage averaged 5.3 ft tall before burning, and after I dropped the dead trees from the data set, the remaining pines averaged 6.0 ft tall on the three burned treatments.

In October 1999 and 4 to 7 months after treatment, height of all longleaf pines was significantly greater on the checks (8.8 ft) than the average for the other four treatments (8.3 ft), and height was significantly greater on the herbicide plots (8.5 ft) than the average for the three burned treatments (8.2 ft) (table 3). Tree height was significantly greater on the July-burn plots than on the March-burn plots. Diameter of longleaf pines did not significantly differ among treatments, although diameter at breast height on the herbicide plots (1.5 in.) was greater than the average for the three burned treatments (1.4 in.) at probability > F-value (P) = 0.07. I found a similar pattern of treatment responses for longleaf pines out of the grass stage.

In November 2000 and 17 to 20 months after treatment, height of all longleaf pines was still significantly greater on the checks (11.9 ft) than the average for the other four treatments (11.3 ft) (table 3). None of the other treatment contrasts were significant, although the July-burn trees (11.5 ft) were taller than the March-burn trees (10.9 ft) at P = 0.07. Diameter did not significantly differ among treatments, although the checks (2.0 in.) had a greater diameter at breast height than the average for the other four treatments (1.9 in.) at P = 0.06. I found a similar pattern of treatment responses for longleaf pines out of the grass stage.

DISCUSSION

The rapidity that loblolly pine and hardwood brush develops in new longleaf pine plantations is a serious problem that managers must address either with fire, herbicides, or a combination of treatments (Haywood and Grelen 2000). However, neither herbicides nor fire are panaceas for managing longleaf pine stands. Fire can destroy seedlings in and emerging from the grass stage, and later the use of fire can adversely affect stand growth and yield (Boyer and Miller 1994, Bruce 1951, Harlow and Harrar 1969, Wahlenberg 1946). Misapplied herbicides can injure desirable plants and contaminate soil and water resources.

Overall, the fire intensities for the three 1999 burns were unacceptably high partly because the delay in burning allowed fine fuels to accumulate over the previous 6 years. Still, delaying the first burn also allowed many of the longleaf seedlings to reach a stature where they could better tolerate heat injury (Bruce 1951, Greene and Shilling 1987, Haywood 1995). Therefore, mortality was mostly among the smallest seedlings that were of little consequence toward future stand development.

Originally we considered that delayed burning would avoid the documented, detrimental effect that repeated March burning has on longleaf pine seedling and sapling growth (Haywood and Grelen 2000). Although mortality was largely among the smallest pine trees, the untreated checks still had greater height growth than the treated plots, and March was still the most detrimental time to burn. This suggests that the application of fire or herbicide had sublethal effects on the trees that were not as obvious as the heat-related death of the smallest trees.

Longleaf pine remains very susceptible to heat-related injury until the seedlings are about 6 ft tall (Bruce 1951). Trees on the burned plots averaged about 6 ft tall at the beginning of the study, and probably most did not have the stature to avoid injury especially at the high fire intensities experienced (table 2). Also, a larger proportion of a smaller tree is exposed to a misapplication of directed herbicide than is a larger tree, and smaller trees are less obvious and therefore more often accidentally sprayed than larger trees. Regardless, neither delaying the first burn nor application of herbicide benefited these 5- and 6-year-old longleaf pines.

Table 3—Survival and growth responses of longleaf pine to the initial series of treatments under the new study design[a]

	Pretreatment		Post-treatment					
	Pines surviving in February 1999				October 1999		November 2000	
Treatment effects	Living pines	Covariate height	Survival	Covariate height	LSM[b] height	LSM D.b.h.	LSM height	LSM D.b.h.
	Percent	*Ft*	*Percent*	*- - - - - - - Ft - - - - - -*		*In.*	*Ft*	*In.*
All longleaf								
1. Check	86	6.3	81a[c]	6.8	8.8	1.47	11.9	2.01
2. Herbicide	86	5.0	81a	5.3	8.5	1.46	11.5	1.97
3. March burn	79	5.5	69b	6.1	7.7	1.30	10.9	1.85
4. May burn	83	5.3	67b	6.3	8.3	1.35	11.4	1.92
5. July burn	84	4.3	66b	5.2	8.6	1.38	11.3	1.91
Prob>F-value	.205	.389	.006	.695	.001	.128	.024	.141
Contrasts[d]								
Trt 1 vs trt 2–5					.002	.106	.012	.067
Trt 2 vs trt 3–5					.026	.064	.106	.159
Trt 4 vs trt 3+5					.217	.895	.217	.371
Trt 3 vs trt 5					.001	.281	.074	.340
Longleaf out of the grass stage								
1. Check	97[e]	6.6	80a[c]	6.8	9.0	1.50	12.1	2.05
2. Herbicide	97	5.3	79a	5.4	8.7	1.49	11.8	2.01
3. March burn	94	5.8	66b	6.4	7.9	1.33	11.2	1.91
4. May burn	96	5.6	66b	6.4	8.5	1.38	11.6	1.96
5. July burn	96	4.6	65b	5.3	8.7	1.41	11.5	1.94
Prob>F-value	.590	.405	.005	.682	.002	.134	.056	.275
Contrasts[d]								
Trt 1 vs trt 2–5					.004	.108	.022	.112
Trt 2 vs trt 3–5					.035	.064	.144	.211
Trt 4 vs trt 3+5					.277	.898	.308	.492
Trt 3 vs trt 5					.001	.308	.215	.633

[a] Seedling age was ignored but the seedlings were in the sixth or seventh growing season after planting when first treated.
[b] LSM = Least-squares means are adjusted to make them the best estimates of what they would have been if all the covariate means had been the same (Steel and Torrie 1980).
[c] By longleaf pine group and for pine survival, means followed by the same letter are not significantly different based on Duncan's Multiple Range Tests (a = 0.05).
[d] The linear contrasts compared (vs) preselected combinations of the preceding treatments (trt), and the Prob>F-value are reported for each contrast.
[e] Percentage of the living pines out of the grass stage when the study began.

LITERATURE CITED

Boyer, William D. 1993. Long-term development of regeneration under longleaf pine seedtree and shelterwood stands. Southern Journal of Applied Forestry. 17(1): 10–15.

Boyer, William D.; Miller, James H. 1994. Effect of burning and brush treatments on nutrient and soil physical properties in young longleaf pine stands. Forest Ecology and Management. 70: 311–318.

Brockway, Dale G.; Outcalt, Kenneth W.; Wilkins, R. Neal. 1998. Restoring longleaf pine wiregrass ecosystems: plant cover, diversity and biomass following low-rate hexazinone application on Florida sandhills. Forest Ecology and Management. 103: 159–175.

Bruce, David. 1951. Fire, site, and longleaf height growth. Journal of Forestry. 49(1): 25–27.

Croker, Thomas C., Jr.; Boyer, William D. 1975. Regenerating longleaf pine naturally. Res. Pap. SO–105. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 21 p.

Greene, Thomas A.; Shilling, Charles L. 1987. Predicting girdling probability for pine and hardwood saplings in low-intensity backfires. Forest Science. 33(4): 1010–1021.

Harlow, William M.; Harrar, Ellwood S. 1969. Textbook of dendrology. 5th ed. New York: McGraw-Hill Book Company. 512 p.

Harms, William R. 1996. An old-growth definition for wet pine forests, woodlands, and savannas. Gen. Tech. Rep. SRS–2. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 7 p.

Haywood, James D. 1995. Prescribed burning and hexazinone herbicide as release treatments in a sapling hardwood-loblolly pine stand. New Forests. 10: 39–53.

Haywood, James D. 2000. Mulch and hexazinone herbicide shorten the time longleaf pine seedlings are in the grass stage and increase height growth. New Forests. 19: 279–290.

Haywood, James D.; Grelen, Harold A. 2000. Twenty years of prescribed burning influence the development of direct-seeded longleaf pine on a wet pine site in Louisiana. Southern Journal of Applied Forestry. 24(2): 86–92.

Outcalt, Kenneth W.; Sheffield, Raymond M. 1996. The longleaf pine forest: trends and current conditions. Resour. Bull. SRS–9. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 23 p.

Steel, Robert G.D.; Torrie, James H. 1980. Principles and procedures of statistics. 2d ed. New York: McGraw-Hill Book Company. 633 p.

Wahlenberg, W.G. 1946. Longleaf pine its use, ecology, regeneration, protection, growth, and management. Washington, DC: Charles Lathrop Pack Forestry Foundation; U.S. Department of Agriculture, Forest Service. 429 p.

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UNDERSTORY HERBICIDE AS A TREATMENT FOR REDUCING HAZARDOUS FUELS AND EXTREME FIRE BEHAVIOR IN SLASH PINE PLANTATIONS

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Abstract—The 1998 wildfires in Florida sparked a serious debate about the accumulation of hazardous forest fuels and the merits of prescribed fire and alternatives for mitigating that problem. One such alternative is application of understory herbicides and anecdotal evidence suggests they may either exacerbate or lessen the fuel accumulation problem. In 1998, a study was initiated in northern Florida to document changes in fuel characteristics in slash pine (*Pinus elliottii*) plantations treated with a mid-rotation understory herbicide and model their potential impacts on fire behavior. Field data showed unmanaged stands contained the highest loadings of understory fuels and in the first year after herbicide treatment, fuel loading did not change. In subsequent years, fuel loading rapidly decreased and remained low. Potential fire behavior, as predicted by BEHAVE, followed this fuel accumulation trend in that catastrophic stand-replacing fires were predicted for unmanaged and recently herbicided stands, and low-intensity surface fires for stands that had been herbicided several years prior.

INTRODUCTION

In 1998, Florida experienced one of its most active wildfire seasons ever (Karels 1998). From mid-May to mid-July, over 2000 wildfires occurred in central and northern Florida. Over 500,000 acres of forest burned, most of them by high-intensity/high-severity, stand-replacing fires. Over 10,000 firefighters from 49 states fought the fires. Property losses included the destruction of, or damage to, 370 businesses and residences. Commercial timber losses exceeded $350 million, suppression costs topped $100 million, and estimated tourism losses of nearly $140 million all contributed to the total estimated cost of $622 to $880 million (Mercer et al. 2000). The magnitude and severity of the wildfires prompted several land management agencies, including the USDA Forest Service and the USDI Biological Resources Division, to combine resources to study the ecological and economic impacts of the wildfires on Florida's forest ecosystems. One facet of the USDA/USDI study addressed the issue of hazardous fuel reduction in commercial pine stands and in the urban/wildland interface before a wildfire occurs.

Dormant-season prescription fire every 4 to 5 years has been the method of choice to control the buildup of hazardous fuels throughout the southern United States (Pyne and others 1996). The frequent use of fire is necessary because redevelopment of the rough is rapid with fire hazard returning to its preburn level in less than 5 years on most sites (Davis and Cooper 1963). In the past several decades, however, constraints have been placed on this practice because of smoke management concerns, liability issues, and misconceptions about the ecological ramifications of fire among the region's sizeable population of out-of-state retirees (Wade 1993).

The continuing need for hazardous fuel reduction and the social limitations of prescription fire have prompted interest in developing other strategies for managing hazardous fuels. One possible alternative is the herbicides that are often used as a mid-rotation treatment in commercial pine plantations to boost growth and reduce future site preparation costs (Oppenheimer et al. 1989). Herbicides reduce height, percent cover, and/or loading of the highly flammable shrub layer although the degree and longevity of hazardous fuel control is not well defined.

This study is two-phased; a detailed fuels inventory followed by computer simulations based on the fuels data. The objective was to compare fire behavior (flame length and rate-of-spread) that probably would occur in slash pine plantations treated with herbicide at five different times after treatment (age-of-rough). Because the 1998 wildfires occurred during a severe drought, fire behavior was simulated for each age-of-rough under June 1998 weather conditions.

METHODS

The fuels data for this study was collected during winter 1998-1999 on forest industry (Georgia-Pacific and ITT Rayonier) land located between Lake Butler and Starke in Bradford and Union counties in the Coastal Plain Physiographic Province of northern Florida. Fifteen stands varying from 4 to 35 acres in size were chosen based on the age of rough, i.e., number of years (1, 2, 3, 6, or untreated) since the herbicide treatment. The "untreated" age class indicated no herbicide spraying since planting and included stands that had been unmanaged for 17 years.

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All of these stands were slash pine plantations grown on a pulpwood rotation of about 30 years. They were 17 years old with an average stand diameter of 8.5 inches and contained 110 – 140 ft^2 of basal area per acre.

In each stand, understory fuel characteristics (cover, height, and loading by size class) were collected as inputs to BEHAVE to build custom fuel models. Percent cover and height were determined for all stands using line transects. Near the center of each stand, six 215ft-long transects were systematically located parallel to one another 80-ft apart. The vegetation was sampled along each transect at 16-ft intervals by holding a 8-ft tall range pole perpendicular to the ground and recording each plant species touching the range pole and the height of the tallest plant. Percent cover and height to the nearest 0.5 ft were determined for five categories; grass, open space, saw palmetto, small shrub, and tall shrub. Grass included all graminoid species, i.e., *Andropogon* spp., *Aristata* spp., and *Panicum* spp., while saw palmetto was species specific. Tall shrub was primarily gallberry but also included all other woody shrubs ³ 0.5 ft tall while small shrub included all < 0.5 ft tall, e.g., blueberry (*Vaccinium* spp.) and runner oak (*Quercus pumila*). Open space represented areas devoid of vegetation but usually blanketed by pine litter. Because sampling was done in January and February, no forbs were found.

The clip-bag-dry method was used to determine loadings of shrub and litter fuels. In this method, six 3-ft x 3-ft quadrats were located on a 100-ft x 100-ft grid near the center of the stand. Quadrats were delineated by a sampling frame and all vegetation, living and dead, within the frame and between 0.1 and 10.0 ft tall was designated as either grass or shrub fuels and clipped, bagged, and dried. All plant material on or in the forest floor (O_i and O_e horizons) was likewise collected and designated as litter fuels.

Fuel samples were dried at 195°F to a constant weight in a wood-drying oven then separated by type (grasses, pine litter including dead downed woody material, and shrubs) and by diameter size class (<0.25 inches and 0.25 to 1.00 inches). These size classes correspond to the time-lag fuel classes of 1-hr and 10-hr, respectively (Fosberg 1970). Fuels >1.00 inches in diameter were virtually nonexistent and ignored for the purposes of this study. After separation, fuels were weighed to the nearest 0.1 ounces on an electronic scale.

All fuels data were used in the NEWMDL program (Burgan and Rothermel 1984) of BEHAVE to create a custom fuel model for each age-of-rough. Physical and chemical characteristics of the palmetto-gallberry fuel complex were obtained from Hough and Albini (1978).

Custom fuel models were used in conjunction with landform and weather data in the SITE module of the FIRE1 program to develop treatment/age-of-rough specific fire behavior estimates (Andrews 1986). The Osceola National Forest provided weather data for June 1998. Cloud cover, ambient air temperature, relative humidity, 20-ft windspeed, precipitation, and fuel moistures were recorded daily at 1300 hours and averaged for the entire month. Each simulation was of a summer fire (June 15th) burning under drought weather conditions. Outputs were flame length (ft) and rate-of-spread (ft/min) for a head fire for each treatment/age-of-rough combination.

STATISTICAL ANALYSIS

Analysis of variance with Student-Newman-Kuels mean separation test was used to compare differences for cover, height, and loading of fuel types and sizes between the different ages-of-rough (SAS Institute Inc. 1993). In all tests $\alpha = 0.05$ and data were transformed as needed to correct for unequal variances and non-normality of residual values. Flame length outputs from each simulation were compared to fire characteristic – suppression charts (Andrews and Rothermel 1982) to rate the difficulty of controlling a wildfire burning under drought and normal conditions.

Table 1—Fuel characteristics (mean ± 1 s.e.) for rough age 1, 2, 3, 6, and 17 years

Fuel Characteristic/Type	Untreated[a]	Age of Rough (years) 1	2	3	6
Cover (percent)					
Grass	0±0C[b]d[c]	0.9±0.4Cd	6.7±0.5Ad	4.9±0.4Bc	0.9±0.2Cd
Litter	18.7±1.7Cb	20.0±2.0Cb	34.2±1.8Bb	69.8±4.8Aa	69.3±4.2Aa
Saw palmetto	6.7±0.8Cc	3.1±0.2Dc	9.3±0.2Bc	0.2±0.2Ed	19.6±0.3Ab
Short Shrub	1.8±2.1Ad	0.4±0.6Ad	0.2±0.1Ae	0.1±0.1Ad	0.2±0.2Ad
Tall Shrub	72.9±7.5Aa	75.6±7.0Aa	49.8±5.3Ba	25.3±3.2Cb	10.2±0.8Dc
Height (ft)	5.0±0.7A	4.6±0.5A	3.6±0.4B	1.6±0.3C	3.6±0.5B
Loading (tons/ac)					
Grass	0±0Bc	0.1±0.1Bc	0.3±0.2Ab	0.1±0.1Bb	0.1±0.1Bc
Litter, 1-hr	4.7±0.4Ca	5.6±0.6Ba	7.5±0.7Aa	7.5±0.8Aa	5.0±1.1BCa
Litter, 10-hr	0.6±0.7Ac	0.4±0.3Ac	0.9±1.1Ab	0.6±1.1Ab	0.8±0.5Abc
Shrub, 1-hr	3.5±0.6Aa	3.5±0.6Ab	1.1±0.3Bb	0.3±0.3Cb	1.6±0.5Bb
Shrub, 10-hr	2.0±0.5Ab	2.0±0.5Ab	0.6±0.6Bb	0.1±0.2Cb	0.9±0.6Bbc

a—Untreated stands = rough age 17 years.
b—Means followed by different uppercase letters are different within that row (μ = 0.05).
c—Means followed by different lowercase letters are different within that fuel characteristic/type (μ = 0.05).

Table 2—Characteristics[a] of the custom herbicide fuel models for rough age 1, 2, 3, 6, and 17 years

Treatment Age-of-rough (years)	Fuel Loading[b] 1-hr (tons/ac)	10-hr (tons/ac)	Live Woody (tons/ac)	Height (ft)	Surface-to - Volume ratio (in^2/in^3)	Moisture of Extinction (%)
Untreated[c]	9.47	2.54	2.96	0.69	328	35
1	8.54	2.06	0.18	0.08	326	34
2	8.37	1.25	0.13	0.06	294	40
3	7.87	0.72	0.07	0.03	282	41
6	5.32	0.98	0.81	0.04	292	32

a - Other characteristics, i.e., live woody S/V ratio (359), and heat content (8436 BTU/lb), were averages from Hough and Albini (1978) and kept the same for all fuel models.

b - Live herbaceous fuel load was 0.05 tons/ac for all fuel models. No 100-hr fuels were included in any of the fuel models because of their scarcity.

c - Untreated stand with a rough age = 17 years.

RESULTS

Before spraying, gallberry dominated the forest floor in these stands but afterwards this shrub was replaced by open space blanketed with pine litter (table 1). Saw palmetto was lacking in this treatment because of intensive site preparation when the plantations were established. Initially, height reduction was unchanged as the dead shrubs remained standing for 1-2 years. By age 3, the dead shrubs had fallen, creating rather open stands. Some shrub growth was detected in year 5 but this was due to skips in the spraying that allowed some shrubs to survive. Fuel loadings were distributed in similar fashion to the shrub height data. The greatest loadings were found in the untreated stands and were usually dominated by the 1-hr fuels in the litter and shrub fuel types. These decreased through time and shifted from the shrub layer to the forest floor.

Custom fuel models were created from these fuels data (table 2) and used in conjunction with weather and land-form data (table 3) to produce fire behavior outputs for each age of rough.

The flame length predictions were initially unchanged following treatment but then declined dramatically with time (table 4). Under drought conditions in the untreated stands, predicted flame length was 17 ft and declined only slightly by age 1 following herbicide treatment to 16 ft. However, at age 2 flame length dropped precipitously to 8 ft and continued downward to 1.3 ft at age 3 before slightly rebounding to 3.3 ft at age 5. Flame length estimates for normal weather conditions followed this same pattern but were reduced by about 30% relative to drought conditions.

Rate-of-spread predictions followed a similar pattern to flame length estimations (table 4). For drought conditions, it was initially high (49 ft/min) and increased slightly at age 1 to 59 ft/min. From that point, rate-of-spread dropped rapidly to 10 ft/min at age 2, 2.3 ft/min at age 3, and 5.6/min at age 5. Normal weather conditions reduced all rate-of-spread estimates by another 45-60%.

Table 3—Drought, normal weather, and environmental conditions[a] used in the fire simulations

Characteristic	Drought	Normal
Drought Index (KBDI[b])	731	293
Ambient Air Temperature (°F)	97	84
Relative Humidity (%)	42	65
20-ft Windspeed (mi/hr)	11	7
Cloud Cover (%)	10	40
1-hr fuel moisture (%)	5	15
10-hr fuel moisture (%)	6	13
Live Woody fuel moisture (%)	104	166
Days w/o rain	25	15
30-day rainfall total (in)	2.1	5.2
Slope (%)	0	0
Elevation above sea level (ft)	100	100
Latitude	30°N	30°N

a—Data are from the Osceola National Forest as recorded daily at the Olustee Lookout Tower at 1300 hours during June 1997 (normal) and June 1998 (drought). N = 30 for all characteristics except for the last 5 which are totals or site descriptors.

b—Keetch-Byram Drought Index assesses the combined effect of evapotranspiration and amount of precipitation in producing moisture deficits in the soil (Keetch and Byram 1968) It was developed specifically for southern fire managers and provides a scale from 0 to 800 with 800 representing desert-like conditions.

