USING PRESCRIBED FIRE TO REGENERATE TABLE MOUNTAIN PINE IN THE SOUTHERN APPALACHIAN MOUNTAINS

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ABSTRACT

stand-replacing prescribed fires am recommended to regenerate stands of Table Mountain pine (*Pinus pungens*) in the southern Appalachian Mountains because the species has serotinous cones and its seedlings require abundant sunlight and a thin forest floor. A 350-hectare prescribed fire in northeastern Georgia provided an opportunity to observe regeneration success at various fire intensity levels. Fires of low and medium-low intensity produced abundant regeneration but may not have killed enough of the overstory to prevent shading. High-intensity fires killed almost all overstory trees but may have destroyed some of the seed source. Medium-bigb intensity fires may be the best choice because they killed overstory trees and produced abundant regeneration. The forest floor remained thick after fires of all intensities, but roots of pine seedlings were able to penetrate a duff layer of up to 7.5 centimeters thick to reach mineral soil.

keywords: fire *intensity*, *Pinus pungens*, *prescribed fire*, southern Appalachian Mountains, Table Mountain pine.

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INTRODUCTION

The southern Appalachian Mountains are appreciated for their diversity of plants and plant communities. Many factors combine to create this diversity, including a mosaic of soils, aspects, elevations, weather pattems, and disturbances. However, a key factor for several communities; which has been missing for several decades, is large-scale fire. Lightning- and human-caused fires played a significant role in the evolution of southern Appalachian plant communities (Van Lear and Waldrop 1989). Fire suppression policies in effect on public lands for the past 70-80 years probably reduced the floral diversity in the southern Appalachians and may threaten the existence of some plant species and communities.

One species of concern is Table Mountain pine, which occurs from central Pennsylvania to northeastem Georgia. It is shade intolerant and found on south- and west-facing ridges at elevations of 3004,225 meters (Zobel 1969). Throughout the region, Table Mountain pine stands are in late seral stages and are succeeding to oaks, particularly chestnut oak (*Quercus prinus*) (Zobel 1969, Turrill et al. 1997). Outbreaks of southern pine bark beetle (*Dendroctonus frontalis*) and ice storms hasten this succession because both disturbances select against Table Mountain pine (Williams 1998). Unless the short-lived, shade-intolerant pines are regenerated, they will be replaced by the longer-lived, shade-tolerant hardwoods. Williams (1998) attributed the decline of Table Mountain pine stands to fire suppression and inadequate understanding of this species' regeneration biology.

Table Mountain pine has serotinous cones, suggesting that fire is needed for successful seed dispersal. For successful seedling establishment, the species also needs high levels of sunlight and little or no forest floor-microsite conditions similar to those created by fire.

Although fire may be essential for regenerating Table Mountain pine stands in the southern Appalachians, supporting research is limited and sometimes contradictory. Zobel (1969) emphasized the need for intense fire by pointing out that although serotinous cones opened in lightly burned areas, seedlings survived only in areas where fires killed overstory trees and erosion exposed mineral soil. Williams and Johnson (1992) found abundant seed in lightly disturbed stands where no fire had occurred. However, seedling establishment was limited to those micorsites that had a thin duff layer (<3.8 centimeters) and that were more open than the surrounding stand.

Prescribed fire research in Table Mountain pine stands is limited to 1 study (Turrill 1998). In that study, 10 fires were planned on federal lands throughout the southern Appalachian region. Of those, only four were successfully burned and only one was a Table Mountain pine stand. Because of the limited number of observations in that study, information on the season, frequency, and intensity of fire required for successful Table Mountain pine regeneration was inconclusive. The study also illustrated the dilemma of using stand-replacing fire. The prescription called for intense crown fires, effectively narrowing the burning window and raising concerns about worker safety and smoke management; If Table Mountain pine can be regenerated without crown fires, then the burning window will be wider and there may be less concern about safety and smoke.

A stand-replacing prescribed fire occurred on a 350-hectare area of the Tallulah Ranger District of the Chattahoochee National Forest in northeastern Georgia on 4 April 1997. This fire was large enough and fire intensity was variable enough to allow comparisons of regeneration success among areas burned at different intensities. This study was initiated in June 1997 to evaluate the effectiveness of a prescribed fire of varying intensities at replacing mixed stands of Table Mountain pines and upland hardwoods.

