SEEDBED REQUIREMENTS FOR REGENERATING TABLE MOUNTAIN PINE WITH PRESCRIBED FIRE[1]

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Abstract—High-intensity, stand-replacement fires have been recommended to regenerate stands of Table Mountain pine (*Pinus pungens* Lamb.) because its seeds require mineral soil to germinate and seedlings are intolerant of shade. Early prescribed fire efforts resulted in poor regeneration success where crown fires created seedbeds with abundant insolation and thin duff. This study examined regeneration success over a range of shading and duff depth conditions in the field and in a greenhouse. In both trials, stem densities that would adequately regenerate Table Mountain pine stands were found on seedbeds with abundant insolation and thin duff. However, stem density was significantly higher under moderate shade and on duff up to 3 in. thick. These findings suggest that prescribed fires of sufficient intensity to eliminate shade and expose mineral soil are unnecessary to successfully regenerate Table Mountain pine.

INTRODUCTION

Southern Appalachian ecosystems evolved with and are adapted to lightning- and human-caused fires (Van Lear and Waldrop 1989). For 7 to 8 decades fire suppression policies on public lands have probably reduced diversity in Southern Appalachian ecosystems and may threaten the continued existence of some plants. One species likely declining due to lack of fire is Table Mountain pine (*Pinus pungens* Lamb.). a species that is endemic to xeric Appalachian sites from central Pennsylvania to northeast Georgia (Zobel 1969). Throughout the region. stands of this species are entering later seral stages. in which dying pines are replaced by oaks and hickories (Turrill and others 1997). Table Mountain pine has serotinous cones and this suggests that fire may be needed to regenerate the species. Williams (1998) staled that Table Mountain pine stands are in decline as a result of fire suppression and inadequate understanding of the species' regeneration biology.

Research on regenerating Table Mountain pine stands is limited and sometimes contradictory. Zobel's (1969) monograph emphasizes the need for intense fire. He found that serotinous cones opened in liihtly burned areas but that seedlings survived only where fire killed the overstory and erosion exposed mineral soil. Williams and Johnson (1992) found that seeds were abundant in lightly disturbed stands where no fire occurred but seedlings did not become established because suitable microhabitat (high insolation and bare soil) was extremely limited. By contrast. Waldrop and Brose (1999) found fewer seedlings where a stand-replacement fire killed all trees than where some trees remained alii to cast shade. They also found that roots of l-year-old seedlings penetrated duff (the O_e and 0, horizons below freshly fallen leaf litter but above mineral soil) up to 3 in. thick, suggesting that bare soil is not necessary for seedling establishment.

This study examined the microsite conditions (shade level and duff depth) where Table Mountain pine was successfully established in two bum units described by Waldmp and Brose (1999). Because the range of shade and duff conditions created by each fire was limited and effects of slope and aspect were confounded. a greenhouse study was conducted to examine the relationship of seedling establishment to a wider range of shade and duff conditions. Results provide an indication of the fire regimes that could be prescribed for successful regeneration of Table Mountain pine.

METHODS

Field Study

A total of 99 sample plots was established in two burn units. one in northeastern Georgia and another in northwestern South Carolina. Plots were 0.05 acre in size and distributed throughout each Table Mountain pine stand to include as much of the stand and. therefore, as many microsite conditions as possible. Fires were prescribed for both areas that would be of sufficient intensity to kill overstory trees and allow abundant regeneration. The Georgia unit was burned in April 1997 and the South Carolina unit in March 1998. Flame heights ranged from 6 to 100 ft in Georgia and from 3 to 40 ft in South Carolina. Waldrop and Brose (1999) give a detailed description of site and burning conditions.

Postburn regeneration and microsite conditions were measured in 28 subplots. each measuring 6 x 6 ft and spaced systematically throughout the 0.05-acre sample plots. All measurements were completed at the end of the lint growing season after burning (late August through early September). On each subplot. counts of pine seedlings and cones and the amount of insolation on the forest floor were recorded. Insolation was estimated between 10:OO and 14:00 on sunny days and described as one of the following categories:

1. full shade: no direct sunlight reaching the forest floor,
2. high shade: 1 to 30 percent Of the area receiving direct sunlight.
3. medium shade: 31-60 percent of the area receiving direct sunlight, or
4. low shade: 61-100 percent of the area receiving direct sunlight.

Full shade was rarely seen in either bum wit so this category was dropped from analysis. Ouff depth was measured at 10 randomly selected locations immediately

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outside each of the 99 sample plots. Numbers of cones in crowns were estimated for each Table Mountain pine in each sample plot.

Differences among treatment means were analyzed using a 3 x 3 factorial arrangement of treatments. Factors included the three shade categories described above and three categories of duff depth (0.5 to 1.5 in., 1.6 to 3.0 in.. and > 3.0 in.). Pine regeneration density was compared with a one-way analysis of variance using the total number of cones on the ground and in tree crowns as a covariate to adjust for seed source differences. Mean separation was by linear contrast (a = 0.05).