Table 4—BEHAVE-derived estimates of flame length, rate-of-spread, and control difficulty for wildfires burning under normal and drought conditions in herbicide-treated slash pine plantations at rough age 1, 2, 3, 6, and 17 years.

Weather Condition		Age of Rough (years)			
Fire Characteristic	Untreated[a]	1	2	3	6
Drought					
Flame length (ft)	17.0	16.1	8.0	1.3	3.3
Rate-of-spread (ft/min)	49.0	59.0	10.0	2.3	5.6
Control Difficulty	extreme	extreme	moderate	low	low-moderate
Normal					
Flame length (ft)	12.0	11.4	5.6	1.0	2.3
Rate-of-spread (ft/min)	27.0	33.0	6.0	1.3	2.2
Control Difficulty	extreme	extreme	moderate	low	low

a - Stand with a rough age = 17 years.

Suppression difficulty of a wildfire varied among age-of-rough but did not vary between drought and normal weather conditions so these parameters were pooled to ease reporting (table 4). In untreated and 1-year-old stands, a wildfire would probably display extreme fire behavior, i.e., torching, crowning, and spotting, making suppression extremely difficult. However, difficulty of wildfire suppression would decrease with time and after year 2 would become quite easy and would likely remain that way through rotation end.

DISCUSSION

In pine flatwood forests, it is the age and development of the rough that determines fire behavior more than any other forest characteristic (Hough and Albini 1978). This study demonstrates the effectiveness and limitations of herbicides as an alternative to prescribed fire for protecting slash pine plantations from stand-replacing wildfires. In the untreated stands, the rough was nearly impenetrable, consisting of almost complete coverage of highly flammable gallberry and saw palmetto that ranged from 3-12 ft tall. A wildfire in such a setting, regardless of whether during drought-enhanced or normal summer weather conditions, would be extremely dangerous, difficult to suppress, and would probably kill all overstory pines.

Herbicide application can reduce this highly flammable rough but it takes time. For the first year after treatment, fuel characteristics changed little. The shrubs were dead but still standing, densely spaced, and retaining fallen needles. Consequently, BEHAVE predicted a wildfire burning under drought conditions would have 17-ft flame length and 49 ft/min rate-of-spread. Under normal weather conditions, these predictions decreased to 12 ft flame length and 27 ft/min rate-of-spread. Difficulty of control would be high to extreme and suppression strategy would be the same as if the fire was burning in an unmanaged stand; necessitating indirect attack and use of natural barriers. Pine mortality from a wildfire in such a scenario would undoubtedly approach 100 percent.

However, fire danger and control difficulties decrease dramatically beginning in year 2 provided that saw palmetto was eradicated during site preparation and herbicide spraying completely covered the stand. Shrub fuels almost disappear and the only 1-hr fuel is the blanket of pine needles above the developing duff layer. The herbicide stands become quite open beginning in year 2. These favorable conditions exist at least until year 6 and quite possibly until final harvest in plantations managed for pulpwood. Under the same weather conditions, fires in such environments would be much less intense than in recently herbicided stands. Direct attack would be relatively safe and easy.

Unfortunately, the decrease in fire intensity may not translate into a decrease in pine mortality. Herbicide-treated stands will have an increased duff accumulation on the forest floor relative to stands that are regularly prescribe-burned. Roots of overstory pines colonize the bottom of this developing duff layer within 3 to 4 years. During drought years this duff layer will be consumed, significantly increasing fire severity. Consequently, a low-intensity fire in a herbicide-treated plantation is likely to root-kill more pines than a higher-intensity fire in a natural stand managed with recurrent prescribed fire because the southern pines have evolved to survive crown scorch approaching 95 percent (Weise et al. 1990; Wade, unpubl. data on file) but cannot tolerate fire damage to their roots (Outcalt and Wade 2000).

Caution must be exercised in interpreting these results and the limitations of BEHAVE must be kept in mind. It is designed to predict average fire behavior at the flaming front of a head fire for a given set of environmental parameters. In this study, we used fuel and weather conditions that we considered typical for early summer in northern Florida and consistent with a near worse-case scenario. Changing location on the fire (flanks or rear) or one or more of the parameters, i.e., windspeed, fuel moisture, or relative humidity, will alter the outputs. Also, outputs are for relative comparison among treatments. Validation of BEHAVE-generated fire predictions to actual fire behavior for these custom fuel models is still needed for the gallberry-saw palmetto fuel complex, especially under drought conditions. Likewise, comparison of actual fire behavior to BEHAVE-generated estimates for the applicable standard fuel models under drought conditions is another topic awaiting research.

CONCLUSIONS

Fire has long been a component of Florida's pine flatwood ecosystems and will undoubtedly continue to be so because of the prevalence of lightning and a growing human population. Because of excellent growing conditions, the rough quickly becomes a hazardous fuel problem that when combined with ignition sources and dry weather can produce extreme fire seasons such as the 1998 season in Florida.

Active fuels management is essential to reduce both size and intensity of wildfires. A passive do-nothing approach to hazardous fuel loadings will result in catastrophic wildfires and exacerbate damage and control difficulties. Herbicide application can be used as an alternative to prescribed fire to control understory development but the forest manager must be aware of this technique's strengths and weaknesses. A single treatment does provide for a long-term reduction of the rough but does not provide immediate fire protection, many of the other benefits of fire, e.g. duff reduction, heat scarification of seeds, nutrient cycling, necessary to maintain the health of natural ecosystems, and may make pines susceptible to root mortality during drought-year fires.

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REFERENCES

Andrews, P.L. 1986. BEHAVE: Fire prediction and fuel modeling system – Burn subsystem, Part 1. USDA For. Serv. Gen. Tech. Rep. INT-194.

Andrews, P.L.; Rothermel, R.C. 1982. Charts for interpreting wildland fire behavior characteristics. USDA For. Serv. Gen. Tech. Rep. INT-131.

Burgan, R.E.; Rothermel, R.C. 1984. BEHAVE: Fire prediction and fuel modeling system - fuel subsystem. USDA For. Serv. Res. Pap. INT-167.

Davis, L.S.; Cooper, R.W. 1963. How prescribed burning affects wildfire occurrence. Journal Forestry 61(12): 915-917.

Fosberg, M.A. 1970. Drying rates of wood below fiber saturation. Forest Science 16: 57-63.

Hough, W.A.; Albini, F.A. 1978. Predicting fire behavior in palmetto-gallberry fuel complexes. Res. Pap. SE-174. Asheville, NC: U.S. Department of Agricuture, Forest Service, Southeastern Forest Experiment Station. 44p.

Karels, J. 1998. Florida's 1998 wildfire season in review. Florida Division of Forestry internal report.

Keetch, J.J.; Byram, G.M. 1968. A drought index for forest fire control. USDA For. Serv. Res. Pap. SE-38. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 32p.

Mercer, D.E.; Pye, J.M.; Prestemon, J.P.; Butry, D.T.; Holmes, T.P. 2000. Final report: Economic consequences of catastrophic wildfires: Assessing the effectiveness of fuel reduction programs for reducing the economic impacts of catastrophic forest fire events. 66 p. Available on the web at http://flame.fl-dof.com/joint_fire_sciences/index.html.

NOAA. 2000. Climatic Data for 1895 to 2000. Available on the web at http://noaa.ncdc.gov.

Oppenheimer, M.J.; Shiver, B.D.; Rheney, J.W. 1989. Ten-year growth response of midrotation slash pine plantations to control of competing vegetation. Canadian Journal Forest Research 19: 329-334.

Outcalt, K.W.; Wade, D.D. 2000. The value of fuel management in reducing wildfire damage. In Neuenschwander, L.F. and Ryan, K.C. (Tech. Eds.), Proceedings of the Joint Fire Science Conference. 271-275 p.

Pyne, S.J.; Andrews, P.L.; Laven, R.D. 1996. Introduction to Wildland Fire 2nd ed. Wiley and Sons Publishing, New York, NY.

SAS Institute. 1993. User's Guide: Statistics Version 6. SAS Institute Inc. Cary, NC.

Wade, D.D. 1993. Societal influences on prescribed burning. In: Hermann, S. (ed.), Proc. 18th Tall Timbers Fire Ecology Conf., Tall Timbers Res. Stat. 351-355 p.

Weise, D.R.; Wade, D.D.; Johansen, R.W. 1990. Survival and growth of young southern pines after simulated crown scorch. In: 10th Conference on Fire and Forest Meteorology. Soc. Am. For. 161-168 p.

PERIODIC BURNING IN TABLE MOUNTAIN-PITCH PINE STANDS

Russell B. Randles, David H. Van Lear, Thomas A. Waldrop, and Dean M. Simon[1]

Abstract—The effects of multiple, low intensity burns on vegetation and wildlife habitat in Table Mountain (*Pinus pungens* Lamb.)-pitch (*Pinus rigida* Mill.) pine communities were studied in the Blue Ridge Mountains of North Carolina. Treatments consisted of areas burned from one to four times at 3-4 year intervals, and controls which remained unburned. The burns altered stand structure by reducing the density of understory trees and shrubs, which inhibits establishment of many shade intolerant species. Woody fuel loading was not reduced by burning although duff depth decreased. With the exception of the four burn treatment, in which fire intensity was higher, these understory burns proved inadequate to regenerate pine. Fire intensity had a more pronounced effect than burning repetition on vegetative structure and composition, as well as pine regeneration.

INTRODUCTION

Fire in the Southern Appalachians was a frequent visitor prior to European settlement due to both anthropogenic burning as well as natural lightning strikes (Delcourt and others 1998, Pyne and others 1996, Van Lear and Waldrop 1989). Plant communities adapted to a regime of frequent burning; one such forest type in the Appalachians is the Table Mountain-pitch pine community (Della-Bianca 1990, Little and Garrett 1990) This ecosystem has been in decline since fire exclusion policies were initiated in the early twentieth century (Williams and others 1990).

The intensity and frequency of fire necessary to create optimum habitat for sustaining Table Mountain-pitch pine ecosystems has not yet been determined. Some suggest that stand replacement fires may be necessary to create the environment necessary for regeneration (Elliot and others 1999, Turrill 1998), while others suggest more frequent, lower intensity fires may create suitable seedbed habitat (Waldrop and Brose 1998, Van Lear 1999). It is likely that a mix of surface and crown fires burned in Table Mountain-pitch pine stands prior to fire exclusion in the early 1900s.

Fire reduces the cover of species such as mountain laurel (*Kalmia latifolia*) and red maple (*Acer rubrum*) which compete with pines and oaks (Elliot and others 1999). Mountain laurel is an important understory competitor on the xeric ridges where stands of Table Mountain pine occur. Ground layer cover in loblolly and shortleaf pine stands was reduced by an average of 19 percent with a fire interval of three years when compared with intervals of six and nine years and unburned areas (Cain and others 1998). This study also showed a reduction in vertical cover percentage with the frequency of burning.

The purpose of this study was to determine effects of multiple, low-intensity fires on (1) structure and composition of vegetation, (2) fuel loading and arrangement, and (3) regeneration of Table Mountain and pitch pine.

METHODS

Study Areas

The study was located in western North Carolina on the Green River and Thurmond-Chatham gamelands of the North Carolina Wildlife Resources Commission. Forest overstories on the sites were in mixed pine (Table Mountain/Pitch Pine)-hardwood with an understory dominated by mountain laurel.

Plot Layout and Burning

Six to ten sample plots, each 10x20 meters, were installed along the ridge line of each treatment area. There were five treatments: Areas burned 1, 2, 3, and 4 times since 1988, as well as unburned controls. All treatments were burned on a three- to four-year interval. Treatment areas burned two and four times were unreplicated because only one of each of these areas was available. All other burned areas were replicated twice and the control was replicated four times.

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Table 1—Bark char height as an index of fire intensity (Average of max. scorch height after each burn)

	Mean Bark Char Height (m)	
Number of Burns	Thurmond-Chatham	Green River
0	0.00	0.00
1	1.52	1.52
2	N/A	2.29
3	4.06	3.05
4	7.62	N/A

Table 2—Species richness and diversity indices of herbaceous plants for each treatment

Treatment	Species Richnes (# Spp/200 sq. m)		Diversity (Shannon-Weiner)	
Control	12.3	A	.959	A
1 Burn	13.6	A	.875	A
2 Burn	10.2	A	.394	A
3 Burn	12.5	A	.840	A
4 Burn	19.5	B	2.00	A

One source of variation which could neither be accounted for nor controlled was fire intensity. For the most part, burns were of similar intensity; however, fires in the four-burn treatment on Thurmond-Chatham were of considerably higher intensity than the others (Personal Communication. 1999. Dean M. Simon)(table 1). All burns were dormant season burns conducted between January and March.

Vegetative Composition and Structure

Within each sample plot, twenty-one 1 square meter points were sampled along three transects extending the length of the plot. These points were sampled for frequency and percent cover of herbaceous species and *Vaccinium* spp. less than 1 meter in height. Importance value (IV(200)) for each species or species group was calculated using the equation IV(200) = (relative frequency plus relative cover)/2. This value was used to calculate a Shannon-Weiner diversity index (h' = (sum(Pi))ln(Pi))for herbaceous plants at each site.

All trees greater than 2 meters tall within each plot were tallied by species and DBH. It was noted whether they were living or dead. Trees less than 6 centimeters DBH were classified as understory trees, those between 6 and 12 centimeters were midstory, and all greater than 12 centimeters were overstory. These arbitrary classifications were based on the general canopy position of trees in these diameter ranges.

The shrub layer was sampled in two 5x10 meter subplots at the ends of each sample plot. Within these subplots species with multiple woody stems were sampled by number of individuals and number of stems for each individual. *Vaccinium* spp. greater than 1 meter in height were included with the shrub sampling. Width of each crown was measured at the widest point and perpendicular to that point and averaged to obtain crown diameter and percent cover of each individual. Maximum height of the shrub was also recorded for each individual.

Fuel Loading

Within each plot, Brown's planar intersect method (1971, 1974) was applied to three 15.24 meter (50 feet) transects to obtain a fuel loading for surface fuels. One hour fuels (0-.6 centimeters diameter) and ten hour fuels (.6-2.5 centimeters diameter) were counted over the first 2.4 meters (8 feet) of each transect. Both 100 hour (2.5-7.6 centimeters diameter) and 1000 hour (greater than 7.6 centimeters diameter) fuels were counted over the entire length of the transect, recording the diameter of any 1000 hour fuels. The depth of litter (L layer) and duff (F and H layers) was determined at .3, 1.8, 2.7 and 3.6 meters (1, 6, 9 and 12 feet) along each transect.

Height of down woody fuels was recorded at 3.0, 6.1, 9.1, 12.2 and 15.2 meters (10, 20, 30, 40 and 50 feet). This information was entered into the equation derived from Brown (1974) to calculate fuel loading. Vertical fuel height was measured as the mean height of vertical fuels (trees excluded) along each transect at 3.0, 6.1, 9.1, 12.2 and 15.2 meters (10, 20, 30, 40 and 50 feet).

Pine Regeneration

Pine regeneration was sampled concurrently with the 21 points described in the vegetation sampling section. However, the area sampled for pine regeneration at each point was 2x2 meters. Pine seedlings were counted and the height of each was recorded. Pines which had resprouted following a previous fire were measured in a similar manner.

Statistical Analysis

Data were analyzed using an incomplete block design with site as a block and number of burns as a treatment. An analysis of variance was performed sing PROC MIXED in Statistical Analysis Software. In cases where the variance was not uniform a square root transformation was performed to reduce the error (Kuehl 2000). Significance was determined at alpha equal to .05.

RESULTS AND DISCUSSION

Vegetative Structure and Composition

Herbaceous Composition and Diversity—Species richness on the four-burn treatment was significantly higher than the control and each of the other treatments (table 2). There were no significant differences in species richness among the other treatments or controls. Since the four-burn treatment burned more intensely than the other stands during each burn, greater species richness can likely be attributed more to fire intensity than number of burns. Shannon-Weiner diversity indices did not differ among treatments and controls (table 2). The low abundance of many species found in the four-burn treatment may offer an explanation for the lack of significance in the diversity index even though the species richness is higher.

Importance values (IV(200))for *Andropogon* spp., low panic grass (*Dichanthelium* spp.), and sweet fern (*Comptonia peregrina*) were higher in the four-burn treatment than in the other burns and control. Species found exclusively in the four-burn treatment included Indian grass (*Sorghastrum nutans*), fireweed (*Erictites hieracifolia*), and sweet fern (*Comptonia peregrina*). Species reduced in importance by burning included *Smilax* spp., which were reduced in each burn, and *Galax urceolata* which decreased in the two- and four-burn treatments (table 3).

Stand Structure—Understory tree density was significantly reduced in the two, three, and four-burn treatments compared to control areas (figure 1). Understory density in the four-burn treatment was also lower than that of the one-burn treatment. This pattern suggests that multiple burns are more effective in reducing understory density than single burns, although a single, high-intensity fire could theoretically fires.

Midstory and overstory densities were also significantly reduced in the four-burn treatment compared to other treatments and controls. However, the fire at this site actually crowned in some overstory trees due to the unusually high intensity during all four burns. There was little overstory mortality in any of the other burned areas because fire intensities were lower. Total basal area was reduced in the four-burn treatment compared to other treatments. Basal area in the two-burn treatment was lower than that in the control and one-burn area. Basal area reductions could be a result of the single replication of the two- and four-burn treatments as well as fire intensity in the four-burn treatment.

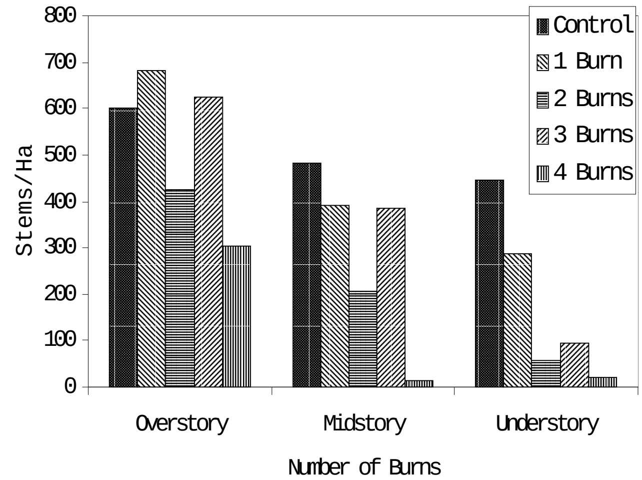

Figure 1—Canopy strata density (stems/ha) for burn treatments and control.

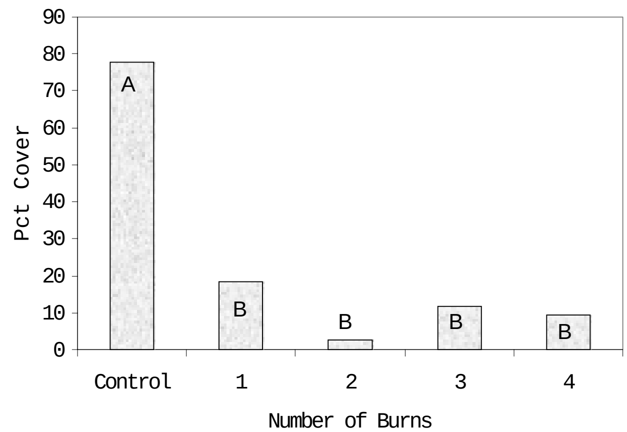

Figure 2—Shrub cover (predominantly mountain laurel) in treatments and control.

Table 3—Importance values (IV200) by species for each treatment

	Number of Burns				
Species	0	1	2	3	4
Andropogon spp.	0.38	0.08	0.31	0.68	11.28
Chimaphila maculata	2.70	0.43	0.54	0.05	0.05
Comptonia peregrina	0.00	0.00	0.00	0.00	10.40
Coreopsis major	0.16	0.08	0.20	0.06	1.25
Dichanthelium spp.	0.24	0.46	0.40	0.58	9.67
Epigaea repens	0.21	0.36	0.31	0.36	0.28
Erichtites hieracifolia	0.00	0.00	0.00	0.00	0.56
Galax urceolata	29.34	29.56	0.85	40.25	6.77
Vaccinium spp.	40.35	63.78	91.58	53.27	39.51
Polygonium convolvulus	0.17	0.61	0.00	0.15	0.00
Pteridium aquilinum	2.36	0.23	5.59	1.40	13.73
Smilax glauca	15.05	2.37	0.21	1.87	4.29
Smilax rotundifolia	8.34	1.78	0.00	1.06	0.11
Sorghastrum nutans	0.00	0.00	0.00	0.00	0.98
Other	0.53	0.32	0.00	0.29	3.28

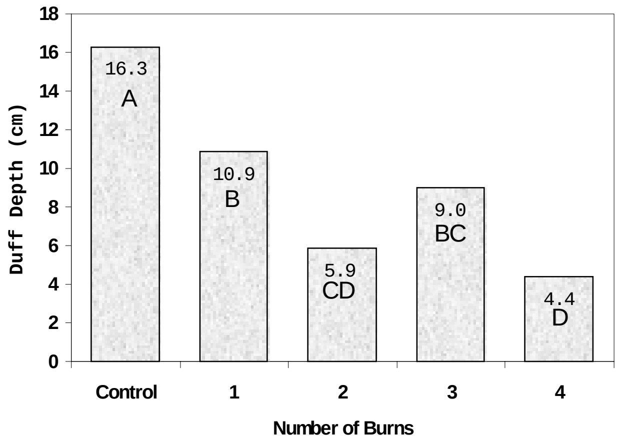

Figure 3—Duff reduction with burningc.