METHODS

Study Area

The study site was conducted in 3 separate Table Mountain pine stands located along an unnamed ridge immediately south of Rabun Bald and Big Ridge in the War Woman Wildlife Management Area of the Tallulah Ranger District in Rabun County, Georgia (34" 56'N; 83" 18'W). One stand was 18 hectares in size and located at an elevation of 1,100 meters. The other 2 stands *were* each 12 hectares in size and located at elevations of 915 and 885 meters, respectively. Topography of all stand areas consisted of a narrow, southeast-facing ridge with accompanying side slopes. The side slopes were extremely steep, often exceeding 100%, and with northeastern or southwestern aspects.

Soils on the southwestern slopes belong to the Ashe Association; those of the northeastern slopes belong to the Ashe-Porters Association (Carson and Green 1981). The Ashe soil series (coarse-loamy, mixed., mesic, Typic Dystrochrepts) is predominant in both associations. Soils of these series are moderately deep, somewhat excessively drained soils that formed in the residuum from biotite gneiss interrupted by narrow dikes of schist. Solum thickness ranges from 40-75 centimeters. Depth to bedrock ranges from 65-l 15 centimeters. Coarse pebbles, cobbles, and stones range from about 5-15% in the A and B horizons. The soil is very strongly acid (pH 4.5–5.0) or strongly acid (pH 5.1-5.5) throughout.

Prior to burning, all 3 stands were similar in composition and stocking of overstory hardwoods and Table Mountain pine. Mean basal area of the study stands was 30.3 square meters per hectare. Hardwoods made up 21.3 square meters of this total and pines the remaining 9 square meters. Chestnut oak was the most abundant hardwood, comprising nearly 50% of the hardwood basal area. Other common hardwoods were, in order of decreasing abundance, scarlet oak (*Q. coccinea*), blackgum (*Nyssa sylvatica*), hickory (*Carya* spp.), red maple (*Acer rubrum*), and sourwood (*Oxydendrum arboreum*). Nearly 80% of the pines were Table Mountain pine, and the remainder was equally divided between pitch pine (*P. rigida*) and eastern white pine (P. *strobus*). Few overstory trees exceeded 40 centimeters diameter at a height of 1.3 meters (DBH) and only two were >15 meters tall. The shrub layer consisted almost entirely of mountain laurel (*Kalmia latifolia*), which ranged in density from nearly impenetrable in some areas to absent in others.

The Prescribed Fire

On 29 March 1997, a week prior to the bum, the site received nearly 2.0 centimeters of precipitation. On the day of the burn, 4 April 1997, the Keetch-Byram Drought Index was 110. Forest floor samples were collected at 1030 hours; moisture content was found to be 8% for the root mat and 6% for the litter layer. Weather conditions were monitored on-site with a belt weather kit. Relative humidity was 51% at 0900 hours, dropped to a low of 27% at 1220 hours, and increased to 32% at 1600 hours. Temperatures ranged from 15°C at 0830 hours to 21°C at 1345 hours. Eye-level winds ranged from 3-13 kilometers per hour and were from the south and southwest.

The fire covered the entire burn unit, including the northeastern and southwestern slopes. Fire lines consisted primarily of existing roads and trails, but hand lines were required along portions of the western and northern sides of the burn unit. Backing tires were set by hand at upper elevations to secure fire lines, beginning at 0900 hours. The interior portion of the bum unit was set by aerial ignition beginning at 1030 hours. An attempt was made to employ a helitorch, but mechanical problems required the use of a plastic sphere dispenser for most of the burn. Spheres were dropped at approximately midslope on the southwest and northeast side slopes. This firing pattern was intended to create a ring fire that would be most intense at the ridgetop, where Table Mountain pine predominated. Once the ring fire was secure, strips were set by hand below the burned area (beginning at 1300 hours), proceeding from upper to lower elevations until the entire unit was burned. All firing was completed by 1600 hours.

Fiie intensity was generally extreme along the ridge with widespread crowning and intermittent torching observed by fireline personnel. Other areas of the unit burned with lower-intensity flames, where flame lengths were generally >1.3 meters but crowning and torching were not observed. Although a substantial proportion of ground fuels was consumed throughout the burn unit, scorch heights were observed to be variable.