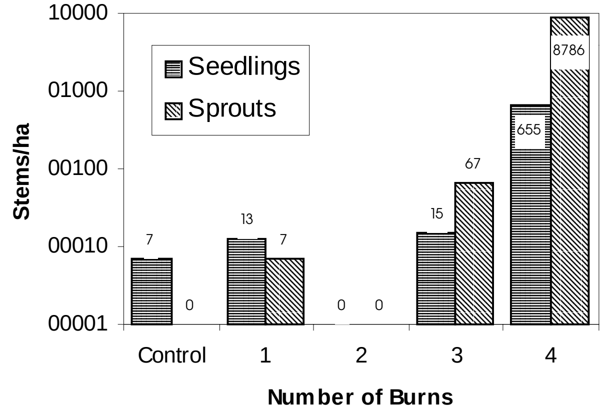

Figure 4—Log-scale of number of pine stems/ha for seedling and sprout regeneration.

Shrub Composition and Structure—Mountain laurel cover was reduced by 59 to 75 percent in the burned treatments but did not significantly differ among burn treatments (figure 2). Repeated winter burns at intervals of several years apparently do not further reduce percent cover of shrubs; rather, the first burn greatly reduces shrub cover and subsequent periodic burns simply maintain this state. Growing season burns might further reduce or even eliminate shrub cover because sprouting vigor is less at this time of year due to lower root reserves.

The height of shrub cover in each burn was significantly lower than that of the controls by 66–91 percent but did not vary from one burn treatment to the next. Mountain laurel was the only shrub found consistently within each area. Other shrubs noted were *Vaccinium* spp., flame azalea (*Rhododendron calendulaceum*), and rosebay rhododendron (*Rhododendron maximum*); however, these shrubs were scattered individuals with little effect on overall cover.

Fuel Loading—Down woody fuel loadings were essentially the same in each of the treatments suggesting frequent burning did not create, or reduce fuel loading. With the exception of the four-burn treatment, burns were generally not of sufficient intensity to kill trees, or if killed, they had not fallen and become surface fuels at the time of sampling. Coarse woody debris on the ground was apparently not consumed by the fires.

Duff depth in each treatment was lower than in the controls, and in most cases, each burn reduced the duff further (figure 3). The exception is the three-burn treatment, which had a mean duff depth slightly, but not significantly, greater than the two burn site. Lack of replication in the two-burn treatment may account for the lower duff depth. Vertical fuel height did not vary in relation to number of burns.

Pine Regeneration—Pine regeneration (seedlings and sprouts) was significantly higher in the four-burn treatment (9440 stems/hectare) than the control (7 stems/hectare) and other burn treatments (avg. 34 stems/hectare) (figure 4). Pine sprouts outnumbered seedlings by a margin of about 13:1 on the four-burn treatment. This pattern suggests that regeneration in this case is not due to the number of fires but rather to intensity of the fires. Had pine regeneration density been due to the number of times the site was burned, a progression in the number of seedlings would likely have been more evident.

Lack of regeneration in the other burn treatments could be caused by the amount of duff remaining on each of the sites after the burns (figure 3), as well as the degree of shading on the one- to three-burn treatments. Waldrop and Brose (1999) suggest that duff depths less than 7.5 centimeters provide a higher probability of germination and seedling survival if a seed source exists. Duff in the three-burn treatment averaged 9.0 centimeters which is still higher than the recommended depth. Results of the two-burn treatment are a bit surprising in that the mean depth was 5.9 centimeters and yet there was no regeneration on sample plots. This depth is not significantly different from the three-burn treatment which is higher than the suggested limit. Growing season burns would likely reduce duff depths more than winter burns and may be more productive in preparing seedbeds. Further study is needed to test this hypothesis. Unfortunately no measure of seed rain or seed viability was conducted so it is unsure how much seed was produced and whether that seed was viable.

Pines are shade-intolerant species and the amount of light reaching the forest floor influences seedling survival. The four-burn treatment had significantly more light reaching the forest floor than the control or any of the other treatments. Reduced shading reflected the intensity with which this stand had been burned on multiple occasions. The type and amount of litter present at seed fall also affects regeneration of Table Mountain pine (Williams, 1990). Most of the litter in these stands was hardwood litter, which reduces the establishment and survival of pine seedlings.

CONCLUSIONS

Multiple understory burns in Table Mountain/pitch pine stands create a more open forest with less cover of shrubs and saplings than unburned forests. Low intensity, dormant-season fires such as those in the one-, two-, and three-burn treatments, however, have little effect on fuel loading and had no quantifiable benefit to the regeneration of Table Mountain and pitch pines. Higher intensity fires such as those in the four-burn treatment created conditions (such as reduced shading and duff depth) that greatly enhanced pine regeneration.

The use of fire to regenerate Table Mountain-pitch pine stands needs further study. Various techniques should be investigated including combinations of thinning and burning, as well as different burning regimes, to develop effective regeneration methods.

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REFERENCES

Brown, J.K. 1971. A planar intersect method for sampling fuel volume and surface area. Forest Science. 17: 96-102.

Brown, J.K. 1974. Handbook for inventorying downed woody material. Gen. Tech. Rep. INT-16. U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 24 p.

Cain, Michael D.; Wigley, T. Bently; Reed, Derik J. 1998. Prescribed fire effects on structure in uneven-aged stands of loblolly and shortleaf pines. Wildlife Society Bulletin. 26: 209-218.

Delcourt, Paul A.; Delcourt, Hazel R.; Ison, Cecil R.; Sharp, William E.; Gremillion, Kristen J. 1998. Prehistoric use of fire, the Eastern agricultural complex, and Appalachian oak-chestnut forests: Paleoecology of Cliff Palace Pond, Kentucky. American Antiquity. 63: 263-279.

Della-Bianca, Lino. 1990. Silvics of North America, vol. 1: Conifers. Washington, DC: U.S. Department of Agriculture, Forest Service: 425-432.

Elliot, Katherine J.; Hendrick, Ronald L.; Major, Amy E.; Vose, James M.; Swank, Wayne T. 1999. Vegetation dynamics after a prescribed fire in the southern Appalachians. Forest Ecology Management. 114: 199-213.

Harlow, R.F.; Hooper, R.G. 1971. Forages eaten by deer in the Southeast. Proceedings of the Annual Conference of the Souteastern Association of Game and Fish Committee. 25: 18-46.

Harlow, Richard F. 1977. A technique for surveying deer forage in the southeast. The Wildlife Society Bulletin. 5: 185-191.

Kuehl, Robert O. 2000. Design of Experiments: Statistical Principles of Research Design and Analysis. 2d Ed. Brooks/Cole. 133 p.

Little, Silas; Garrett, Peter W. 1990. Silvics of North America, vol 1: Conifers. Washington, DC: U.S. Department of Agriculture, Forest Service: 456-462.

Pyne, Stephen J.; Andrews, Patricia L.; Laven, Richard D. 1996. Introduction to Wildland Fire. John Wiley and Sons, Inc., New York. 279-282.

Turrill, N.L., Buckner, E.R.; Waldrop, T.A. 1997. *Pinus Pungens* Lamb. (Table Mountain Pine): A threatened species without fire? In: Greenlee, J., ed., Proceedings of Effects of Fire on Threatened and Endangered Species and Habitats. International Association of Wildland Fire: 301-306.

Waldrop, Thomas A.; Brose, Patrick H. 1998. A comparison of fire intensity levels for stand replacement of table mountain pine (*Pinus pungens* Lamb.) Forest Ecology and Management. 113: 155-166.

Williams, Charles E.; Johnson, W. Carter. 1990. Age structure and maintenance of *Pinus Pungens* in pine-oak forests of Southwestern Virginia. American Midland Naturalist 124: 130-142.

Williams, Charles E.; Lipscomb, Mary V.; Johnson, W.Carter; Nilsen, Erik T. 1990. Influence of leaf litter and soil moisture regime on early establishment of Pinus pungens (Table mountain pine). American Midland Naturalist. 124: 142-153.

IMPACTS OF LONG-TERM PRESCRIBED FIRE ON DECOMPOSITION AND LITTER QUALITY IN UNEVEN-AGED LOBLOLLY PINE STANDS

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Abstract—Although fire has long been an important forest management tool in the southern United States, little is known concerning the effects of long-term fire use on nutrient cycling and decomposition. To better understand the effects of fire on these processes, decomposition rates, and foliage litter quality were quantified in a study investigating uneven-aged loblolly pine (*Pinus taeda* L.) management and prescribed fire in the Upper Coastal Plain of southern Arkansas. A portion of the study area had been burned on a 2 to 3-year cycle since 1981 while another portion of the study area had not been burned. Decomposition rates were determined by placing litterfall from each area into litterbags, installing these bags in the field within each area, and monitoring the litterfall weight loss over a 10-month period. Decomposition potential was determined using a cotton strip assay method. Foliar litter quality was evaluated by determining C, N, P, K, Mg, and Ca concentrations for samples collected from both treatments. Decomposition rate and potential were not significantly different in the burned and unburned areas. However, burning significantly affected foliar litter quality by increasing K, Ca, and Mg concentrations, but decreasing C. Decomposition rates and/or mass loss were significantly higher for foliar litterfall collected from the burned than unburned areas 0.5 months following placement of litterbags in the field.

INTRODUCTION

In the southern pine belt of the United States, the dependence of the pine forest upon fire is well documented (Barnes and others 1998, Wade and Lunsford 1989). Although fire has been considered a damaging agent with few benefits in the past, it is now apparent that fire can be important in the maintenance and establishment of forests (Barnes and others 1998). Today, the use of prescribed fire has become a well-accepted silvicultural practice. Prescribed fire is often used to reduce fuels; prepare sites for regeneration; dispose of logging debris; improve wildlife habitat; manage for competing vegetation and disease; improve aesthetics, access, and grazing; perpetuate fire dependent species; and to manage for endangered and other species (Wade and Lunsford 1989). Fuel burned by prescribed fires may include dead trees, logs, slash, needles, leaves, and other litter (McCullough and others 1998).

The effects of fire on forest ecosystems are complex and can be beneficial or detrimental depending on fire intensity, stand structure, and community composition (Barnes and others 1998). Positive benefits of fire can include increased nutrient uptake, accelerated tree growth, enhanced nutrient cycling (Clinton and others 1996), and improved nutrient availability (Shoch and Binkley 1986, Wade and Lunsford 1989). Negative effects of prescribed fire may include damage to the forest floor and organic matter, nutrient loss, soil erosion, decreased soil aeration and penetrability, and vegetation injury or mortality (Wade and Lunsford 1989).

Because prescribed fire is an important part of southern pine management, it is essential to determine how frequent application of fire over long periods of time alters forest ecosystem processes. One such process that could be altered by fire is organic matter decomposition. Decomposition and oxidation of litterfall, as well as the subsequent mineralization of nutrients contained in the litterfall, regulate the accumulation of organic matter and account for a substantial amount of the nutrients that are cycled in forest ecosystems (Fogel and Cromak 1977). With this in mind, we superimposed a litter decomposition study within an ongoing investigation of the silvicultural effects of fire in uneven-aged loblolly pine (*Pinus taeda* L.) stands in southeastern Arkansas. The objectives of our study were to determine: (1) if pine foliar litterfall on burned areas decomposes at a different rate than litterfall on unburned areas, (2) if pine foliar litterfall collected from burned areas decomposes at a different rate than litterfall collected from unburned areas, and (3) if decomposition potential is different between burned and unburned areas. These objectives were accomplished by examining pine litterfall decomposition, cotton tensile strength loss, and foliar nutrient contents.

METHODS

Study Area

The study was located in the Crossett Experimental Forest in Ashley County, Arkansas, at 32° 02’ N mean latitude and 91° 56’ W mean longitude. The study area is 53 m above mean sea level with nearly level topography. Annual precipitation averages 140 cm. Soils are predominantly Bude and Providence silt loams (fine-silty, mixed, thermic, Glossaquic

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and Typic Fragiudalfs, respectively) that have an impervious layer at a depth of 50-100 cm, which impedes internal drainage and root growth (Gill and others 1979). Soil reactivity varies from medium acid to very strongly acid. Site index for loblolly pine is 27 m at age 50 (Cain 1993).

Treatments

Starting in the late 1930's, the study sites were managed using uneven-aged silviculture with single-tree selection and the complete exclusion of fire (Cain 1993). After the late 1960's, no harvesting, burning or vegetative control was performed until 1980. The following treatments were initiated in January of 1981 and consisted of: 1) an unburned control, 2) an irregular winter burn [every 2-3 years], 3) a winter burn every 5 years, and 4) a winter burn every 10 years (Cain and others 1998). The treatments were installed in each of the three 16-ha compartments. Four contiguous 1-ha plots comprised a 4-ha burn treatment in each compartment. Each 1-ha plot had an interior measurement plot of 0.65 ha that was surrounded by a 10-m wide isolation strip. For the purposes of this study, only the unburned control and irregular burn treatments were used. In 1992, the unburned control plots were treated with a broadcast application of Arsenal AC™ herbicide (1.7 kg a.i.) in 113 liters of water/ha using skidders. The most recent burn on the irregular burned treatment was conducted in October 1998.

All measurements occurred in the interior 0.65-ha plot located within a selected 1-ha plot in a treatment. Each of the selected 1-ha plots has been maintained at a residual pine basal area of 14 m^2/ha using single-tree selection on a six year harvesting schedule since 1980. Thus a total of six plots were used in the study, one unburned control and one irregularly burned plot in each of the three compartments. Within each of the measurement plots, three 4 x 4 m subplots were located. Vegetation within each of the 4 x 4 m subplots was trimmed to ground level in three strips (approximately 40 cm wide) for litterbag installation.

Litterbags

The litterbag method (Melillo and others 1982, Lockaby and others 1995) was utilized to measure decomposition rates on both treatments. Each nylon litterbag was 30 cm x 30 cm with a mesh size of 5 mm on the top and 2 mm on the bottom. In the fall of 1999, pine foliar litterfall was collected from all plots within the two treatments. The litter was air dried, mixed by treatment, and stored for later use in litterbags.

One set of litterbags was filled with 20 g of air-dried pine foliar litter collected from the burned treatments and a second set of litterbags was filled with 20 g of air-dried pine foliar litter collected from the unburned control treatment. Litterbags from both sets were placed on the forest floor surface in each of the trimmed strips located in each subplot on February 28, 2000. One litterbag from each set (foliage collected from the unburned and irregular burned treatments) was collected from each subplot after 0.5, 1, 2, 5, 7, and 10 months. Litterbags were transported in plastic bags to the laboratory, where all foreign material was removed. Litter was dried at 70° C for 48 hours and weighed. Loss on ignition from each sample was determined by heating the litter to 375° C for 16 hours. These values were then used to give a corrected (ash free) mass. The corrected mass, which is free from contamination by mineral soil, was used for statistical analysis. In addition, a correction factor was applied to adjust the initial air-dried weight of the litter to an oven-dried basis.

Cotton Strip Assay

A cotton strip assay (Latter and Howson 1977, Latter and Walton 1988, Butterfield 1999) was used to evaluate decomposition potential in the burned and unburned treatments. This technique is useful in assessing decomposition potential because the cloth is a uniform substrate and allows for examination of decomposition potential at different depths. In both April and July of 2000, sets of five 12 x 30 cm sheets of burial cloth manufactured by Shirley Dyeing and Finish Ltd. (Sagar 1988) were buried on each subplot to a depth of 25 cm using methods described by Latter and Howson (1977). After 30 days of incubation, the sheets were removed for analysis. In the laboratory, strips were cut and frayed to a width of 1 cm at each of four depths (3-5, 7-10, 12-15, and 21-24 cm). Tensile string was determined for each strip using a Scanpro Alwetron TH-1 tensile strength tester. Strips were equilibrated in a climate-controlled room at 50 percent relative humidity and 20^{o} C for 2 weeks prior to strength testing. The tensile strengths of strips from incubated sheets were subtracted from the tensile strengths of strips cut from control sheets that had been installed in the soil and immediately removed at the start of each incubation period. The use of the control sheets adjusted for the loss of tensile strength during installation and removal. The difference of these two values divided by the control strip tensile strength gave percent tensile strength loss for the incubated strips. Reduction of tensile strength calculated in this way reflects oxidation of carbon through decomposition.

Litter Quality

Several studies have used litter quality as a variable to assess decomposition rates (Fogel and Cromak 1977, Taylor and others 1989). Initial quality of loblolly pine litterfall was assessed for each treatment. Seven subsamples of the litter collected from each treatment were dried, ground, and analyzed for macronutrient concentrations. Concentrations of P, K, Ca, Mg, and S in the litterfall were determined using inductance coupled plasma (University of Arkansas, Soil Test Laboratory, 1990) after a perchloric acid digestion (Alder and Wilcox 1985). N and C concentrations were determined by combustion using a LECO CN2000 analyzer.

Statistical Design

Corrected mass loss from the litterbags was analyzed using ANOVA with a split-plot through space and time design with compartment as the blocking factor. The cotton strip data were analyzed using ANOVA with a split-split plot design. The litter quality data was analyzed using a paired t-test. All tests were done with a significance level at a = 0.05.

RESULTS AND DISCUSSION

After 10 months, there was no statistical evidence that 20 years of prescribed fires had significantly altered decomposition rates at these sites (figure 1). The corrected mass loss of the pine litterfall did not significantly differ between the

Table 1—Initial nutrient concentration of foliar litter collected from irregular burned and unburned treatments in three uneven-aged loblolly pine stands in Crossett, AR

Nutrient	Source	Mean Concentration (pct)	Standard Error
C	Burned	47.8 a[a]	0.083
	Unburned	48.2 b	0.104
N	Burned	0.43 a	0.006
	Unburned	0.43 a	0.012
P	Burned	0.26 a	0.001
	Unburned	0.27 a	0.002
K	Burned	0.13 a	0.004
	Unburned	0.11 b	0.007
Ca	Burned	0.36 a	0.006
	Unburned	0.33 b	0.011
Mg	Burned	0.09 a	0.002
	Unburned	0.08 b	0.003
S	Burned	0.04 a	0.001
	Unburned	0.04 a	0.001

[a] Concentrations for a given nutrient followed by the same letter are not significantly different at a = 0.05.

burned and unburned treatments for any of the collection dates. However, corrected mass of the litterfall was consistently lower on average in bags collected from the unburned than the burned treatment. Differences in corrected mass between the treatments were less than 2.2 percent for all collection periods.

Similar to the corrected mass loss of litter in the bags, cotton tensile strength loss (decomposition potential), did not significantly differ between the burned and unburned treatments for a given incubation period or depth (figure 2). Cotton tensile strength loss varied among incubation periods and depths but showed no consistent trends between treatments. Variation due to depth and incubation period (April or July) was generally much greater than variation between treatments (figure 2).

In contrast, corrected mass from litterbags containing pine litterfall from the irregular burned treatment was significantly lower than litterbags containing pine litterfall collected from the unburned treatment (figure 3). At the 0.5-month collection period, litterfall collected from the irregular burned treatment had lost 56 percent more mass than litterfall collected from unburned areas. After this time, mass of the two litterfall sources remained significantly different throughout the 10 months. The difference in mass between the two sources remained at approximately the same levels detected after ½ months. These results suggest that long-term prescribed fire can indirectly affect mass loss, and perhaps decomposition. The litterfall collected from the burned areas either decomposed faster or experienced rapid leaching after only 2 weeks. This suggests that there is an inherent difference in nutrient concentration, chemical composition, or possibly physical characteristics between the litterfall sources and that these differences need to be quantified.