Sampling Procedures

Three months after the fire, the entire burn unit was surveyed so that study areas exhibiting a range of fire intensity effects could be selected. Sixty sample plots, 10 X 20 meters in size (0.02 hectares), were placed throughout the stands to include areas burned at all fire intensity levels. Within each 0.02-hectare sample plot, the height, DBH, and species of each tree >3 meters tall were recorded To characterize the preburn stand conditions, all trees were assumed to be alive before burning unless they were in a late stage of decay. The height of bark char was recorded for all trees and each tree was characterized as alive, top-killed but sprouting, dying, or dead. Bark char height was defined as the lowest point on the bole of the tree above ground that was not blackened by the fire. The number of cones in the crowns of all Table Mountain pines was estimated to the nearest five.

Shrubs and hardwoods <3 meters tall were identified to species and tallied in subplots, 5 X 10 meters in size, located at each end of all sample plots. Two measurements of crown spread were made for each shrub, one at the widest point of the crown and the other at a right angle to the first measure. These measurements were used to estimate the average crown radius of each shrub and calculate its crown area.

Densities of seedlings and sprouts and microsite conditions were measured in each of 28 regeneration plots, 1 X 1 meter in sire; spaced systematically throughout each 0.02-hectare plot. Seven regeneration plots were established along each of 4 parallel transects so that their centers would be at a 3 X 3-meter spacing. In each regeneration plot, two PVC pipes, 2 meters in length, were placed at right angles to each other and crossing at their centers. With tbis placement, the pipes outlined 4 1 X l-meter quadrants. The number of pine seedlings was recorded in all 4 quadrants, but seedlings were too young to determine species. Quadrant tallies were totaled for each regeneration plot and seedling density was calculated on a hectare basis. However; regeneration cannot be considered a success if seedlings are not well distributed throughout the area. Thertfore, stocking was used as a measure of seedling dispersal. The burned areas were considered to have 100% stocking if at least 1 seedling occurred in each of tht 28 regeneration plots. This stocking approximates a seedling spacing of 3 X 3 meters of 1,077 seedlings per hectare. Although this spacing is wider than recommended for pine' plantations, it has been shown to produce stands dominated by pine in the Piedmont and southern Appalachian region (Waldrop et al. 1989, Waldrop 1997).

Soil exposure (i.e., fire severity) and insolation are 2 microsite conditions important to successful Table Mountain pine seedling establishment. Severity was quantified by rating each of the 28 regeneration plots as follows:

0. unburned,
1. burned with partially-consumed litter present,
2. no litter present, 100% of the area covered by root mat,
3. soil exposed on 130% of the area,
4. soil exposed on 31–60% of the area, or
5. soil exposed on 61–100% of the area.

Insolation was likewise rated and estimated between 1000–1400 hours on sunny days and described as one of the following categories:

1. full shade,
2. l-3096 of the area receiving direct sunlight,
3. 31–60% of the area receiving direct sunlight, or
4. 61–100% of the area receiving direct sunlight.

Hardwood seedlings and sprouts were counted and recorded by species in 1 systematically selected quadrant at each of tht 28 regeneration plots. Multiple sprouts arising from the same rootstock were counted as 1 stem. The number of sprouts per rootstock was also recorded.

To determine whether the pine seedlings were surviving on water and nutrients absorbed by their roots from the duff or whether their roots had penetrated the thick root mat and reached the mineral soil, pines were destructively sampled along transects located approximately 6 meters away from each of the 60 large (0.02-hectare) plots in the burned area. These transects were 18 meters long and parallel to the long (20-meter) side, of the plots. Along each transect, 10 pine seedlings and their root systems were excavated and measured. Seedlings were selected using a random-systematic sampling scheme. Near the beginning of each transect, a seedling was randomly selected, and then, at each 2-meter increment along tht transect the nearest seedling was measured. Measurements included seedling height, root mat thickness, root length within the root mat, and root length within mineral soil. All measurements were completed at the end of the first postburn growing season (mid-September 1997).

Determination of Fire Intensity

Because our objective was to compare response of Table Mountain pine regeneration to different levels of fire intensity, it was imperative that we categorize fire intensity. This classification was done by subjectively placing each of the 60 plots into one of 4 fire intensity levels (low, medium low, medium high, or high) based on observed fire effects. Placement of plots into these levels was verified by discriminant function analysis, which used bark char height, height of largest fire-

Table 1. Distinguishing characteristics of the 4 fire intensity categories.

Intensity	Mean bark char height (meters)	Height of tallest dead tree (meters)	Proportion of tree height charred (%)	Prebum cover of mountain laurel (%)
Low	1.8	10.0	14.3	26.2
Medium Low	6.5	14.9	44.3	29.6
Medium High	12.2	16.4	87.0	41.1
Hiah		14.9		85.9

Table 2. Basal area (BA) and mortality of overstory trees by fire intensity level.

Intensity	Prebum pine BA (sq. m./hectare)	Postburn pine BA (sq. m./hectare)	Prebum hardwood BA (sq. m./hectare)	Postburn	
				Hardwood BA (sq. m./hectare)	Pine + Hardwood mortality (%)
Low	6.2A[a]	5.9B	22.1A	16.8B	45.1
Medium Low	10.9A	6.08	23.6A	5.1A	84.6
Medium High	7.9A	1.1A	15.5A	0.5A	95.0
High	6.6A	0.0A	20.4A	1.0A	98.9

[a] Means followed by the same letter within a column are not significantly different at the $P \leq 0.05$ level.

killed tree, proportion of tree height charred by fire, and prebum cover of mountain laurel as the primary factors distinguishing among fire intensity levels. Fourteen of the 60 plots were reclassified, and no plot shifted more than 1 category. After reassignment, the number of plots in each fire intensity category was:

Intensity	n
Low	9
Medium low	28
Medium high	9
High	14

A more detailed description of the classification of fire intensity was given by Waldrop and Brose (1999).

Statistical Analysis

The study was analyzed as an unbalanced completely random design with fire intensity as the independent variable. Comparisons of treatment means among fire intensity levels were conducted by analysis of variance with mean separation by linear contrast ($a = 0.05$). To adjust for differences in seed source, analysis of covariance was used to test for differences in pine seedling density and stocking among the fire intensity levels. The covariates were number of cones on the ground and number of cones in the crowns of trees.

RESULTS

Fire Effects on Stand Characteristics

Low-intensity areas had 26% prebum'cover by mountain laurel, fire-killed trees up to 10 meters tall, and bole char to a height of 2 meters (14.3% of tree height) (Table 1). Pine basal area was unchanged, but hardwood basal area decreased from 22.1 to 16.8 square meters per hectare (Table 2). Mean severity and insolation values were 2.3 and 3.2, respectively, indicating that little mineral soil was exposed and that there was still considerable shade (Table 3). Approximately 50% of the overstory trees were killed, but nearly all mortality was to stems < 18 centimeters DBH (Table 2).

Characteristics of the areas burned at the medium-low intensity level were quite similar to the low-intensity areas, with the exception of the fire-killed trees, which were up to 15 meters tall, and the substantial reduction in pine and hardwood basal areas in the medium-low intensity areas (Tables 1-3). Eighty-five percent of trees ≥2.54 centimeters DBH were killed, but most were C25.4 centimeters DBH (Table 2).

In the medium-high intensity areas, prebum mountain laurel cover was 41%, mean bark char height was 6.5 meters, and tree height was 44.3% charred (Table 1). Postburn basal areas for hardwoods and pines were 0.5 and 1.1 square meters per hectare, respectively (Table 2). Surprisingly, fire severity did not differ from the lower intensity categories, but insolation was much greater (Table 3) as 95% of all overstory trees were killed by the fire (Table 2).

In the high-intensity areas, prebum mountain laurel cover was 86%, mean bark char height was 12.2 meters, and most trees had evidence of char over their entire height (Table 1). Mortality among overstory trees was nearly 100% (Table 2), which reduced stand basal area to only 1.0 square meter per hectare (Table 2). As in the medium-high intensity category, insolation reaching the forest floor was high while fire severity was unexpectedly low (Table 3).