Nutrient analysis of the collected litter showed no significant differences for N, P, S, or C/N ratios (table 1). However, litterfall collected from the burned treatment contained significantly higher concentrations of K, Ca, and Mg but lower concentrations of C than in litterfall from the unburned treatments. These differences, although small, may explain a portion of the initial differences in corrected mass loss in litterfall from the two treatment areas. It is also possible that differences in physical characteristics or soluble sugar contents of the litterfall contributed to the initial difference in weight loss. Examining nutrient contents in combination

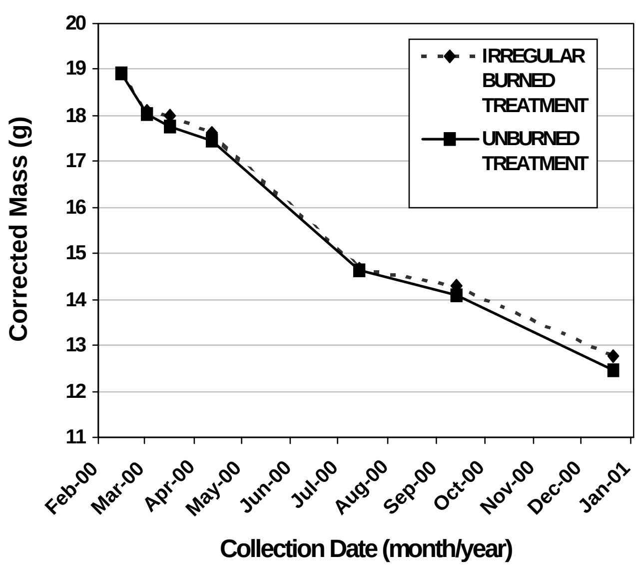

Figure 1—Corrected mass loss of decomposing foliar litter placed in irregular burned and unburned treatments in three uneven-aged loblolly pine stands in southeastern Arkansas.

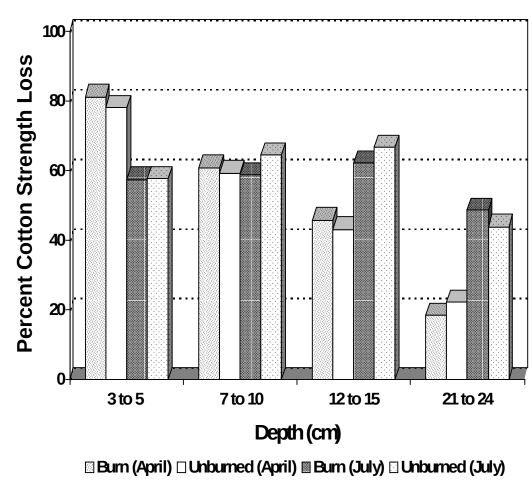

Figure 2—Percent cotton tensile strength loss over 30-day periods in April and July 2000 in irregular burned and unburned treatments in three uneven-aged loblolly pine stands in southeastern Arkansas.

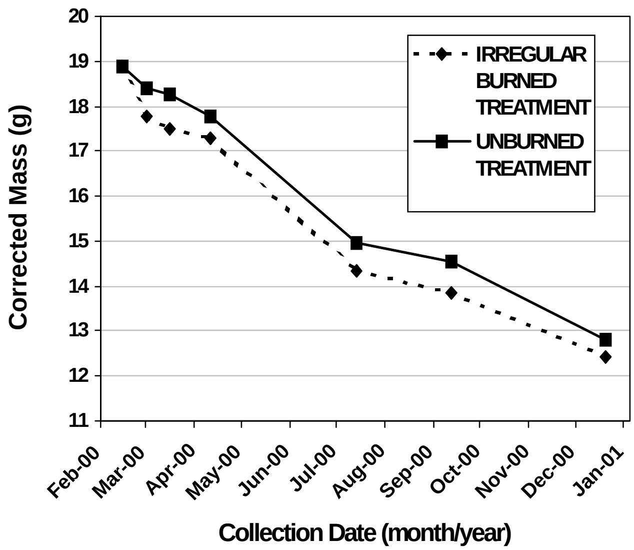

Figure 3—Corrected mass loss of decomposing foliar litter collected from irregular burned and unburned treatments in three uneven-aged loblolly pine stands in southeastern Arkansas.

with cellulose, lignin, or soluble sugar concentrations could have provided a better explanation of the corrected mass loss, but, we did not perform those analyses.

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REFERENCES

Adler, P.R. and Wilcox, G.W. 1985. Rapid perchloric acid digest methods for analysis of major elements in plant tissue. Communication in Soil Science and Plant Analysis. 16: 1153-1163.

Barnes, B.V.; Zak, D.R.; Denton, S.R.; Spurr, S.H. 1998. Forest ecology. New York, NY: John Wiley and Sons, Inc. 774 p.

Butterfield, J. 1999. Changes in decomposition rates and Collembola densities during the forestry cycle in conifer plantations. Journal of Applied Ecology. 36: 92-100.

Cain, M.D. 1993. A 10 year evaluation of prescribed winter burns in uneven-aged stands of Pinus taeda L. and P. echinata Mill.: woody understory vegetation response. International Journal of Wildland Fire. 3: 13-20.

Cain, M.D.; Wigley, T.B.; Reed, D.J. 1998. Prescribed fire effects on structure in uneven-aged stands of loblolly and shortleaf pines. Wildlife Society Bulletin. 26: 209-218.

Clinton, B.D.; Vose, J.M.; Swank, W.T. 1996. Shifts in above-ground and forest floor carbon and nitrogen pools after felling and burning in the southern Appalachians. Forest Science. 42: 431-440.

Fogel, R.; Cromak, K. 1977. Effect of habitat and substrate quality on Douglas-fir litter decomposition in western Oregon. Canadian Journal of Botany. 55: 1632-1640.

Gill, H.V.; Avery, D.C.; Larance, F.C.; Fultz, C.L. 1979. Soil survey of Ashley County, Arkansas. Washington, DC: U.S. Department of Agriculture Soil Conservation Service and Forest Service. Fayetteville, AR: Arkansas Agricultural Experiment Station. 174 p.

Latter, P.M.; Howson, G. 1977. The use of cotton strips to indicate cellulose decomposition in the field. Pedobiologia. 17: 145-155

Latter, P.M.; Walton, D. 1988. The cotton strip assay for cellulose decomposition studies in soil: History of the assay and development. In: Harrison, A.F., and others, eds. Cotton strip assay: An index of decomposition in soils. Grange-Over-Sands, England: Institute of Terrestrial Ecology: 7-9.

Lockaby, B.G.; Miller, J.H.; Clawson, R.G. 1995. Influences of community composition on biogeochemistry of loblolly pine (*Pinus taeda*) systems. American Midland Naturalist. 134: 176-184.

McCullough, D.G.; Werner, R.A.; Neumann, D. 1998. Fire and insects in northern and boreal forest ecosystems of North America. Annual Review of Entomology. 43: 107-127.

Melillo, J.M.; Aber, J.D.; Muratory, J.F. 1982. Nitrogen and lignin control of hardwood leaf litter dynamics. Ecology. 63: 624-626.

Sagar, B.F. 1988. The Shirley soil burial test fabric and tensile strength testing as a measure of biological breakdown of textiles. In: Harrison, A.F. and others (eds.). Cotton strip assay: An index of decomposition in soils. Grange-Over-Sands, England: Institute of Terrestrial Ecology: 11-16.

Shoch, P.; Binkley D. 1986. Prescribed burning increased nitrogen availability in a mature loblolly pine stand. Forest Ecology and Management. 14: 13-22.

Taylor, B.R.; Parkinson, D.; Parsons W.F.J. 1989. Nitrogen and lignin contents as predictors of litter decay rates: a microcosm test. Ecology. 70: 97-104.

EFFECTS OF PRESCRIBED FIRE ON HERPETOFAUNA WITHIN HARDWOOD FORESTS OF THE UPPER PIEDMONT OF SOUTH CAROLINA: A PRELIMINARY ANALYSIS

Thomas M. Floyd, Kevin R. Russell, Christopher E. Moorman, David H. Van Lear, David C. Guynn, Jr., and J. Drew Lanham[1]

Abstract—Despite a large body of knowledge concerning the use of prescribed burning for wildlife management, amphibians and reptiles (collectively, herpetofauna) have received relatively little attention regarding their responses to fire. With few exceptions, previous studies of herpetofauna and prescribed burning have been confined to fire-maintained, pine-dominated ecosystems in the Coastal Plain of the southeastern United States. We initiated a study to examine effects of prescribed burning on herpetofauna in Piedmont upland hardwood stands. Linear drift fence arrays with pitfall traps were installed within control and treatment plots to assess effects of burn treatments through analysis of species captures. Treatment plots were subjected to low intensity winter and growing season fire. The initial prescribed burn treatments were implemented in February and March (1999) while the second prescribed burn treatments were implemented in April (2000). All treatment plots were burned with strip head fires set 10-20 feet apart resulting in flame lengths averaging less than 1 foot. Direct searching and drift fence sampling immediately after each prescribed burn revealed 1) no evidence of direct herpetofaunal mortality, and 2) no evidence of emigration from burn plots. Statistical analysis of data through the installation of the second burn (May 1999 through April 2000) revealed no significant difference between burned and unburned treatments for abundance, richness (S), diversity (H'), or evenness (J')($P > 0.1$) of the herpetofaunal community.

INTRODUCTION

Prescribed burning is used to achieve a variety of silvicultural objectives including controlling heavy fuel accumulation, exposing mineral soil, releasing available nutrients for seedbed preparation, and controlling certain diseases, insects, and competing vegetation (Hunter 1990, Pyne and others 1996). Prescribed burning is also an important tool for wildlife management because it influences the amount and type of food and cover by modifying habitat structure. Despite a large body of knowledge concerning the use of prescribed burning for wildlife management, amphibians and reptiles (collectively, herpetofauna) have received relatively little attention regarding their responses to fire (deMaynadier and Hunter 1995, Harlow and Van Lear 1981, 1987, NCASI 1999, NCASI 1993, Russell and others 1999, Smith 2000). With few exceptions (i.e., Ford and others 1999, Kirkland and others 1996), previous studies of herpetofauna and prescribed burning have been confined to fire-maintained, pine-dominated ecosystems in the southeastern Coastal Plain (e.g., Lyon and others 1978, Means 1978, Means and Campbell 1981, McLeod and Gates 1998). Because little data are available concerning responses of herpetofauna to fire in other regions and forest types, we initiated a study to examine the effects of prescribed burning on herpetofauna in Piedmont upland hardwood stands.

Increased demands on southeastern forests, both public and private, are expected to continue (Sharitz and others 1992, USDA Forest Service 1988). As demands on timber resources increase, the use of prescribed fire as a forest management tool will continue to expand. If herpetofauna are to be considered in future forest management decisions, the effects of forestry practices such as prescribed burning on herpetofauna must be better understood. Objectives of this research effort included the determination of both the direct and indirect effects of prescribed fire on the diversity and abundance of herpetofaunal species within pine-hardwood forests in the Piedmont of the Southeast. Questions addressed within this research are of particular relevance in light of the utilization of prescribed fire in hardwood-dominated forest habitats within recent research to regenerate oak species (e.g., Barnes and Van Lear 1998, Brose and others 1999a, Brose and others 1999b, Van Lear 1991).

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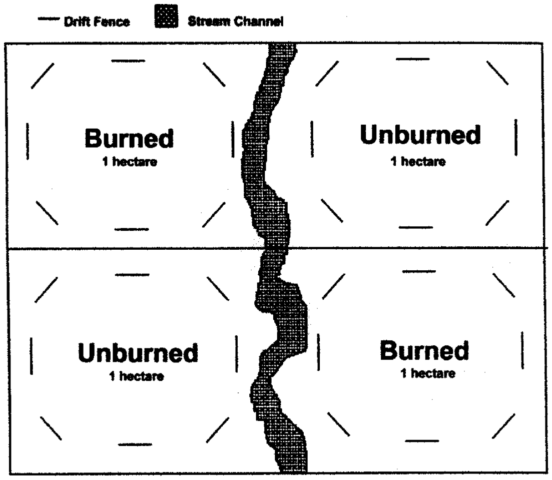

Figure 1—Experimental design of treatment and control plots of each of the three research sites, Clemson University Experimental Forest, Clemson, South Carolina, May 1999-April 2000.

METHODS AND STUDY AREA

Study Design and Site Selection

Study sites were located within the northern portion of the 17,356 acre Clemson University Experimental Forest (CUEF) in Pickens County in the Upper Piedmont of northwestern South Carolina. The CUEF is characterized by slightly to moderately rolling hills with elevations to 1,000 feet above sea level. Soil associations are Pacolet-Madison-Wilkes and Cecil-Hiawassee-Catuala (Typic Kanhapludults and Typic Hapludalfs). Soils are strongly acidic, firm and clayey being derived from gneiss, mica schist, hornblende schist and schist (Smith and Hallbeck 1979).

We evaluated the effects of prescribed burning on herpetofauna species found within three sites located along separate stream drainages within hardwood forest stands. These sites were selected based on similarity of species composition (dominant vegetation), vegetative structure, and aspect. The upland hardwood stands adjacent to each stream were divided into approximately 2.5 acre (1 hectare) control (unburned) and burn treatments (figure 1), for a total of six burn and control plots, respectively.

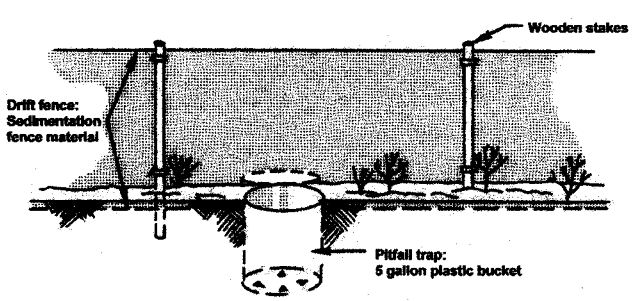

Figure 2—Schematic of pitfall-drift fence array construction, Clemson University Experimental Forest, Clemson, South Carolina, May 1999-April 2000 (diagram adapted from: Gibbons and Semlitsch 1982).

Herpetofaunal Sampling

Herpetofaunal species composition of the study sites were determined through the capture of individuals within pitfall-drift fence arrays. Linear drift fence arrays with pitfall traps (Gibbons and Semlitsch 1982) were installed along the perimeter of each plot to sample small terrestrial herpetofauna. Each drift fence array consisted of a 30 foot section of silt cloth with 2 pitfall traps (each a 5 gallon bucket, buried flush with the soil surface) at each end of the fence for a total of 4 pitfalls/fence (figure 2). Each plot had eight drift fences for a total of 96 drift fences and 384 pitfall traps among the three sites. All herpetofauna captured were identified to species, sex (when possible), age class, measured to the nearest mm in snout-vent length (SVL) and total length (TL), and marked. After all information was recorded and a mark assigned, herpetofauna were released on the opposite side of the fence from which they were captured.

Prescribed Fire Treatments

The initial prescribed burn treatments were implemented in February 1999 (sites 1, 2) and March 1999 (site 3) with strip head fires set 15-30 feet apart resulting in flame lengths averaging slightly over 1 foot. The second prescribed burn treatments (intended to be "growing season" burns) were implemented in April 2000 for all three sites with strip head fires set 10-20 feet apart. Flame lengths averaged less than 1 foot because of light fuel loading.

Statistical Analysis

We calculated species richness (S; Margalef 1958), evenness (J'; Pielou 1969), and diversity (H'; Shannon 1948) for amphibian and reptile communities at each site. Student's t-tests (Brower and others 1990) were calculated to compare mean values of abundance, richness, evenness, and diversity between burned and unburned (control) treatments. We also determined abundance for each order or suborder (or family), (i.e., frogs, toads, salamanders, newts, turtles, lizards, and snakes). We then compared the mean values of abundance, richness, evenness, and diversity for each of these taxonomic groups between burned and unburned site treatments using t-tests.

RESULTS

Direct searching and drift fence sampling immediately after prescribed burns revealed 1) no evidence of direct herpetofaunal mortality, and 2) no evidence of emigration from burn plots. Within the data analyzed (May 1999 through April 2000), 29 species of amphibians and reptiles were captured from the three drainages combined. Four species of the 29 were captured only in burned plots, while 5 species were captured only in unburned plots (table 1). Preliminary analysis of data following the first prescribed fire treatment using indices of species overlap (i.e., a measure of the number of shared species) indicated greater differences between sites (e.g., site 1 vs. site 2: 0.615) than between burn and control treatments (0.800). Statistical analysis of data through the installation of the second burn (May 1999 through April 2000) revealed no significant difference between burned and unburned

Table 1–Herpetofaunal taxa captured from burned and control plots in the Clemson University Experimental Forest, South Carolina, May 1999-April 2000

Taxonomic group	Common name	Treatment	
		Burn	Control
AMPHIBIA (amphibians)			
Caudata (salamanders)			
Desmognathus fuscus	(northern dusky salamander)	*	*
Desmognathus monticola	(seal salamander)		*
Desmognathus ocoee	(Ocoee salamander)	*	*
Desmognathus quadramaculatus	(black-bellied salamander)		*
Eurycea cirrigera	(southern two-lined salamander)	*	*
Eurycea guttolineata	(three-lined salamander)		*
Gyrinophilus porphyriticus dunni	(Carolina spring salamander)	*	*
Notophthalmus v. viridescens	(red-spotted newt)	*	*
Plethodon chlorobryonis	(Atlantic Coast slimy salamander)	*	*
Pseudotriton ruber schencki	(black-chinned red salamander)	*	*
Total salamanders		**51**	**77**
Anura (frogs and toads)			
Acris c. crepitans	(eastern cricket frog)	*	*
Bufo a. americanus	(eastern American toad)	*	*
Bufo terrestris	(southern toad)	*	
Bufo fowleri	(Fowler's toad)	*	*
Hyla chrysoscelis/versicolor	(gray treefrog)		*
Rana clamitans melanota	(northern green frog)	*	
Total anurans		**57**	**48**
Total amphibians		**108**	**125**
REPTILIA (reptiles)			
Serpentes (snakes)			
Carphophis a. amoenus	(eastern worm snake)	*	*
Diadophis punctatus edwardsii	(northern ring-necked snake)	*	*
Elaphe o. obsoleta	(black ratsnake)	*	*
Heterodon platirhinos	(eastern hog-nosed snake)		
*			
Nerodia s. sipedon	(common watersnake)	*	
Storeria o. occipitomaculata	(northern red-bellied snake)		*
Tantilla coronata	(southeastern crowned snake)	*	
Total snakes		**16**	**20**
Lacertilia (lizards)			
Anolis c. carolinesis	(northern green anole)	*	*
Eumeces fasciatus	(common five-lined skink)	*	*
Eumeces inexpectatus	(southeastern five-lined skink)	*	*
Sceloporus undulatus hyacinthinus	(northern fence lizard)	*	*
Scincella laterallis	(little brown skink)		*
*			
Total lizards		**69**	**54**
Testudines (turtles)			
Terrapene c. carolina	(eastern box turtle)	*	*
Total turtles		**2**	**3**
Total reptiles		**87**	**77**
Total captures		**195**	**203**

treatments for abundance, richness (S), diversity (H'), or evenness (J')(P > 0.1). Analysis of abundance, richness, diversity, and evenness for taxonomic groups (frogs, toads, salamanders, newts, turtles, lizards, and snakes) revealed no significant difference with respect to treatment (P > 0.1). However, captures of individuals tended to be greater within unburned (control) plots for salamanders and snake species (figure 3) and may prove significant as more data becomes available with continued sampling.

DISCUSSION

The lack of statistically significant differences in data between treatments may be attributed to the limited subset of project data available for this preliminary data analysis. Significant differences between burned and control treatments may be found in future analyses of data collected over a greater temporal scale. We believe that the differences (although not statistically significant) observed in salamander species capture between burned and unburned plots are an indirect result of the low intensity prescribed fire treatments. Surface fires introduced to the treatment plots substantially reduced or completely eliminated the litter mass, but not the duff mass, on the forest floor until leaf fall the following autumn.

Ash (1995) postulated that reductions in litter mass, depth, and moisture may contribute to the disappearance of terrestrial salamander species as they depend on a moist environment for dermal respiration and on litter as their primary foraging substrate. Furthermore, low intensity surface fire in mature upland mixed hardwood stands may reduce moisture content of the soil surface through the elimination of leaf litter and by increasing the amount of solar radiation reaching the soil surface (Barnes and Van Lear 1998).

Plethodontid salamanders (the lungless family of salamanders with an entirely terrestrial life cycle) spend roughly 70 - 80 percent of their lives in underground burrows, emerging at night to forage within the leaf litter under favorable conditions (Ash 1995, Taub 1961). The combined effect of decreased surface soil moisture and repeated reduction or elimination of leaf litter mass by prescribed fire treatments could result in a decrease in the relative humidity in these burrows, resulting in the gradual decline of salamander populations within burned plots, especially in more xeric sites (e.g., ridge tops).

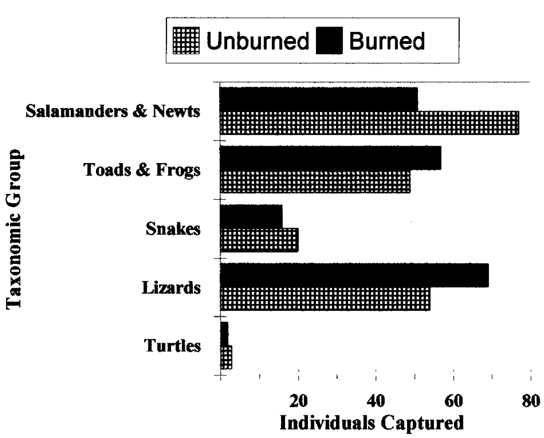

Figure 3—Total number of individuals captured by taxonomic group following burning in the Clemson University Experimental Forest, Clemson, South Carolina, May 1999-April 2000.

SUMMARY AND CONCLUSIONS

Preliminary analysis of a subset of project capture data (May 1999 through April 2000) revealed no significant difference between burned and unburned treatments with respect to abundance, richness (S), diversity (H'), or evenness (J')(P > 0.1). Analysis of abundance, richness, diversity, and evenness for taxonomic groups (frogs, toads, salamanders, newts, turtles, lizards, and snakes) revealed no significant difference with respect to treatment (P > 0.1). Based on these preliminary analyses, the use of prescribed fire in hardwood forests of the Upper Piedmont of South Carolina does not appear to have a measurable negative effect on herpetofaunal communities associated with these upland hardwood habitats. However, we believe that the differences (although not statistically significant) observed in salamander species capture between burned and unburned plots are an indirect result of the low intensity prescribed fire treatments. We therefore suggest continued monitoring of the research sites and analysis of additional data, as data collected over a greater span of time may reveal differences among species such as Plethodontid salamanders. Analysis of additional data will be conducted in the near future.

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REFERENCES

Ash, A.N. 1995. Effects of clear-cutting on litter parameters in the southern Blue Ridge Mountains. Castanea. 60(2): 89-97.

Barnes, T.A.; Van Lear, D.H. 1998. Prescribed fire effects on advanced regeneration in mixed hardwood stands. Southern Journal of Applied Forestry. 22(3): 138-142.

Brose, P.; Van Lear, D.H.; Cooper, R. 1999a. Using shelterwood harvests and prescribed fire to regenerate oaks stands on productive upland sites. Forest Ecology and Management. 113(2-3): 125-141.

Brose, P.; Van Lear, D.H.; Keyser, P.D. 1999b. A shelterwood-burn technique for regenerating productive upland oak sites in the Piedmont region. Southern Journal of Applied Forestry. 23(3): 158-163.

Brower, J.; Zar, J.; von Ende, C. 1990. Field and laboratory methods of general ecology. 3rd ed. Dubuque, Iowa: W.C. Brown Publishers. 237 p.

DeMaynadier, P.G.; Hunter, M.L., Jr. 1995. The relationship between forest management and amphibian ecology: a review of the North American literature. Environmental Reviews. 3: 230-261.

Ford, W.M.; Menzel, M.A.; McGill, D.W.; Laerm, J.; McCay, T.S. 1999. Effects of a community restoration fire on small mammals and herpetofauna in the Southern Appalachians. Forest Ecology and Management. 114(2-3): 233-244.

Gibbons, J.W.; Semlitsch, R.D. 1982. Terrestrial drift fences with pitfall traps: An effective technique for quantitative sampling of animal populations. Brimleyana. 7: 1-16.

Harlow, R.F.; Van Lear, D.H. 1981. Silvicultural effects on wildlife habitat in the South (an annotated bibliography)1953-1979. Department of Forestry Technical Paper Number 14. Clemson University, Clemson, SC.

Harlow, R.F.; Van Lear, D.H. 1987. Silvicultural effects on wildlife habitat in the South (an annotated bibliography)1980-1985. Department of Forestry Technical Paper Number 17. Clemson University, Clemson, SC.

Hunter, M.A., Jr. 1990. Wildlife, forests, and forestry: principles of managing forests for biological diversity. Englewood Cliffs, New Jersey: Prentice Hall. 370 p.

Kirkland, G.L., Jr.; Snoddy, H.W.; Miller, T.L. 1996. Impact of fire on small mammals and amphibians in central Appalachian deciduous forest. American Midland Naturalist. 135(2): 253-260.

Lyon, L.J.; Crwaford, H.S.; Czuhai, E.; Fredriksen, R.L.; Harlow, R.F.; Metz, L.J.; Pearson, H.A. 1978. Effects of fire on fauna: state-of-knowlege review. General Technical Report, WO-6. Washington, D.C.: U.S. Department of Agriculture, Forest Service. 22 p.

Margalef, D.R. 1958. Information theory in ecology. Yearbook of the Society for General Systems Research. 3: 36-71.

McLeod, R.F.; Gates, J.E. 1998. Response of herpetofaunal communities to forest cutting and burning at Chesapeake Farms, Maryland. American Midland Naturalist. 139(1): 164-177.

Means, D.B. 1978. The Pine Barrens treefrog: fire, seepage bogs, and management implications. In: Proceedings of the rare and endangered wildlife symposium. R.R. Odom; Landers, L., eds. Georgia Department of Natural Resources, Game and Fish Division, Technical Bulletin WL -4. Athens, GA.: 77-81.

Means, D.B.; Campbell, H.W. 1981. Effects of prescribed fire on amphibians and reptiles. In: Wood, G.W.,ed. Prescribed fire and wildlife in southern forests: Proceedings of a symposium; 1981 Apr 6-8; Myrtle Beach, SC. Georgetown, SC: The Belle Baruch Forest Science Institute of Clemson University: 89-96.

National Council of the Paper Industry for Air and Stream Improvement, Inc. (NCASI). 1993. Forestry, wildlife, and habitat in the East: An annotated bibliography, 1986-1990. Technical Bulletin No. 651. New York: National Council of the Paper Industry for Air and Stream Improvement, Inc: 1-317, appendices.

National Council of the Paper Industry for Air and Stream Improvement, Inc. (NCASI). 1999. Forestry, wildlife, and habitat in the East: An annotated bibliography, 1991-1995. Technical Bulletin No. 781. Research Triangle Park, N.C.: National Council of the Paper Industry for Air and Stream Improvement, Inc: 1-725, appendices.

Pielou, E.C. 1969. An introduction to mathematical ecology. New York: Wiley-Interscience. 286 p.

Pyne, S.J.; P.L. Andrews; R.D. Laven. 1996. Introduction to wildland fire. Second edition. New York: John Wiley and Sons. 769 p.

Russell, K.R.; Van Lear, D.H.; Guynn, D.C., Jr. 1999. Prescribed fire effects on herpetofauna: review and management implications. Wildlife Society Bulletin**.** 27(2): 374-384.

Shannon, C.E. 1948. A mathematical theory of communication. Bell System Technical Journal. 27(1,2): 379-423; 27(3): 623-656.

Sharitz, R.R.; Boring, L.R.; Van Lear, D.H.; Pinder, J.E., III. 1992. Integrating ecological concepts with natural resource management of southern forests. Ecological Applications. 2(3): 226-237.

Smith, B.R.; Hallbeck, D.C. 1979. General soil map, South Carolina. South Carolina Agricultural Experiment Station, Clemson University, Clemson, South Carolina.

Smith, J.K.,ed. 2000. Wildland fire in ecosystems: effects of fire on fauna. General Technical Report, RMRS-42-vol. 1. Ogden, UT: U. S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 83 p.

Taub, F.B. 1961. The distribution of the red-backed salamander, *Plethodon c. cinereus*, within the soil. Ecology. 42(4): 681-698.

U.S. Department of Agriculture, Forest Service. 1988. The South's fourth forest: alternatives for the future. Forest Resources Report No. 24. Washington, D.C.: U.S. Department of Agriculture, Forest Service.

Van Lear, D.H. 1991. Fire and oak regeneration in the southern Appalachians. In: Proceedings: fire and the environment: ecological and cultural perspectives. General Technical Report SE-69. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 15-21.

ECTOMYCORRHIZAE OF TABLE MOUNTAIN PINE AND THE INFLUENCE OF PRESCRIBED BURNING ON THEIR SURVIVAL

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Abstract—High-intensity prescribed fires have been recommended to regenerate Table Mountain pine (*Pinus pungens)*. However, tests of these burns produced few seedlings, possibly due to soil sterilization. This study examined abundance of mycorrhizal root tips in the field after a high-intensity fire and in the laboratory after exposing rooting media to various temperatures. One- and two-year old seedlings in the field had abundant mycorrhizal root tips formed by symbiotic relationships with at least three fungal species. Laboratory tests showed reduced mycorrhizal root tip formation only after prolonged exposure to very high temperatures. This study suggests that poor regeneration after high-intensity prescribed fires was not caused by a lack of mycorrhizal fungi.

INTRODUCTION

There is increasing evidence that fire is an important component of the Table Mountain pine (*Pinus pungens*) community. Although not currently threatened or endangered, Table Mountain pine is being replaced by more shade-tolerant hardwoods in the Appalachian Mountains because of fire exclusion (Van Lear and Waldrop 1989). Early work suggested that Table Mountain pine requires a very high intensity fire in order to promote adequate regeneration (Zobel 1969). However, research to date does not define in sufficient detail the necessary fire regime to provide regeneration.

Attempts at determining the optimum fire regime have had limited success. Waldrop and Brose (1999) found that a high intensity fire was not necessary for successful regeneration of Table Mountain pine. While a lower-intensity fire is easier and safer to conduct, a medium-intensity fire was deemed to be best because it killed most of the overstory, which would allow sunlight to reach the soil surface. High-intensity fires led to the poorest regeneration success in that study. This may have been caused by combustion of cones or the high temperatures may have sterilized the upper soil which would have reduced minimally effective levels of mycorrhizal fungi. This study was conducted to determine the possible deleterious effects of high-intensity fire on ectomycorrhizae in Table Mountain pine seedlings.

METHODS

Study Area

The study area was the same as that used by Waldrop and Brose (1999) and was located in the Chattahoochee National Forest near Clayton, Georgia. Sites 1 and 2 were both 12 ha in size and at elevations of 914 and 884 m, respectively. Site 3 was 18 ha in size and was at 1100 m elevation. All three stands were similar in composition and stocking with an overstory of Table Mountain pine and understory of various hardwoods. Because of the previous lack of fire, the understory consisted of thickets of mountain laurel (*Kalmia latifolia*) and young hardwoods.

All three stands were burned as one unit on April 4, 1997, a total of 345 ha. Fire intensities within sample plots were classified by Waldrop and Brose (1999). Nine plots were classified as having been burned by low intensity fires, 28 as medium-low, 9 as medium-high, and 14 were high intensity. Site 3 burned at high and medium-high intensities and sites 1 and 2 burned at low and medium-high intensities.

Field Quantification of Mycorrhizae

Three months after the fire, 60 sample plots, 10x20 m^2 in size, were established throughout the three stands (Waldrop and Brose 1999). Four first- or second-year seedlings of Table Mountain pine were collected in October 1998 on the down-slope side of each of seven arbitrarily selected plots in site 1, eight plots in site 2, and seven plots in site 3. Seedlings were disinterred by carefully removing the attached soil ball and as much of the root system as possible. In the laboratory, each seedling was exposed to running tap water for two minutes to soften and remove soil particles. Seedling size was estimated by measuring stem length, tap root length, and length of lateral and short roots. Each root tip was visually inspected to determine presence of ectomycorrhizae. ANOVA and t-tests were conducted to compare seedling size and presence of mycorrhizae with plot location and seedling age.

Histology

After the preceding measurements were completed, representative root tips were severed and fixed in 3.5 percent glutaraldehyde, dehydrated, and embedded in plastic resin (JB-4 embedding kit, Fisher). Transverse sections 6-8 Fm thick were prepared using glass knives and a JB-4.3, JB-4A Porter Blum microtome. Sections were affixed to clean microscope slides, dried, stained with toluidine blue and

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Table 1—Statistics of Table Mountain pine seedlings from the field collections

Site	n	Mean Length (mm) Stem	Root	Total	Mycorrhizal Root tips
First-year seedlings					
1	2	8.5a[1]	5.3a	13.8a	7.0a
2	10	9.3a	6.5a	15.8a	25.0a
3	28	8.3a	9.4a	17.7a	20.0a
Second-year seedlings					
1	26	13.7a	8.7a	22.4a	42.5a
2	22	15.4a	10.1a	25.5a	36.7a

[1]Means with the same lowercase letter within a column are not significantly different at the 0.05 level.

safranin-fast green, and viewed under 100X magnification. Four sections from each root tip were examined and the following measurements were recorded: 1) mantel thickness and morphology, 2) diameter of cortical cells, and 3) morphology and diameter of intercellular hyphae. Comparison of these measurements with published data (Trappe 1962, Jackson and Mason 1984, Marx 1977, Hacskaylo 1961) indicated that *Cenococcum* spp., *Pisolithus tinctorius*, and *Suillus granulatus* were the most common symbionts of Table Mountain pine seedlings.

Axenic culture

In order to confirm that these species were, indeed, capable of forming ectomycorrhizae with Table Mountain pine, cultures of *Cenococcum graniforme*, *C. geophilum*, *P. tinctorius*, and *S. granulatus* were obtained from the American Type Culture Collection (Beltsville, MD). The cultures were maintained on Melin-Norkrans media.

Seeds of Table Mountain pine were surface disinfected by swirling in a 1 percent solution of sodium hypochlorite for three minutes, rinsed in three changes of sterile distilled water, and then plated on acidified potato-dextrose agar to test for surface sterility and to induce germination.

Axenic growth chambers consisted of 1-quart canning jars with a 1.27 cm dia piece of PVC pipe glued in a hole in the lid and plugged with cotton. The open end was covered loosely with a piece of aluminum foil to allow for aeration but to minimize dust contamination. Each jar contained a mixture of 400 ml of vermiculite and 256 ml of Melin's (1921) nutrient solution as modified by Norkrans (1949). The jars were autoclaved for 30 minutes at 121^0 C two separate times with a 24-hour period in between to allow for germination of heat-resistant spores. A layer of aluminum foil was wrapped around the bottom half of each jar to exclude light from the root zone. The jars were placed in a growth chamber programmed for an 18-hour photoperiod and a constant temperature of 22^0 C. Average light intensity was 21.83 microeinsteins (FE $/sm^2$).

An aseptic seed with a radicle 1-3 mm in length was transplanted into each jar at a depth of 6 mm. At the same time, 2-10 mm discs of inoculum from 30-day-old cultures of the respective fungus were placed on the vermiculite surface. After four months incubation, the seedlings were removed, measured as with the field quantifications, and inspected for mycorrhizal development.

The experiment included a total of 60 jars, with 5 treatments which included each of the four fungi and a control with only an aseptic seedling and 12 replications within each treatment. The entire experiment was performed twice. Results were analyzed by ANOVA and t-tests.

Heat treatments

A heated water bath was used to determine the resistance of mycorrhizal fungi to heat. Pure cultures of each of the respective mycorrhizal fungi were grown in 1-quart canning jars as described above, except that pine seedlings were not placed in the jars for the first part of the experiment. After 30 days incubation, the jars containing their respective fungal cultures were placed in a water bath at 25^0 C (control), 50^0 C, 60^0 C, or 80^0 C, respectively, for 60 minutes. After cooling for 24 hours, two aseptic seeds of Table Mountain pine each with a radicle 1-3 mm in length were planted in each jar. The jars were incubated for 90 days, after which time the seedlings were removed, measured as with the field quantifications, and inspected for mycorrhizal development. Sixty jars were used, separated into five sets of twelve each. Each set included the four fungi and a control. The experiment was repeated twice. ANOVA and t-tests were conducted.

RESULTS AND DISCUSSION

Field Quantification of Ectomycorrhizae

Sites 1 and 2 had burned with similar low- to medium-fire intensities whereas site 3 burned at a much higher intensity. Because of this, there was no difficulty in finding an adequate number of either first- or second-year

Table 2—Statistics of Table Mountain pine seedlings in axenic culture, in first/second experiments

Fungal Species	# of Seedlings	Total Length (mm)	# root tips (avg.)	# mycorrhizal root tips (avg.)
C. gran.	11/	15.6a[1]/	56.6a/	0.6a/
	11	14.4a	29.4a,b	5.3b
C. geop.	12/	21.4a/	45.8a,b/	3.8a/
	12	13.3a	21.2a,b	7.5b
S. gran.	10/	28.2b/	52.2a,b/	4.5a/
	10	16.4a	31.3a	21.1a
P. tinc.	10/	18.0a/	20.6c/	4.4a/
	11	13.2a	13.6b	7.6b
Control	11/	16.0a/	31.2b,c/	0.0a/

seedlings at the first two sites but it was very difficult to find either first- or second-year seedlings at site 3. Hence, only a limited number of first-year seedlings could be found and there are no second-year seedling data for site 3.

There was no significant difference in average stem length, root length, total length, and average number of root tips with mycorrhizae among first-year and second-year seedlings of Table Mountain pine between the study areas (table 1). However, there was a significant difference in mycorrhizal root tips between first- and second-year seedlings. Approximately 70 percent of the root tips from all three sites were mycorrhizal, suggesting that mycorrhizal development began in the first growing season after the fire and continued into the second season. The data also suggest that soil temperatures did not reach lethal levels, even with the high-intensity fire.

Table 3—Average number of mycorrhizal root tips formed at various temperatures and by different fungal species

Temperature (^{0}C)	Experiment 1	Experiment 2
25	6.1 a,b[1]	5.4 a
50	7.7 a	2.1 a,b
60	2.3 b,c	3.8 a,b
80	0.1 c	0.3 b
Fungus		
Control	0.0 b	0.0 b
C. geo.	0.0 b	0.9 b
C. gran.	1.7 b	1.1 b
S. gran.	8.9 a	5.8 a
P. tinct.	9.7 a	5.8 a

[1]In each experiment, means followed by the same lowercase letter are not significantly different at the 0.05 level.

Histology

There were three distinct morphological types of ectomycorrhizae observed on the roots of Table Mountain pine. These matched published descriptions of *Suillus granulatus*, *Pisolithus tinctorius*, and *Cenococcum* sp. (Chambers and Cairney 1999, Riffle 1973, Marx and others 1969). The most important diagnostic attributes were color, type of branching, root tip length and diameter, mantle diameter, presence of the hartig net, and size of cortical cell. Visual examination of mycorrhizal root tips and the histological sections indicated that *P. tinctorius* was the slightly more abundant of the three fungal symbionts in all three sites in both first- and second-year seedlings. The occurrence of mycorrhizal root tips on first-year seedlings in site 3 suggests that soil sterilization did not occur.

Axenic Culture

The two axenic culture experiments produced relatively low levels of mycorrhizal root tips and the results were somewhat variable (table 2). Total seedling length with any of the fungi did not differ significantly from the control except in the first experiment where total seedling length of 28.2 mm for *S. granulatus* was significantly greater than that for any of the other fungi or the control. In the first experiment, only seedlings with *C. graniforme* were associated with a larger number of root tips (56.6) than the control (31.2), yet this difference was not observed in the second experiment, nor was there any difference in the average number of mycorrhizal root tips between any of the fungi and the control. In the second experiment, only *S. granulatus* produced a significantly greater number of mycorrhizal root tips (21.1) than the control (0.0). Mycorrhizal fungi are notoriously difficult to work with in axenic culture and it is suspected that the low infection rates seen here are due to the lack of a clear understanding of all the subtle growth variables necessary for successful infection.

Heat Treatments

This experiment was conducted twice, with similar results produced both times. Hence, only the results of experiment one are presented. At the control temperature of 25^{0} C, 74 percent of *S. granulatus* root tips were mycorrhizal, 49 percent of *P. tinctorius* root tips were mycorrhizal, 16 percent of *C. graniforme* root tips were mycorrhizal, and *C. geophilum* and sterile seedlings had no response (figure 1). The mean mycorrhizal count for all the fungal species was 6.1 per seedling.

At 50^{0} C, 79 percent of *P. tinctorius* root tips were mycorrhizal, 75 percent of *S. granulatus* root tips were mycorrhizal, 10 percent of *C. graniforme* root tips were mycorrhizal, and *C. geophilum* and sterile seedlings had no response (figure 1). The mean mycorrhizal count for all the fungal species was 7.7 per seedling.

At 60^{0} C, 31 percent of *P. tinctorius* root tips were mycorrhizal, 13 percent of *S. granulatus* root tips were

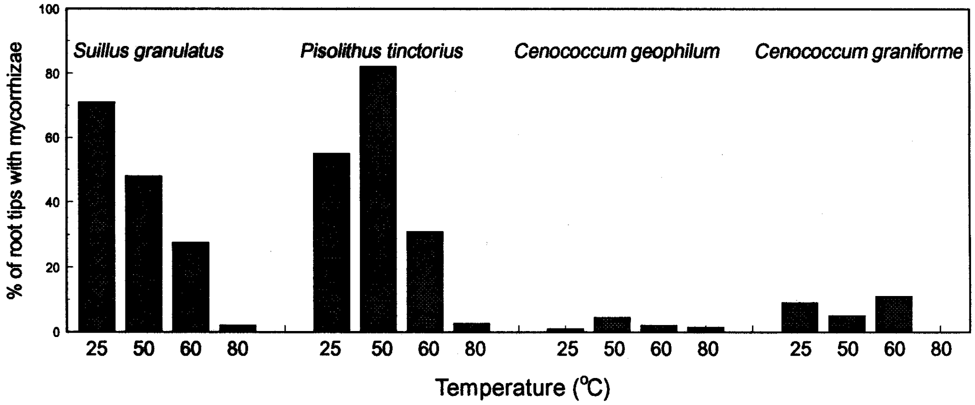

Figure 1—Percentage of Table Mountain root tips with mycorrhizae by fungal species formed after heat treatments at various temperatures.

mycorrhizal, and the two *Cenococcum* species and the control had no response (figure 1). The mean mycorrhizal count for all the fungal species was 2.3 per seedling.