Pine Seedling Establishment

Postburn counts of pine seedlings suggest that fires were of sufficient intensity to open serotinous cones throughout the burn unit. Postburn pine density ranged from 3,448 to >22,230 stems per hectare (Table 4). An unexpected result was that the lowest pine densities

Table 3. Effects of fire intensity on soil exposure and insolation.

Intensity	Mean soil exposure category	Mean insolation category
Low	2.3A[a]	3.2A
Medium Low	2.2A	3.4A
Medium High	2.0A	3.70
High	2.0A	3.60

[a] Means followed by the same letter within a column are not significantly different at the $P \leq 0.05$ level.

Table 4. Effect of fire intensity on density and stocking of pine regeneration 1 growing season after burning.

Intensity	Density (stems/hectare)	Stocking (%)
Low	13,852AB[a]	77.3B
Medium Low	22,551 A	93.8A
Medium High	9,016B	63.7BC
High	3,448B	51.1C

[a] Means followed by the same letter within a column are not significantly different at the $P \leq 0.05$ level.

Table 5. Regeneration (sprouts per hectare) of predominant hardwood species and species groups by fire intensity category.

Intensity	Blackgum	Oaks[a]	Sassafras	Other hardwoods[b]	Total
Low	15,968	4,670	474	2,658	32,150
Medium Low	16,379	8,586	9,472	2,932	37,371
Medium High	15,200	6,118	1,875	3,396	26,590
High	11,404	7,815	4,861	7,457	31,537

[a] Includes black oak (Q. *velutina*), chestnut oak, scarlet oak, and white oak (*Q. alba*).
[b] Includes American chestnut (*Castanea dentata*), black locust (*Robinia pseudoacacia*), red maple, sourwood, yellow-poplar (*Liriodendron tulipifera*), and other species.

were found in plots burned at the highest tire intensity levels. This finding may indicate that cones were consumed by fire, or seeds were kilkd by intense heat where flames reached into the crowns of trees.

Even though plots burned at high intensity levels had fewer seedlings than other plots, the 1,400 seedlings per hectare that were present should produce pine-dominated stands if the seedlings are well dispersed However, pine seedlings were found in only 51% of the regeneration plots sampled (Table 4). This pattern indicates that portions of the sampled stands had no pine regeneration and may become dominated by hardwoods. Plots burned at the medium-high intensity level also had low pine stocking. Pine density and stocking levels of plots burned at low and medium-low intensities should be adequate to create pine-dommated stands if the seedlings receive adequate sunlight and moisture.

Competition from hardwoods and shrubs that sprouted after the fire may inhibit the development of a pine-dominated stand. The most common hardwood species among the regeneration was blackgum, the oaks, (especially chestnut oak), and sassafras (*Sassafras albidum*) (Table 5). There were no significant differences in the total number of sprouts per hectare among the tire intensity categories or for any of the species individually. This result suggests that most hardwoods survived even the high-intensity fires and sprouted. The total number of sprouts per hectare was high at all intensity levels, ranging from 27,170 to >37,000.

Sampling of the root mat showed little evidence of fire-intensity effects (Table 6). Root mat thickness varied significantly among plots burned at various intensity levels, but there was no clear relationship between fire intensity and postburn root mat thickness. The thinnest root mats occurred in plots of the low and medium-low intensity categories. Greater fire residence time for these lower-intensity fires may account for these differences. However, preburn measurements of root mat depth were not taken, so this conclusion is speculative.

The relationship of total root length, root mat thickness, and seedling height shows the importance of burning away as much of the root mat as possible. In this study, total root length was unaffected by fire intensity or root mat depth (Table 6). The roots of all seedlings sampled were approximately 10 centimeters long. Therefore, seedlings had a larger portion of their roots penetrating into the mineral soil in areas where the root mat was thin. In plots with the thinnest root mats (medium-low intensity), the proportion of seedlings with roots reaching the mineral soil, the length of root in mineral soil,' and seedling height were significantly higher than in any other plots. Even though pine seedling growth was better with thinner root mats, complete removal of the forest floor is not recommended. Stone et al. (1995) showed that severe burns on Appalachian sites create excessive erosion and reduce site productivity.