At 80^0 C, there was almost no mycorrhizal growth (figure 1), with *S. granulatus*, *P. tinctorius*, and *C. geophilum* producing only 3 percent to 6 percent of mycorrhizal root tips. The mean mycorrhizal count for all the fungal species was 0.1 per seedling.

There was a significant difference in mycorrhizal count among the various temperatures (table 3). Mycorrhizal abundance tended to drop at temperatures over 50^0 C and was almost eliminated at 80^0 C. There was also a significant difference in mycorrhizal count among fungi, with both *P. tinctorius* and *S. granulatus* different from *C. graniforme* and *C. geophilum* as well as the control. *S. granulatus* and *P. tinctorius* gave the most favorable results in the heat treatment experiments (figure 1). Both species grew well at the lower temperatures and, except for some variation at 50^0 C in experiment 2, both fungi grew in the same relative temperature range. Neither survived well at temperatures reaching 80^0 C.

CONCLUSIONS

Table Mountain pine was confirmed to be symbiotic with at least three mycorrhizal fungi, all of which are known for their preference for dry habitats and, hence, are very well adapted to form beneficial relationships with Table Mountain pine. This research also showed experimentally that these fungi cannot survive a prolonged temperature exceeding 80^0 C. Regardless of fire intensity, it is unlikely that temperatures of 80^0 C would be achieved to any significant soil depth. In the experimental burned area exposed to a high-intensity fire, the behavior of mycorrhizal formation in first- and second-year seedlings suggests that the mycorrhizal fungi either survived the intense fire intensities or they recolonized the site quickly. While it is probably desirable to perform prescribed burns at something less than a medium-high intensity, it seems clear from the results of the present research that even a medium-high intensity probably does not seriously harm the mycorrhizal symbionts in the soil of the burned areas.

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REFERENCES

Chambers, S. M. and J. W. G. Cairney. 1999. *Pisolithus*. Ectomycorrhizal Fungi: Key Genera in Profile. New York: Springer, Inc:1-31.

Hacskaylo, E. 1961. Factors influencing mycorrhizal development in some cultural practices. Recent Advances in Botany 14: 1744-1748.

Jackson, R. A. and P. A. Mason. 1984. Mycorrhizae. The Camelot Press, Ltd., Great Britain. 60 p.

Marx, D. H. 1977. Tree host range and world distribution of the ectomycorrhizal fungus *Pisolithus tinctorius*. Canadian Journal of Microbiology 23: 217-223.

Marx, D. H., W. C. Bryan and C. B. Davey. 1969. Influence of temperature on aseptic synthesis of ectomycorrhizae by *Thelephora terrestris* and *Pisolithus tinctorius* on loblolly pine. Forest Science 16: 424-431.

Melin, E. 1921. Uber die Mykorrizen pilze von *Pinus sylvestris* L. und *Picea abies* (L.) Karst. Svensk. Bot. Tidskr.15: 192-203.

Norkrans, B. 1949. Some mycorrhizae-forming *Tricholoma* species. Svensk. Bot. Tidskr. 43: 485-490.

Riffle, J. W. 1973. Pure culture synthesis of ectomycorrhizae on *Pinus ponderosa* with species of *Amanita*, *Suillus*, and *Lacterius*. Forest Science. 19: 242-250.

Trappe, J. M. 1962. Fungus associates of ectotrophic mycorrhizae. Botanical Review 28: 538-606.

Van Lear, D. H. and T. A. Waldrop. 1989. History, use and effects of fire in the Southern Appalachians. Gen. Tech. Rept. SE-54: U.S. Department of Agriculture, Forest Service. 20 p.

Waldrop, T. A. and P. H. Brose. 1999. A comparison of fire intensity levels for stand replacement of Table Mountain pine (*Pinus pungens* Lamb.). Forest Ecology and Management 113: 155-166.

Zobel, D. B. 1969. Factors affecting the distribution of *Pinus pungens*, an Appalachian endemic. Ecological Monographs 39: 303-333.

PRESCRIBED FIRE IN THE INTERFACE: SEPARATING THE PEOPLE FROM THE TREES

David T. Butry, John M. Pye, and Jeffrey P. Prestemon[1]

Abstract—Land managers in Florida rely on prescribed fire to prepare sites for regeneration, improve wildlife habitats, reduce vegetative competition, facilitate timber management activities, and mitigate wildfire risk. More than one million acres of land is scheduled for prescribed fire each year in Florida, nearly five times more than the area burned by wildfires. However, little has been done to understand the characteristics of communities affected by fire: who live in these communities and where are they located, where could additional prescribed burning and other wildfire risk mitigation activities be targeted, and how might continued population growth affect future tolerance for these practices? To shed light on these questions we use GIS overlay and correlation techniques to characterize and compare fire-affected zones in Florida. Characteristics studied include: population demographics, road density, neighborhood forest stand attributes, amount of forest fragmentation, and sources and frequency of wildfire ignition. We find that prescribed burning occurs in places where, on average, people are younger, earn lower incomes, have less formal education, are more frequently Caucasian, and live in more rural areas than people living in places without any prescribed fire or wildfire. High rates of prescribed burning occur in areas with less fragmented forests, more government management, and greater dominance by pine (Pinus spp.) forest types. Wildfires, on the other hand, occur most often in areas where forests are fragmented, ecologically more diverse, and privately owned.

INTRODUCTION

Prescribed fire is used extensively in Florida. Silvicultural burn permits were issued for roughly 500,000 acres a year from 1993 to 1999. Since 1981 wildfires on average have accounted for an additional 200,000 burned acres each year, as severe or catastrophic years (those totaling in excess of 400,000 acres) occur every four or five years. Since prescribed burning and wildfire are not uniformly distributed across the state (figures 1 and 2), residents' experiences with fire are likely to vary depending on where they live. Florida, with almost 16 million people in 2000, is the fourth most populous state in the U.S., and its population grew nearly 24 percent during the 1990's. Much of this population growth is due to a large influx of retirees, immigrants, and other northern migrants. Coupled with the state's large seasonal population, many Floridians may be quite new to wildfires, not to mention its large prescribed burning program. Such unfamiliarity, combined with high populations in certain locations, may result in new and greater constraints on wildfire risk reduction strategies, thereby resulting in greater risks of wildfire.

The purpose of this paper is to examine the people of Florida's wildland-urban interface, areas with a mix of people, development, and wildlands, and the fire-prone landscape in which they reside. We characterize where wildfires and prescribed fires occur and the relationships between where fires are found and whom they affect. The state of Florida provides an excellent study area with its diverse and growing population scattered among landscapes that frequently burn.

DATA

Our analysis combines six datasets: two from the Florida Division of Forestry (FDF), and the others from publicly available Census, USDA Forest Service, and remote sensing products.

Wildfires

The first FDF dataset provides information on all wildfire incidents reported to the State including the date of incident, number of acres burned, the ignition source, and the township, range, and cadastral section in which it occurred. Ignition sources include lightning, arson, and several other human-caused ignitions, which we grouped as accidents. These data span the calendar years 1981 to 1999 and do not include fires on federal lands.

Prescribed burning

In order to start a prescribed fire in Florida, a permit must be obtained from the State less than one day in advance. Records for each fire permit include the date of issuance, number of acres to be treated, location of at least one section of the prescribed burn, and the reason for the burn. Reasons include hazard reduction, disease control, site preparation for seeding or planting, wildlife habitat enhancement, and others. We group the reasons into two different types: seed and site prep (prior to seed and site prep) and traditional (everything else). The data span calendar years 1989 to 1999, although full statewide coverage did not begin until 1993.

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Demographics

The US Census Bureau's Topologically Integrated Geographic Encoding and Referencing (TIGER) 1995 data from the Environmental System Research Institute (ESRI), describe population, race, age, education, income, and home value by Census block-group for the 1990 Census. We also obtained from ESRI the TIGER/line road coverage.

Fragmentation

A 30-meter resolution forest fragmentation grid coverage, derived from the Multi-Resolution Land Characteristics (MRLC) Consortium's land cover map, was obtained from the USDA Forest Service (see Riitters and others 1997). These data are used to classify Florida into 6 fragmentation classes based on percent forest cover and percent of forest connectivity: interior forest, edge forest, perforated forest, transitional forest, patch forest, and no forest (figure 3).

Interior forests have 100 percent forest cover and forest connectivity. Perforated and edge forests have high levels of forest cover (greater than 60 percent), but differ in their levels of forest connectivity (ranging from 0 to 100 percent). For the same level of forest cover, the edge forest has a higher level of forest connectivity, whereas, for the same level of forest connectivity, the perforated forest has more forest cover.

Transitional and patch forests can both have any level of connectivity (ranging from 0 to 100 percent), but are differentiated by their levels of forest cover. Transitional forests have between 30 to 60 percent forest cover, whereas patch forest have between 0 to 30 percent forest cover.

Forest Ownership and Type

Stand level characteristics were obtained from the plot records of Florida's 1995 Multiple Resource (MR) database, maintained by the USDA Forest Service's Forest Inventory and Analysis (FIA) unit in Asheville, NC. We use the plot ownership and forest type variables.

METHODS

First, we relate the aggregated number of burn permits issued by cadastral section to the number of wildfire ignitions by source for the "fire years" 1993 to 1999. Since the fire year runs from October 1 to September 30, fire year 1993 encompasses October 1, 1992, to September 30, 1993.

Second, we create a cadastral section road density measure consisting of all State, Interstate, and US highways in the section, divided by the area (in acres) of the section. The road density measure, along with the section burn permit and wildfire records, is rasterized into a 30-meter cell grid, the same as the forest fragmentation index. The burn permit and wildfire records are then compared with road density and the forest fragmentation index.

Third, we examine the FIA 1995 plot survey data (point analysis) to relate the plot's forest ownership and forest type to the incidence of prescribed fire, wildfire, or no fire since the previous FIA survey (1987).

Fourth, we aggregate the Census TIGER block-group to the section level using a Geographic Information System (GIS), enabling us to observe the demographic attributes of those communities residing within a section (approximately a one square mile neighborhood) and observe how demographics vary with different levels of prescribed burning and wildfire.

RESULTS

The most intense areas of prescribed burning appear to be in the north central and panhandle regions of Florida (figure 1), while wildfire ignitions occur more evenly throughout Florida, most heavily in the southwestern region (figure 2). A negative relationship exists between the number of burn permits issued and the number of wildfire ignitions, regardless of the ignition source (table 1). Of the cadastral sections examined, only half (52 percent) of the Florida landscape escaped all fire (prescribed or wild) for the periods covered. However, this may be an overestimation since our data only specified one section for each burn permit and wildfire (the section it started in), and fires may span multiple sections. Approximately 75 percent of wildfire ignitions occur in sections without a record of any prescribed burning. Areas that average no more than one burn permit a year experience another 21 percent of the ignitions, with the remaining 4 percent occurring in areas with more than one permit a year.

Prescribed fire occurs more frequently on government owned (federal, state, and local) and managed forest, than on forests owned by industry or private landowner. Consistent with these statistics is that the most common forest type prescribed burned is slash pine (*Pinus elliottii*) (FIA analysis, table 2), a species widely planted and managed in the state.

Table 1—Number of prescribed burns and wildfires occurring in a township, range, section

PB Permits in a Section	Arson Ignitions	Accidents Ignititions	Lightning Ignitions	Number of Possible Sections
None	4,510	11,006	4,355	33,264
1 to 7	1,534	3,993	1,193	9,362
8 to14	171	538	100	1,067
15 to 21	52	177	31	321
>21	59	186	27	308
All (>0)	1,816	4,894	1,351	11,058

Table 2—Percent of fire disturbance type by Forest Inventory and Analysis (FIA) plot ownership and forest- type

Type of Fire Disturbance	Gov't	Forest Industry	Private	Predominant Forest Type (pct)
Prescribed Burned	59	14	23	Slash Pine (49)
Wildfire	19	8	49	Baldcypress-Water Tupelo (32)
No Fire Disturbance	29	26	52	Slash Pine (33)

Table 3—Percent of prescribed burning and wildfire found in each forest fragmentation type

Fragmentation	Prescribed Burned?		Burned by Wildfire?	
Type	Yes	No	Yes	No
Interior	18	12	11	17
Edge	15	9	17	15
Perforated	19	12	13	11
Transitional	19	22	10	8
Patch	21	27	33	28
No Forest	7	16	14	18
Total	99	98	98	97

Table 4—Demographic comparison between areas without fire and those with either prescribed burning or wildfire

Demographics	PB& No Fire	Wildfire& No PB	Any Fire& Burn	No Fire& Burn
Pop. Density	0.08	0.41	0.11	0.55
55&Over (pct)	23	26	24	25
Not Caucasian (pct)	19	17	15	21
No College (pct)	46	44	46	45
House Value ($)	8,202	12,220	8,702	10,532
Income ($)	9,431	10,595	9,613	10,102

House value and income given as per capita, in 1990 dollars. Population Density given as persons per acre.

Table 5—Demographic comparison between areas with any prescribed burning categories 'traditional' and 'seed & site prep' in the neighborhood

Demographics	Traditional Burn	Seed & Site Prep Burn
Pop. Density	0.10	0.06
55&Over (pct)	24	23
Not Caucasian (pct)	19	16
No College (pct)	45	47
House Value ($)	10,755	10,723
Income ($)	10,182	10,148

House value and income given as per capita, in 1990 dollars.
Population given as persons per acre.

Table 6—Demographic comparison between areas with any wildfire ignition categories arson, accidental, and lightning in the neighborhood

Demographics	Arson Wildfire	Accidental Wildfire	Lightning Wildfire
Pop. Density	0.38	0.37	0.19
55&Over (pct)	26	25	27
Not Caucasian (pct)	15	17	14
No College (pct)	45	45	45
House Value ($)	11,003	10,417	13,713
Income ($)	10,200	10,143	10,874

House value and income given as per capita, in 1990 dollars. Population density given as persons per acre.

The landscape composition of wildfire-prone forests differs from those with prescribed burning. Almost half of the FIA plots reporting wildfire are privately owned. In contrast to the pine-dominated areas with prescribed burning, FIA plots with wildfire are dominated by the baldcypress (*Taxodium distichum*) and water tupelo (*Nyssa aquatica*) forest type (32 percent, table 2). Furthermore, wildfires ignitions appear to occur most often in the patch fragmentation class, those forests with less cover and connectivity (table 3). Road density is also two times higher in these wildfire prone regions.

Demographic differences are correlated with the amount of wildfire or prescribed burning. Table 4 shows that population density is lower in areas with fire than without (0.11 persons/acre versus 0.55 persons/acre, respectively). Areas with prescribed burning or wildfires have populations that are, on average, slightly younger, more likely to be Caucasian, and wealthier than areas without any fire (prescribed fire or wildfire). However, neighborhood differences exist between areas with prescribed fire only and those with wildfire only. Areas with wildfire and no prescribed burning tend to be more densely populated, have a larger proportion of older Floridians, and have higher per capita income and home values.

Examining prescribed fire by management objective (traditional burns versus site prep/prior-to-seed burns), we do not observe any striking difference (table 5), but distinguishing areas by wildfire ignition source, regardless of whether prescribed burning exists in that area or not, reveals a couple of differences. Compared to areas without wildfires, lightning ignitions tend to occur in sparsely populated, predominantly Caucasian neighborhoods (table 6). Also, lightning ignition appears to happen in wealthier neighborhoods, whereas arson and accidental ignitions tend to occur in lower income, more populated neighborhoods.

CONCLUSION

Florida's fire-prone wildland-urban interface is quite different, both physically and socio-economically, from areas without fire (prescribed fire and wildfire). Areas with high rates of prescribed burning are more commonly slash pine forests under government ownership, and these areas have much lower rates of wildfire ignitions.

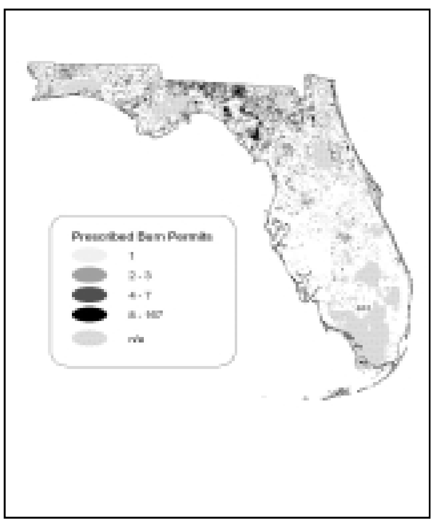

Figure 1—Number of prescribed burn permits issued from fire years (October-September) 1993-1999. Federal lands excluded.

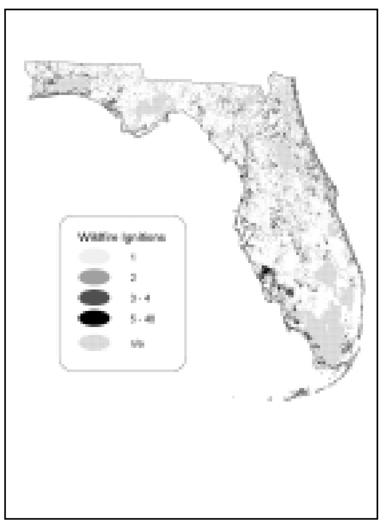

Figure 2—Number of wildfire ignitions from fire years (October-September) 1993-1999. Federal lands excluded.

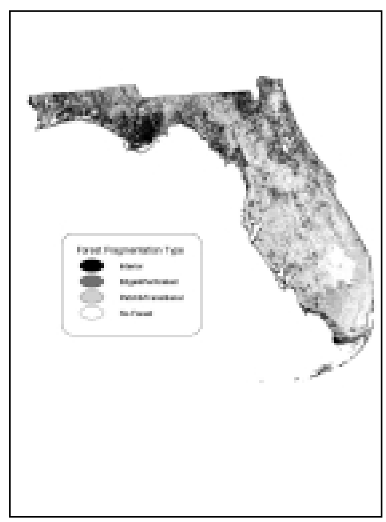

Figure 3—Forest fragmentation index, 1992

Government land managers may use prescribed fire, more so than private land managers, for a numbers of reasons including that governments maintain large land holdings, have greater expertise with prescribed fire, and are more likely to operate under policies to maintain the health of fire adapted ecosystems. Liability concerns over possible prescribed fire escapes may deter private landowners from using it, perhaps inducing them to use other types of fuel reduction techniques. Forests frequented by wildfires, however, tend to be privately owned, dominated by baldcypress-water tupelo, and have relatively less forest cover and lower forest connectivity than their prescribed burning neighbors. Reducing wildfire risk in baldcypress-water tupelo stands may be difficult given their close association with open water. However, drought condition may be severe enough to dry out these areas, leaving the baldcypress stands susceptible to wildfire, as seen during the catastrophic fires of 1998 (Mercer and others 2000).

The residents of those parts of Florida where fire is more common are, on average, more likely to be Caucasian, older, less educated, and earning lower incomes than those living in less risky areas. However, there is a marked difference between those living in places that experience prescribed burning and no wildfire, and those living in areas with wildfires and no prescribed burning. Those living in wildfire areas tend to be older, more often Caucasian, and wealthier than those with only prescribed fires, and this is particularly true for wildfires started by lightning. These differences may highlight the reasons people choose to live within the wildland-urban interface in the first place. Many people choose the interface for its amenities, while others, especially the retired and the poor, base their decision on economic criteria (Davis 1990). Prescribed burning may serve as a proxy for intensively managed forestlands, which may offer fewer amenity benefits, creating lower land prices, and thereby attracting those with lower incomes. Wildfire-prone areas without prescribed burning, on the other hand, may provide greater amenity benefits over areas without fire, providing benefits such as greater forest access than prescribed burned areas, providing benefits such as less smoke and a feeling of a more 'natural', undisturbed forest (less active management). Differences may also be related to differences in forest types. Many of these unmanaged wildfire-prone forests may be baldcypress-tupelo forests, located on more valuable properties near water. This would help account for the income and housing value differences between prescribed burned and wildfire only areas.

With Florida's continuing population growth, more and more people are moving into the wildland-urban interface and creating greater challenges for policymakers and land managers to reduce wildfire risk. Since catastrophic fires can produce large economic effects (Mercer and others 2000, Butry and others 2001), successful risk reduction programs can reap great dividends. However, populations either unaccustomed to prescribed fire or those with compromised respiratory health may be opposed to the use of fire and the resulting smoke. These attitude can be changed however, as Cortner and others (1990) found attitudes towards fire management have been changing over the last few decades. Indeed, demographic analyses such as these may help land managers and educators better target prescribed fire and wildfire education programs, potentially easing some concerns of residents. Alternatively, identification of such populations could facilitate the development and targeted application of wildfire risk reduction strategies that do not involve prescribed fire or that encourage such burning in times of the year when residents are least affected.

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LITERATURE CITED

Butry, D.T.; Mercer, D.E.; Prestemon, J.P.; Pye, J.M.; Holmes, T.P. 2001. What is the price of catastrophic wildfire? Working Paper. Forestry Science Laboratory, Southern Research Station, USDA Forest Service, Research Triangle Park, NC.