Root measurements from all 60 sample plots were combined to show the relationship of root mat depth to several pine seedling characteristics (Table 7). The number of seedlings sampled generally decreased with increasing root mat depth. This pattern probably reflects a combination of increased mortality with increased root mat depth and reduced sampling probability for the smaller area covered by thicker root mats. As we expected, the percentage of seedlings that had roots reaching the mineral soil decreased with increasing root mat depth. A significant finding, however, is that the roots of >80% of sampled seedlings were able to penetrate root mats as thick as 7.6 centimeters and almost all sampled seedlings had roots that penetrated root mats 5.1 centimeters thick. This finding makes it clear that total consumption of the forest floor is not required for germination and survival of Table Mountain pine.

Table 6. Height and rooting characteristics of pine seedlings by fire intensity category.

Intensity	Postburn forest floor thickness (centimeters)	Seeding height (centimeters)	Total root length (centimeters)	Length of root in soil (centimeters)	Percentage of seedlings with roots in ths soil
Low	5.3AB[a]	6.9A	9.4	4.6A	71.1A
Medium Low	3.8A	8.6B	10.4	6.98	94.68
Medium High	7.68	7.1A	10.2	3.6A	63.0A
High	6.66	7.4A	9.7	4.3A	56.1A

[a] Means followed by the same letter within a column are not significantly different at the $P \leq 0.05$ level.

Table 7. Seedling height and percentage of seedlings with roots penetrating the forest floor into mineral soil by forest floor depth.

Root mat thickness (centimeters)	Seedlings sampled	Number with roots In the soil	Percent of total	Mean seedling height (centimeters)
2.5	170	162	95.3	8.9
5.0	223	209	93.7	8.1
7.5	103	83	80.6	7.4
10.0	70	28	40.0	6.6
12.5	47	9	19.1	6.4
15.0+	37	2	5.4	5.8

Seedling height was smaller as root mat depth increased (Table 7). However, all of the seedlings present had survived the first growing season and those on thicker root mats may extend a larger portion of theii roots to mineral soil in the next growing season.

DISCUSSION

Previous research indicated that successful regeneration of Table Mountain pine required a thin forest floor with duff thickness ranging from bare mineral soil to a maximum of 4 centimeters (Zobel 1969, Williams and Johnson 1992), and that a high-severity fire was necessary to prepare such a seed bed. However, this study shows that Table Mountain pine can also regenerate on root mats thicker than 4 centimeters as >80% of the sampled seedlings that were growing in root mats between 5.0–7.5 centimeters thick had roots reaching mineral soil. These differences in results may be due to location, the earlier studies being conducted primarily in the central Appalachian region as opposed to Georgia. There may be minor morphological or physiological differences within the species due to regional climate variation.

Our findings suggest that a high-severity fire is not needed to ensure pine regeneration. Prescribed bums can be conducted when the lower layers of the forest floor are moist, thus protecting steep slopes from erosion and loss of site productivity. This moderately thick root mat may be beneficial to new seedlings as a moisture-conserving mulch, protecting them from the mild to moderate summer droughts common in the southern Appalachian region.

Previous research also indicated that Table Mountain pine seedlings were shade intolerant (Zobel 1969, Williams and Johnson 1992). suggesting that high-intensity stand-replacing fires were necessary for successful regeneration. This study found seedling density and stocking were lowest in plots burned with high-intensity fires, possibly because those fires consumed or killed a portion of the seed. Plots burned at low or medium-low intensities had many surviving overstory trees. Seedlings in these plots may not survive shading and underground competition unless more of the overstory trees die in the near future. Medium-high intensity fire may be the best choice. In plots burned at this intensity level, overstory mortality was near 100%, insolation to the forest floor was abundant, seedling density was adequate, and stocking was nearly adequate.

Definitive recommendations about the fire intensity needed to successfully regenerate Table Mountain pine stands should not be made based on the 1 growing season's observations although results of this study indicate that high fire intensity may not be as necessary as previously thought. Table Mountain pinecones opened after fires with intensities ranging from low to high, and seedlings were abundant regardless of intensity level. However, future competition from hardwood sprouts may eliinate many of the pine seedlings. Stand development will be monitored for several years to clarify the effect of hardwood competition on pine survival.

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