Cortner, H.J.; Gardner, P.D.; Taylor, J.G. 1990. Fire hazards at the urban-wildland interface: what the public expects. Environmental Management 14(1): 57-62.

Davis, J.B. 1990. The wildland-urban interface: paradise or battleground? Journal of Forestry. January 1990: 26-31.

Mercer, D. E.; J.M. Pye; J.P. Prestemon; D.T. Butry; T.P. Holmes. 2000. Economic effects of catastrophic wildfires. Unpublished final report. Forestry Sciences Laboratory, Southern Research Station, USDA Forest Service, Research Triangle Park, NC. http://www.rtp.srs.fs.fed.us/econ/pubs/dem001.htm

Riitters; K.H., O'Neil; R.V.; Jones, K.S. 1997. Assessing habitat suitability at multiple scales: a landscape-level approach. Biological Conservation 81: 191-202.

HIGH-INTENSITY FIRES MAY BE UNNECESSARY FOR STAND REPLACEMENT OF TABLE MOUNTAIN PINE: AN OVERVIEW OF CURRENT RESEARCH

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Abstract—After several decades of fire suppression, ridgetop pine communities of the Southern Appalachians are entering later seral stages and beginning to disappear. They typically have an overstory of Table Mountain pine (*Pinus pungens*), which is being replaced by shade-tolerant chestnut oaks (*Quercus prinus*). Previous papers suggest that high-intensity fires that open the forest canopy and expose mineral soil can restore these communities. Three recent studies examined plant-community response to prescribed fires of varying intensity. Four supporting studies help explain some of the results of these field studies. High and medium-high intensity fires provided adequate sunlight for pine seedlings, whereas medium-low and low intensity fires did not. Sufficient seedling densities to restore pine-dominated stands were present after all but the highest intensity fires. High-intensity fires may have reduced mycorrhizal abundance and moisture availability for new germinants. Fires of lower intensity than previously recommended or multiple fires of very low-intensity may best provide conditions for pine regeneration.

INTRODUCTION

Fire exclusion policies in the Southern Appalachian Mountains probably have reduced the diversity of the region and may threaten some plants and plant communities (Van Lear and Waldrop 1989). A species of concern is Table Mountain pine (*Pinus pungens* Lamb.). This Appalachian endemic has serotinous cones throughout its range, suggesting that fire may be needed for regeneration (Zobel 1969). Microsite conditions needed for seedling establishment, such as high levels of sunlight and little or no forest floor, are similar to those created by high-intensity fire. Table Mountain pine stands throughout the region are entering late seral stages and are often characterized as being dominated by oaks (particularly chestnut oak, *Quercus prinus*) and hickories (*Carya* sp.) (Zobel 1969). As a result of changing species dominance and stand structure, the Southern Appalachian Assessment recognizes Table Mountain pine woodlands as one of 31 rare communities (SAMAB 1996).

Most research addressing the role of fire in Table Mountain pine stands has been limited to post-wildfire studies, which suggest that high-intensity prescribed fires are needed to remove the forest canopy and expose mineral soil for successful regeneration (Zobel, 1969, Williams and Johnson 1992). Williams (1998) suggested that Table Mountain pine stands are in decline as a result of fire exclusion and inadequate understanding of the species regeneration biology.

High-intensity, stand-replacement prescribed burning may reverse the decline. However, accomplishing these burns is difficult. Such prescriptions provide a narrow window of opportunity and raise questions about worker safety and smoke management. To date, only three studies have conducted prescribed burns to better understand the conditions necessary for Table Mountain pine regeneration. This paper examines the results of the three prescribed fire studies and four supporting studies of regeneration ecology to evaluate the need for high-intensity, stand replacement fires for regenerating Table Mountain pine.

CURRENT RESEARCH ON STAND-REPLACEMENT PRESCRIBED BURNING

Studies of stand-replacement prescribed burning were conducted at three separate burn units in the southern Appalachian mountains, including the Grandfather Ranger District, Pisgah National Forest; Tallulah Ranger District, Chattahoochee National Forest; and a burn unit managed by both the Andrew Pickens Ranger District, Sumter National Forest and the Buzzard's Roost Preserve of the South Carolina Heritage Trust Program. In this paper, we refer to these burn units as the Grandfather, Tallulah, and Buzzard's Roost burns, respectively. Welch and others (2000) described the Grandfather burn. Waldrop and Brose (1999) described the Tallulah burn.

Several supporting studies provide insight to disturbance history and methods of evaluating stands for their potential of regeneration success. Waldrop and others (1999) conducted a greenhouse study to evaluate the effects of

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Table 1—Characteristics of Table Mountain pine stands one year following stand-replacement prescribed burning

		Fire Intensity Level			
Variable	**Low**	**Med-Low**	**Med-High**	**High**	**Fire**
Pine basal	5.9	6.0	1.1	0.0	Tallulah[1]
area (m^2/ha)	8.4	6.4	0.0		Buzzard's Roost
		21.6			Grandfather[2]
Hardwood	16.8	5.1	0.5	1.0	Tallulah
basal area	11.8	4.2	7.6		Buzzard's Roost
(m^2/ha)		4.3			Grandfather
Total basal	22.7	11.1	1.6	1.0	Tallulah
area (m^2/ha)	19.2	10.8	7.6		Buzzard's Roost
		25.9			Grandfather
Hardwood	32,150.0	37,371.0	26,590.0	31,537.0	Tallulah
sprouts	20,553.0	25,582.0	17,505.0		Buzzard's Roost
(num/ha)		2,295.0			Grandfather
Pine seedlings	13,852.0	22,551.0	9,016.0	3,448.0	Tallulah
(num/ha)	551.0	995.0	961.0		Buzzard's Roost
		7,699.0			Grandfather

[1]Waldrop and Brose (1999)
[2]Welch and others (2000)

shade and duff on seedling establishment. Other studies include the dendrochronology of ridgetop pine stands across the Southern Appalachians (Brose and others 2002), seed biology of Table Mountain pine (Gray and others 2002), and mycorrhizal associations in burned Table Mountain pine stands (Ellis and others 2002). We will discuss results from each.

Fire Intensity and Stand Replacement of Table Mountain Pine

The Tallulah burn was on the War Woman Wildlife Management Area of the Tallulah Ranger District, Chattahoochee National Forest in north Georgia. Prior to burning, mean total basal area in study stands was 28.2 m^2 per ha. Hardwoods made up 22.7 m^2 of this total and Table Mountain pines the remaining 5.5 m^2. The fire was ignited by hand and by helicopter in April 1997 to create a ring fire that reached greatest intensity within ridgetop Table Mountain pine stands. The Tallulah burn was large enough and its intensity varied enough to allow comparisons of regeneration success among areas burned at different intensities (Waldrop and Brose 1999).

The Buzzard's Roost Burn was on a tract of approximately 100 ha managed by the South Carolina Heritage Trust Program and 45 ha managed by the Andrew Pickens Ranger District, Sumter National Forest. Prior to burning, stand basal area was 10.9 m^2 per ha hardwoods and 10.1 m^2 pine. Ignition was by helicopter on March 4, 1998. Fire intensity ranged from subcanopy ground fires to flame lengths reaching the lower levels of the stand canopy.

The Grandfather burn was a 3-ha prescribed fire on the Grandfather Ranger District, Pisgah National Forest. Basal area consisted of 8.7 m^2 per ha in hardwoods and 23.6 m^2 per ha in pines. Ground crews used a combined ring and head fire technique to burn the stand in May 1996. Flames reached to lower limbs on most trees and entered the canopy on a small portion of the stand.

The prescriptions applied in these studies produced four fire intensities defined by Waldrop and Brose (1999): low, medium-low, medium-high, and high. All intensities were observed in the Tallulah burn and all but high intensity was observed in the Buzzard's Roost burn. At the Grandfather burn, only the medium-low intensity was observed. Waldrop and Brose (1999) gave a detailed description of how fire intensity was classified using discriminant functions. General descriptions of intensity categories are as follows: Flames of low intensity fires never reached into the crown of trees and uniformly burned the area. Medium-low-intensity fires had flames slightly taller than those of low-intensity fire; they burned less uniformly and produced hot spots where flames reached into crowns and killed large trees. Flames of medium-high intensity fires typically reached into the crowns of all overstory trees. Flames of high-intensity fires generally exceeded the crowns of overstory trees and carried from crown to crown.

High-intensity fires occurred only in the Tallulah burn where they killed almost all overstory trees, leaving only 1.0 m^2 of basal area per ha (table 1). Medium-high intensity fires occurred at Tallulah and Buzzard's Roost. These fires were also effective for killing overstory trees, leaving only 1.6 and 7.6 m^2 per ha of basal area, respectively. Mortality was high in all diameter size classes following both high- and medium-high-intensity fires. Sunlight reaching the forest floor may have been adequate for seedling survival following fires of both intensities. High- and medium-high intensity fire were the only ones of sufficient intensity to kill enough of the overstory to achieve conditions of stand replacement.

In all three studies, medium-low- and low-intensity fires reduced canopy cover (table 1), but residual basal area may have been too high to allow stand replacement. At the Tallulah burn, medium-low-intensity fires reduced basal area to 11.1 m^2 per ha and 10.8 m^2 per ha at the Buzzard's Roost burn, but left 25.9 m^2 per ha at the Grandfather burn. Low-intensity fires had little effect on basal area, leaving 22.7m^2 per ha at the Tallulah burn and 19.2 m^2 at the Buzzard's Roost burn. Mortality was greatest in lower d.b.h. classes (< 15 cm d.b.h.) following fires of medium-low and low-intensity. Shade from surviving trees after low- and medium-low intensity fires may prevent pine seedling survival.

We observed prolific hardwood sprouting following fires of all intensities (table 1). Generally, there were over 20,000 stems per ha one year after burning at all fire intensities. Most were growing rapidly. Competition from these sprouts may eliminate any pine regeneration after a fire of any fire intensity. This result suggests that multiple, low-intensity fires may be necessary to reduce hardwood abundance while maintaining a seed source among large pines.

Post-burn counts of Table Mountain pine seedlings in the Tallulah and Grandfather burns suggest that fires were of sufficient intensity to open serotinous cones throughout burn units, even in areas burned at low-intensity. In these two units, post-burn pine density ranged from 3,448 to more than 22,500 stems per ha (table 1). An unexpected result was that the lowest pine densities in the Tallulah burn were in areas burned at the highest intensity. This suggests that cones were consumed or seeds killed by intense heat, or that the seedbed became less suitable by excessive exposure to sunlight and evaporation.

Table Mountain pine regeneration was poor at all fire intensities in the Buzzard's Roost burn. A number of factors could cause poor regeneration success, including thick residual duff or lack of viable seed. Duff layers after burning at Buzzard's Roost averaged only 4.4 cm deep and did not vary by fire intensity. Duff remaining after the Tallulah burn was generally deeper with 5.3, 3.8, 6.4, and 6.6 cm for the low-, medium-low-, medium-high-, and high-intensity fires, respectively. The percentage of seedlings with roots penetrating mineral soil at Tallulah was 71.1, 94.6, 63.0, and 56.1 for the same order of fire intensities (Waldrop and Brose 1999). Welch and others (2000) observed pine regeneration on approximately 9.1 cm of combined litter and duff after the Grandfather burn. Successful regeneration of Table Mountain pine on the thicker duff layers found in the Tallulah and Grandfather burns may indicate that lower availability of viable seed caused low regeneration counts at the Buzzard's Roost burn. Methods for estimating seed viability prior to burning are currently unavailable for Table Mountain pine stands.

Supporting Studies

Seed biology—In the past, studies of prescribed burning assumed an adequate seed source that did not vary among stands or stand conditions. Any regeneration failures could have been caused by an inadequate seed source. An ongoing study by Gray and others (2002) helps identify stands that have an adequate seed source for regeneration. Preliminary results indicate that seed viability was moderate, generally between 20 and 50 percent, from cones of all ages, and from trees older than 10 years (table 2). Viability did not appear to vary by age after trees reached 10 years. However, viability seemed to increase as cones matured to 4 or 5 years old. These results indicate that, if cone numbers are adequate, stands over a wide range of ages may be candidates for burning. A surprising result is the presence of cones with viable seed on young trees. Trees within the 5- to 10-year age class had 3-year-old cones with 23 percent seed viability. This result suggests that Table Mountain pines are adapted to regenerating under regimes of low-intensity fires, which may occur every 5 to 10 years. These results also indicate that if frequent low-intensity fires are used, that viable seed will become available every 2 to 3 years as long as fires do not kill overstory pines.

Table 2—Percent viability of Table Mountain pine seed by tree age and cone age within a tree

	Cone Age				
Tree age class	2 years	3 years	4 years	5 years	All Ages
5 to 10 years	8	23	1	-	-
11 to 25 years	20	32	41	23	27
26 to 50 years	33	11	24	56	31
51 to 75 years	29	20	34	36	30
75+ years	29	13	54	39	33
All tree age classes		24	21	34	36

Seedbed habitat—In order to assess seedling establishment, Waldrop and others (1999) conducted a greenhouse study that used shade and duff treatment combinations similar to those observed in the field. Duff categories included depths of 0, 5, and 10 cm; and shade levels of 0, 30, 63, and 85 percent. Figure 1 shows the total number of seedlings per plot in all combinations of duff and shade at the end of the 90-day greenhouse study. Stem density typically was greater in 5-cm duff than in bare soil or 10-cm duff. This pattern remained constant for all shade categories except the 0-shade category. In 0 shade, stem densities in pots with 5 cm of duff were equal to stem densities in pots without duff. Without shade, the mulching effect of a 5-cm duff layer may not have been adequate to prevent moisture deficit and seedling death.

Lack of shade reduced seed germination and the survival of germinants, while heavy shade reduced survival. More seedlings become established under 30-percent shade than under full light or the higher shade levels. This pattern was constant among pots with 5 and 10 cm of duff, but differed among pots with no duff (figure 1). With no duff, fewer seedlings per pot occurred under 30-percent shade than under no shade, although this difference was not

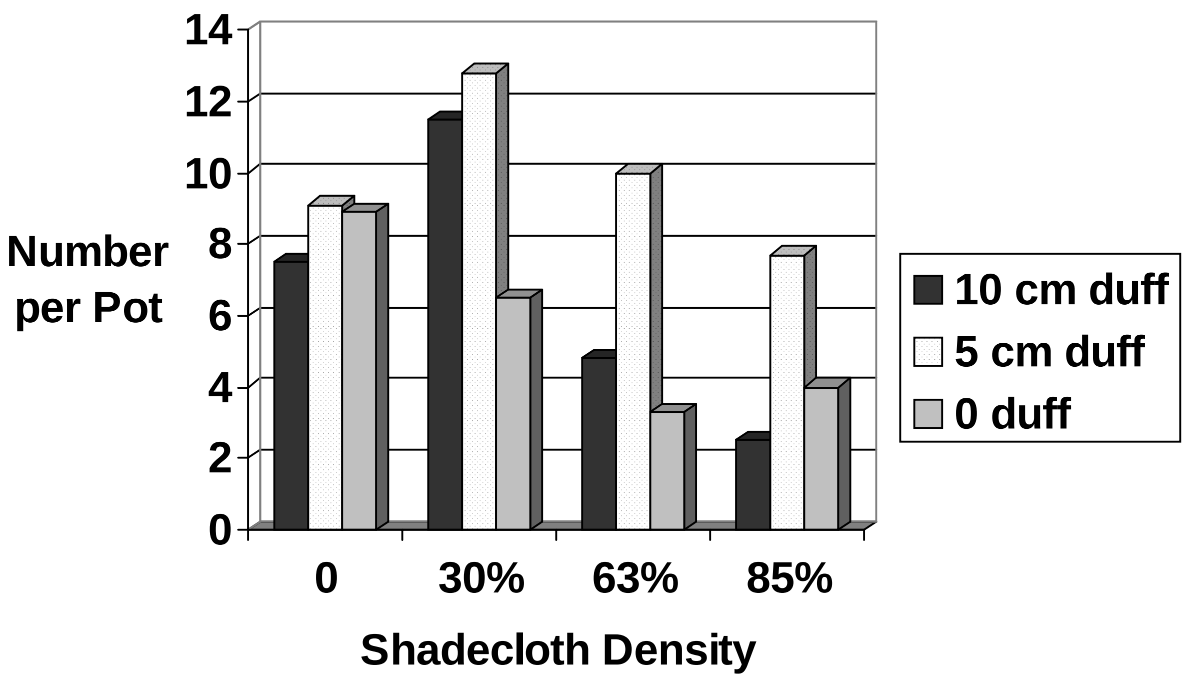

Figure 1—Seedlings per pot after the 90-day greenhouse study for all combinations of shade level and duff depth.

significant. Without the mulching effect of duff, 30-percent shade may not be adequate to prevent moisture deficit.

The moderate levels of shade and duff, suggested by this study as optimum seedbed habitat, differ somewhat from previous recommendations. Although the exact fire regimes necessary to create this type of habitat are unknown, these results do not suggest that a single high-intensity fire is mandatory. Multiple lower-intensity fires can maintain an overstory and seed source and reduce the duff without exposing mineral soil.

Fire Intensity and Mycorrhizae—The need for mycorrhizae is generally accepted for southern pine seedlings grown in nurseries, but it has not been studied for nontimber species such as Table Mountain pine. Neary and others (2000) suggested that fire intensity strongly affects the degree and duration of reduced soil microbial activity. An ongoing study by Ellis and others (2002) examines the relationship of fire intensity to mycorrhizal development on Table Mountain pine roots. Preliminary results indicate that *Pisolithus tinctorius*, *Suillus granulatus*, and *Cenococcum* spp. are the predominant symbionts that form mycorrhizal root tips in Table Mountain pine stands. Two years after burning, seedlings growing in areas burned at medium-low and medium-high fire intensities had twice as many mycorrhizal root tips (40 percent) than seedlings from sites burned at high intensities (22 percent), indicating a lasting negative impact of high-intensity prescribed fires. Laboratory results were similar, showing that mycorrhizal roots tips are less common after fungi have been exposed to temperatures over 50°C and almost absent after exposure to temperatures up to 80°C. These results suggest that poor formation of mycorrhizal root tips could have caused poor regeneration of Table Mountain pine in the Tallulah burn after high-intensity burning. Frequent low-intensity burning would be one means of avoiding loss of mycorrhizal fungi.

Dendrochronology—Little is known about the disturbance history of Table Mountain pine stands. The species may have been maintained by frequent low- to medium-intensity fires, infrequent high-intensity stand-replacing fires, or a combination of both. Brose and others (2002) conducted a dendrochronology study on the Tallulah, Buzzard's Roost, and other sites. A preliminary analysis of stand dynamics suggests a history of frequent disturbance that lasted until the 1950's (figure 2). Pines in the dominant canopy position are between 100 and 158 years old. However, numerous smaller pines are between 50 and 100 years old. Shrubs, particularly mountain laurel, are less than 50 years old, and there are no pines younger than 50 years. The frequency pattern of pine age classes indicates that pines were regenerating from the 1850's through the 1950's, and that these stands were relatively open. Well-established fire exclusion policies in the 1950's allowed the shrub layer to become dominant and prevented continuing pine regeneration. Successful restoration of these stands cannot be expected with a single prescribed burn of any intensity. Multiple burns or other control methods will be required to remove shrubs and competing hardwoods.

CONCLUSIONS

High-intensity fires are attractive for a number of reasons: they provide a means of killing overstory trees and opening the forest floor to direct sunlight; they provide the heat

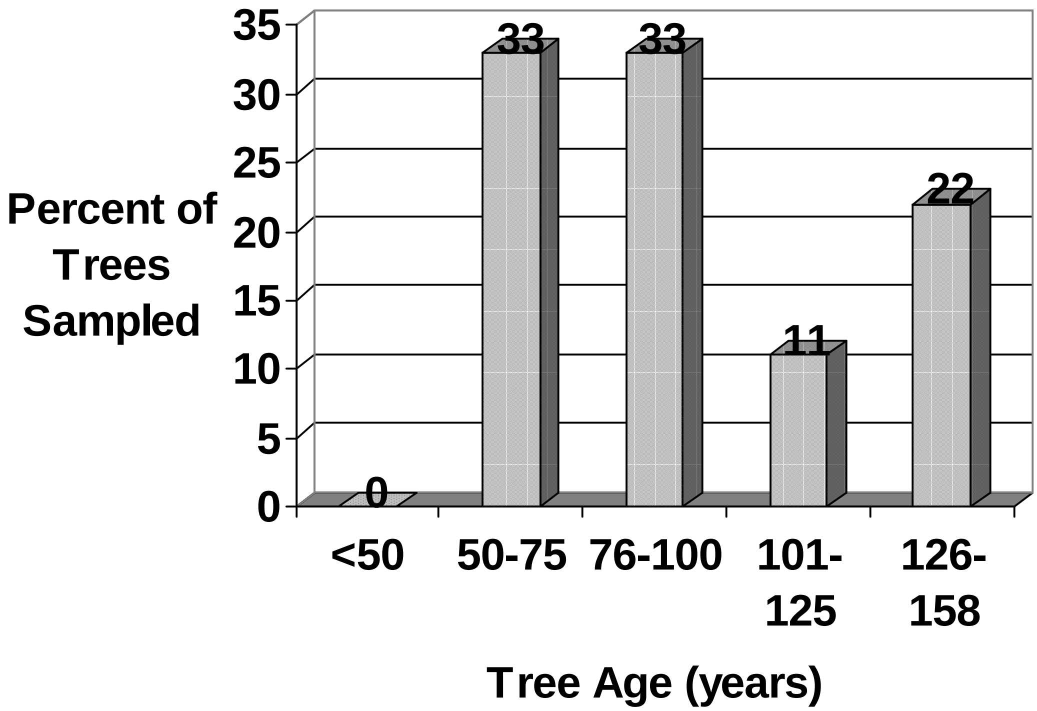

Figure 2—Age distribution of Table Mountain pines sampled on two north Georgia sites.

needed to open serotinous cones; and they reduce thick duff layers or expose mineral soil. However, none of the fires observed in these studies were successful for replacing older stands of mixed pines and hardwoods with newly regenerated stands of pines. Low-intensity medium-low intensity fires failed to kill more than a few overstory trees. High intensity fires killed most overstory trees but had few pine seedlings. Medium-high intensity fires provided abundant overstory mortality and pine regeneration. However, fires of all intensities failed to control competition from hardwood and shrub sprouts.

The support studies presented here provide indirect evidence that frequent burning may restore ridgetop pine communities. The dendrochronology study shows that pines in study stands were uneven-aged and had regenerated frequently until the time of fire exclusion. The seed biology study suggests that a viable seed source is present over a wide range of tree ages and in cones that have been on trees for up to 5 years. Studies of seedbed habitat and mycorrhizal populations provide evidence that the severe conditions produced by high-intensity burning are not necessary and may be detrimental to regeneration. Moisture may be limited due to lack of mycorrhizal tips on roots, loss of a mulching effect from the duff, and direct sunlight reaching the forest floor. These conditions may have been common in pre-1950's stands that burned often.

Results presented here suggest that ridgetop pine stands were created by lower-intensity fires than once were thought necessary, and that such fires would aid in community restoration. Low-intensity prescribed fires, which can be used when the lower layers of the forest floor are moist, are less dangerous and present a larger window of opportunity than high-intensity fires.

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LITERATURE CITED

Brose, Patrick H.; Tainter, Frank; Waldrop, Thomas A. Regeneration history of Table Mountain/pitch pine stands in two locations in the Southern Appalachians. [This proceedings].

Ellis, Lisa E.; Waldrop, Thomas A.; Tainter, Frank H. Ectomycorrhizae of Table Mountain pine (*Pinus pungens*). [This proceedings].

Gray, Ellen; Rennie, John; Waldrop, Thomas. Patterns of seed production in Table Mountain pine *(Pinus pungens*). [This proceedings].

Neary, D.G.; DeBano, L.F.; Ffolliott P.F. 2000. Fire impacts on forest soils: a comparison to mechanical and chemical site preparation. In: Moser, W. Keith, ed. Proceedings of the twenty-first Tall Timbers fire ecology conference; 1998 April 14–16; Tallahassee, FL. Tall Timbers Research, Inc.: 85–94.

Southern Appalachian Man and the Biosphere (SAMAB). 1996. The Southern Appalachian assessment terrestrial technical report. Rep. 5 of 5. Atlanta: U.S. Department of Agriculture, Forest Service, Southern Region.

Van Lear, David H.; Waldrop, Thomas A. 1989. History, use, and effects of fire in the Southern Appalachians. Gen. Tech. Rep. SE–54. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 20 p.

Waldrop, T.A.; Brose, P.H. 1999. A comparison of fire intensity levels for stand replacement of Table Mountain pine (*Pinus pungens* Lamb.). Forest Ecology and Management. 113: 115–166.

Waldrop, Thomas A.; Mohr, Helen H.; Brose, Patrick H.; Baker, Richard B. 1999. Seedbed requirements for regenerating Table Mountain pine with prescribed fire. In: Haywood, James D., ed. Proceedings of the tenth biennial southern silvicultural research conference; 1999 February 16–18; Gen. Tech. Rep. SRS–30. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 369–373.

Welch, N.T.; Waldrop, T.A.; Buckner, E.R. 2000. Response of Southern Appalachian Table Mountain pine (*Pinus pungens*) and pitch pine (*P. rigida*) stands to prescribed burning. Forest Ecology and Management. 136(2000): 185–197.

Williams, C.E. 1998. History and status of Table Mountain pine-pitch pine forests of the Southern Appalachian Mountains (USA). Natural Areas Journal. 18: 81–90.

Williams, C.E.; Johnson, W.C. 1992. Factors affecting recruitment of *Pinus pungens* in the Southern Appalachian Mountains. Canadian Journal of Forest Research. 22: 878–887.

Zobel, D.B. 1969. Factors affecting the distribution of *Pinus pungens*, an Appalachian endemic. Ecological Monographs. 39: 303–333.

GROWTH RESPONSE FROM HERBICIDE, PRESCRIBED FIRE, AND FERTILIZER TREATMENTS IN MIDROTATIONAL LOBLOLLY PINE: FIRST-YEAR RESPONSE

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Abstract—This study was initiated to determine growth response resulting from the application of prescribed fire and herbicide, with and without fertilization. In southeast Texas, herbicide, prescribed fire and fertilizer treatments were applied in mid-rotational loblolly pine plantations 1.5 years after thinning. Five replications were established at each of two study sites located on similar soils, aspects and slopes. Half of each replication was randomly selected and fertilized. Eight treatment plots were established in each replication with one of each of the four treatments of control, herbicide, fire, and herbicide/fire randomly applied to fertilized plots and one of each of the four treatments randomly applied to non-fertilized plots. Pre-treatment measurements were taken in a 0.04 ha measurement plot nested within each treatment plot. A late season herbicide treatment of Imazapyr and Arsenal was applied in October 1999. Burning was conducted in early spring of 2000 followed by fertilizer applications of diammonium phosphate and urea. Post-treatment measurements were taken in December 2000. Growth response and significant treatment differences are presented in this paper.

INTRODUCTION

Loblolly pine (*Pinus taeda*) plantations often receive little or no treatment between the time of stand establishment and harvest (Nyland 1996). However, studies have shown the benefit of mid-rotation manipulation in terms of increased pine growth rate, improved species composition, and wood quality (Zutter and Miller 1998, Haywood and others 1998, Borders and Bailey 1997, Cain and Yaussy 1984).

Intermediate treatments include release cuttings to improve species composition, the application of prescribed fire to remove competition and reduce crown fire hazard (Nyland 1996), the application of herbicides to remove competition (Haywood and others 1997), and fertilization to improve growth (Young and Giese 1992).

Because loblolly pine is naturally found on low and moist sites, it has evolved with no special adaptation to fire in its early years (Wright and Bailey 1982). Therefore, the use of fire in loblolly pine stands is often limited to site preparation or competition control and fire hazard reduction at mid-rotation. Although loblolly pine is less fire resistant when young, as trees age, bark thickens (Villarrubia and Chambers 1978, Cooper and Altobellis 1969) resulting in a higher tolerance to moderate fires. In addition, sunlight deprived lower limbs will fall, causing the tree crown to be less accessible to damaging flames. Both of these factors increase the tolerance of loblolly pine to moderate fire (Wade and Lunsford 1988).

Herbicides may be used as an intermediate treatment to remove competing woody vegetation, herbaceous vegetation, or both woody and herbaceous vegetation (Borders and Bailey 1997). Mid-rotational loblolly pine benefits from the removal of woody competition that severely limits its diameter growth and its ability to completely occupy a site (Hodges 1990). However, growth response may vary due to site quality, season of treatment, and type and density of competing vegetation (Lauer and Glover 1990, Hodges 1990). Herbicide and prescribed fire are often applied together as a mid-rotational treatment in loblolly pine stands (Borders and Bailey 1997).

Fertilizer may be used to improve pine tree growth in mid-rotational loblolly pine plantations. Studies over the past 20 years have shown increases in tree growth due to the use of fertilization at mid-rotation (Allen and others 1983, Gent and others 1986). Fertilization may also be best used at mid-rotation when the stand has filled most of the growing space and more nutrients are becoming tied up in living and dead plant material (Smith 1986). Fertilization alone may result in a shift toward competing vegetation, causing increases in pine mortality (Borders and Bailey 1997). It is possible that the addition of fertilizer may result in further reductions in the thickness of loblolly's already moderately protective bark (Tiarks and Haywood 1993). Growth response to fertilization may vary from site to site depending on pre-treatment soil conditions such as nutrients, soil type, and water availability (Borders and Bailey 1997). Chemical herbicide control of competing vegetation may be

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combined with fertilization. Mid-rotational loblolly pine growth may be increased when chemical competition control is added to fertilization (Borders and Bailey 1997).

OBJECTIVES

1. Determine the effect on growth in mid-rotational loblolly pine resulting from the application of prescribed fire and herbicide, with and without fertilization.
2. Compare the effect of fire and/or herbicide applications on competition control in mid-rotational loblolly pine plantations, as well as, determine if any fertilization interaction exist between either or both fire and herbicide.

METHODS

Study Area

Site one is known as the Cherokee Ridge site. This site was hand planted on a 1.83 m X 3.05 m spacing in 1985. In July 1998 this site was thinned to a basal area of 13.10 m^2ha^1. Approximately 465 trees per hectare remain. Soils consist of moderately well-drained to well-drained sandy loam or fine sandy loam surface soil. Slopes range from 3 to 15 percent.

The second site is known as the Sweet Union site. This site was machine planted on a 1.83 m X 3.66 m spacing in 1982. In 1998, the site was thinned to a basal area of 22.26 m^2ha^1. Surface soils consist of loamy sand on slopes that range from 3 to 15 percent. Both sites are located on International Paper Company property.

Plot Establishment

The experimental design for this study is a split plot with fertilizer treatment as the whole plot and vegetation control treatments as sub-plots. Five replications were established at each of the two sites. One–half of each replication was randomly selected and treated with fertilizer. In each replication, 8 treatment plots measuring 0.1 ha were randomly established, leaving approximately a 10-meter buffer between each treatment plot. A measurement plot measuring 0.04 ha was nested within each 0.1 ha treatment plot. The four treatments of control, herbicide, fire, and herbicide/fire were randomly located in the eight 0.1 ha treatment plots, with one of each of the four vegetative control treatments conducted for fertilized and one of each of the four vegetative control treatment conducted for the unfertilized area.

Methodology

Before treatment, each tree within the 0.04 ha measurement plots was identified to species and tagged with a numbered metal tag nailed to the tree at DBH. Treatments were applied after the completion of baseline data collection, approximately 1.5 years after thinning. A late season, ground-applied herbicide treatment was applied in October 1999 to remove competing vegetation. This included the herbicide application for the prescribed-fire/herbicide treatment. Imazapyr and Arsenal was applied at the rate of 5.5-6.9 kg per ha. An early spring burn was conducted in March 2000 prior to green-up to remove competing aboveground stems. Fertilizer treatments were applied with a hand spreader following the fire.

At the end of the 2000 growing season, the height of each numbered tree within the 0.04 ha measurement plot was re-measured using a clinometer and the diameter was re-measured using a diameter tape. Parameters evaluated were height and diameter growth of individual trees.

Analysis of variance for a Randomized Complete Block Design was conducted on data to test for treatment differences and Duncan's multiple range test was used to identify significant treatment differences at the significance level of 0.1 for the response variables of height and diameter growth.

Table 1—Mean height growth (m.) and diameter growth (cm.) in Loblolly pine (*Pinus* taeda) for the Sweet Union and Cherokee Ridge study sites in southeast Texas for the four treatments of control, herbicide, fire, and herbicide/fire. Height (m.) and diameter (cm.) growth for fertilized and non-fertilized plots

	Control		Herbicide/Fire Height		Fire		Herbicides	
	Height	Diameter	Height	Diameter	Height	Diameter	Height	Diameter
Sweet Union	0.82*	0.54	0.75	0.61	0.65	0.62	0.71	0.68
Cherokee Ridge	0.78	1.10*	0.82	1.00	0.71	0.91	0.65	1.12*

	Fertilized		Non-Fertilized	
	Height	Diameter	Height	Diameter
Union	0.76 *	0.60	0.69	0.64
Cherokee Ridge	0.70	1.04	0.77	1.02

*Significant treatment effect at p=0.1 level

RESULTS

Analysis of variance indicated significant treatment effects for the treatments of control and herbicide/fire, as well as, a site/fertilizer interaction for height growth. The site/fertilizer interaction occurred on the Sweet Union site, which possessed greater height growth on control plots that received fertilizer (table 1). In addition, height growth seems to have been affected to a lesser degree on herbicide/fire plots which also received fertilizer. However, too much overlap exists between herbicide/fire and other treatments to consider this significant. Analysis of variance also indicated that diameter growth was significant on the Cherokee Ridge site (table 2). While no fertilization interaction occurred on this site, Duncan's Multiple range test revealed that herbicide and control plots produced significant increases in diameter growth. The mean increase in diameter growth at the Cherokee Ridge site was twice as great as the increase at the Sweet Union site (table 2). Analysis of variance conducted on pre-treatment heights and diameters indicated a significant difference between the two sites for both height and diameter (table 2). The Cherokee Ridge site had taller, larger diameter trees before the application of treatments than the Sweet Union site. Analysis of second year data indicated that while Cherokee Ridge still had taller trees, height growth at the Sweet Union site had increased at the same rate and narrowed the difference between the two sites (table 2). The Sweet Union site, however, has not been able to produce the diameter growth found on the Cherokee Ridge site, which still possessed larger diameter trees and exhibited a significant increase in diameter growth. Significant height and diameter growth was recorded on Replication 2 at the Cherokee Ridge site while significant diameter growth was indicated on Replication 1 at the Cherokee Ridge site.

DISCUSSION

The Cherokee Ridge and Sweet Union study sites were impacted by different silvicultural treatments applied prior to this study. Both sites were thinned in 1998. However, the Cherokee Ridge site was left with a basal area of 13.10 m^2ha^1. Trees were row thinned, as well as, removed from within rows. The Sweet Union site was thinned only by row and left with a basal area of 22.26 m^2ha^1.

Because height growth is less sensitive than diameter growth to stocking density, the Sweet Union site may be responding to less crowded conditions by shifting resources toward height rather than diameter growth. Although both of these stands were seventeen-years-old, significant height and diameter differences were present before treatment. Trees at the Sweet Union site possessed less height than those trees at the Cherokee Ridge site. At one year post-treatment, there were no significant differences between the mean height growth at either site. While trees at the Cherokee Ridge site were still taller, height difference between the two sites has decreased. The fact that height increases at the Sweet union site were significant on fertilized control plots suggests that increases in height growth were a combination of fertilizer and thinning effects. More densely stocked conditions forced trees upward for available sunlight. Trees that were already responding to thinning with height growth, gained more benefit from the additional treatment of fertilizer.

In addition to fertilized control plots, height growth at Sweet Union was also significant on herbicide/fire treatments. Because herbicide was applied prior to the application of fire, hardwood and herbaceous competition was very dry resulting in a more intense fire. Why a more intense fire would result in improved height growth can not be explained at this time. However, it could be speculated that height growth response was more a result of the application of fertilizer rather than the application of herbicide or fire. The fact that significant height growth response was indicated on fertilized control plots that received no other treatment supports this speculation. Diameter at the Cherokee Ridge site was significantly greater prior to treatment than diameter at the Sweet Union site. Because diameter is more responsive to decreases in stocking density, the Cherokee Ridge site may still be responding to less dense conditions with increases in diameter. This may explain the increase in diameter associated with the herbicide treatment. Removal of competition within a plot already responding with diameter increases to less dense conditions increased beneficial results. In both cases, the conclusion may be that trees, which were responding well in either height, diameter, or both, experienced even more improved tree growth with additional treatment. It is important to note that significant treatment effects were calculated using mean increases in height and diameter. Therefore, a tree 30-centimeters in diameter and 18 meters tall had no advantage in statistical calculations over smaller diameter trees that had acquired less height except as an indicator of site productivity prior to treatment. Because control plots received no competition control treatments, treatment effects noted at both sites in control plots for both height and diameter increases indicated lingering thinning responses.

Table 2—Mean pre-treatment and post-treatment height (m.) for Loblolly Pine (*Pinus taeda*) and diameter (cm.) for the Sweet Union and Cherokee Ridge study sites in southeast Texas

Site	*Pre-Treatment*		*Post-Treatment*		*Increase*	
	Height	Diameter	Height	Diameter	Height	Diameter
Sweet Union	15.33*	17.50	16.06	18.11	0.73	0.61
Cherokee Ridge	15.71	19.95*	16.41	20.98*	0.70	1.03*

*Significant at p=0.1 level

CONCLUSIONS

It appears that on both sites, trees that were growing well before treatment were growing as well or better after treatment. Study trees at both sites were among healthy well-growing populations, which appear to have maintained growth with little mortality during this study year, in which southeast Texas experienced a significant drought. Subtle difference occurring among treatments in such a population may be difficult to detect with first year data. Even in a year of normal rainfall, a study with results from only one year cannot reliably answer questions about the use of fertilization and its ability to improve tree growth. Nor do one year's results answer long-term questions about improved growth resulting from the use of competition control. In future years, treatments that appeared to have had no significant impact in first year's data may, in fact, become significant.

REFERENCES

Allen, G.G.; M.J. Cousin; J.F. Friedhoff; R.C. Maggio; W.F Miller; J.C. Powell. 1983. Growth enhancement of a juvenile loblolly pine forest by treatment with a controlled release herbicide. International Pest Control. 6: 172-173.

Borders, B.E; R.L. Bailey. 1997. Loblolly pine - pushing the limits of growth. Athens, GA: University of Georgia; CAPPS: Consortium on Accelerated Pine Production Studies; Technical Report CAPPS 1997-1. 9 p.

Cain, M.D.; D.A. Yaussy. 1984. Can hardwoods be eradicated from pine sites? Southern Journal of Applied Forestry. 8(1): 7-14.

Cooper, R.W.; A.T. Altobellis. 1969. Fire kill in young loblolly pines. Fire Control Notes (Washington). 30(4): 14-15.

Gent, J.A.; H.L. Allen; R.G. Campbell; C.G. Wells. 1986. Magnitude, duration, and economic analysis of loblolly pine growth response following bedding and phosphorus fertilization. Southern Journal of Applied Forestry. 10: 124-128.

Haywood, J.D.; A. Martin Jr.; H.A. Pearson; H.E. Grelen. 1998. Seasonal biennial burning and woody plant control influence native vegetation in loblolly pine stands. Asheville, NC: USDA Forest Service. Southern Research Station Technical report SRS-14. 10 p.

Haywood, J.D.; A.E. Tiarks; M. A. Sword. 1997. Fertilization, weed control, and pine litter influence loblolly pine stem productivity and root development. New Forest. Kluwer Academic Publishers, Netherlands. 14:233-249.

Hodges, D.G. 1990. Profitability of hardwood and herbaceous weed control in loblolly pine stands. In: Coleman, S.S.; Neary, D.G., eds. Proceedings of the Sixth biennial southern silvicultural research conference; 1990 October 30 - November 1, Memphis, TN. Gen. Tech. Rep. SE-70. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 811-821.

Lauer, D.K.; G.R. Glover. 1990. A region-wide study to model loblolly pine growth response to degree and timing of harwood control and herbaceous weed control. In: Coleman, S.S.; Neary, D.G., eds. Proceedings of the Sixth biennial southern silvicultural research conference; 1990 October 30 - November 1, Memphis, TN. Gen. Tech. Rep. SE-70. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 584-590.

Nyland, R. D. 1996. Silviculture concepts and applications. McGraw-Hill. 90-96, 99-105 p.

Smith, D.M. 1986. The practice of silviculture. Eighth edition New York: John Wiley and Sons. 515 p.

Tiarks, A.E.; J.D. Haywood. 1993. Bark yields of 11-year-old loblolly pine as influenced by competition control and fertilization. In: Brissette, J.C., ed. Proceedings of the Seventh biennial southern silvicultural research conference; 1992 November 17-19, Mobile, AL. Gen. Tech. Rep. SO-93. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 525-529.

Villarrubia, C.R.; J.L. Chambers. 1978. Fire: Its effect on growth and survival of loblolly pine, *Pinus taeda L*. Louisiana Academy of Science. 41: 85-93.

Wade D.D.; J.D. Lunsford. 1988. A guide for prescribed fire in southern forest. U.S.F.S. Southern Region Tech. Report R8-TP11. Atlanta, GA: United States Department of Agriculture.

Wright H.A.; A.W. Bailey. 1982. Fire Ecology, United States and southern Canada. New York: John Wiley and Sons, Inc. 302 p.

Young R.A.; Ronald L. Giese. 1982. Introduction to forest Science. 2nd ed. New York: John Wiley and Sons, Inc. 304-306 p.

Zutter, B.R.; J.H. Miller. 1998. Eleventh-year response of loblolly pine and competing vegetation to woody and herbaceous plant control on a Georgia Flatwoods site. Southern Journal of Applied Forestry. 22(2): 88-95.