Greenhouse Study

me greenhouse study used a set of shade and duff treatment combinations like the field study but with en additional shade treatment. Duff depths were 0.2. and 4 in.: shade levels were 0, 30, 63, and 85 percent shade. Although 0 percent shade was never observed in the field. this category was added to the greenhouse study to test seedbed conditions recommended by Turrill and others (1997). Duff depth categories represent the range of post-bum conditions reported by Waldmp and Brose (1999).

Treatments were arranged in a split-plot design with shade as the main plot effect and duff depth as the subplot effect. Soil and duff were collected fmm the South Carolina bum unit Soil was placed in 6-i". square pots and duff was added to depths of 2 or 4 in. The desired shade levels were obtained by placing commercial shade cloth over a set Of 24 pots, 8 pots (subsamples) for each of the three duff categories. All treatment combinations were replicated three times in a randomized complete block design.

On November 1, 1998, a total of 25 seeds was placed in each pot. Seeds had bee" collected from 12 trees that were felled in an area adjacent to the Georgia bum unit. Viability was found to be 90.4 percent in a laboratory test using seeds placed on moist paper in petri dishes. Greenhouse temperatures approximated summer conditions with nightly lows of 65 to 70 °F and afternoon highs of 90 to 95 °F. A watering schedule was selected that would roughly approximate me observed rainfall pattern that occurred on me Georgia bum unit: during the first growing season after burning. Rainfall at me closest weather station (Clayton, GA) was abundant during the first half of the growing season but infrequent during the second half. From May 15 through June 30, 1997 a total of 18.4 in. of rain was recorded. The maximum period without rain was 4 days. Rainfall from July 1 through August 15, 1997 was only 4.5 in. and there were periods of 12 and 14 days with no rain. To approximate this pattern, pots were watered every 2 to 3 days during the first 45 days of the study and every 7 to 10 days during the second 45 days.

Germination, mortality. and seedling height were measured periodically through January 29.1999 (90 days after sowing). Differences among treatment combinations for germination, survival, seedling density. and height were detected by analysis of variance with mea" Separation by linear contrast (α = 0.05).

RESULTS AND DISCUSSION

Duff Depth

Eve" though seed viability was over 90 percent i" me laboratory test. fewer than 70 percent of the greenhouse seeds germinated. Germination varied somewhat by duff depth. with a significantly lower rate on 4-in. duff than On 2-in. duff or on bare soil (table 1). Survival rates for those seedlings that emerged also varied by duff depth. The best survival over me 90-day study was on bare soil (57 percent), which was significantly higher than survival on the 2-i". duff (42 percent) but not significantly higher than Survival on the 4-i". duff (50 percent).

The total number of seedlings in each pot at the end of the 90-day study was a function of both germination and survival. It also indicated the relative density of seedlings that could become established under similar field conditions. Seedling density was significantly higher in 2-in. duff than on bare soil or in 4-in. duff in the greenhouse (table 1). Pots with bare soil dried quickly and the seedlings could not benefit from the mulching effect that was probably available to seedlings growing in 2-i". duff. Low stem numbers in 4-h. duff were caused by a lower germination rate and. although it was not measured here. the inability of roots to penetrate duff layers of ≥3 in. (Waldmp and Brose 1999). The lower germination and survival 0" thicker duff likely would not constitute regeneration failure under field conditions. On the thickest duff layer (4 in.). germination and survival were over 50 percent.

Table 1—Germination, survival, and stem density by duff depth I" greenhouse and field studies

Greenhouse				Field	
Duff depth	Germination[a]	Survival[b]	Density	Duff depth	Density
Inch	Percent		Stems/pot	Inch	Stems/acre
0	64.9a[c]	57.3a	5.7b	0.5-1.5	3,749.4a
2	63.0a	41.9b	9.9a	1.6-3.0	5,152.8a
4	56.6b	49.9ab	6.5b	over 3.0	1,338.0a

[a] Percentage of 25 seed, ma, germinated at any time throughout the 90-day study.
[b] Percentage of germinants that survived to the end of the 90-day study.
[c] Means followed by the same letter within a column are not significantly different at the 0.05 level.

The pattern Of stem density by duff depth in the field was similar to that in the greenhouse (table 1). Although not statistically significant, stem density in medium duff (1.6 to 3.0 in. thick) was greater than in thin (0.5 to 1.5 in.) or thick duff (> 3.0 in.). Although density was higher in thin end medium duff layers, almost 2.000 seedlings per acre were present in thick duff layers. If most were to survive, those seedlings would produce a stand dominated by Table Mountain pine.

Shade

Differences in germination and survival were more pronounced among shade categories ma" among duff depths. In me greenhouse study, germination rates were significantly higher under all levels of shade than under no shade (table 2). The best germination occurred under 63-percent shade. Shade also affected the Survival rates of germinants. Over 70 percent of germinants growing under 30-percent shade survived throughout the 90-day study (table 2). This survival rate was significantly higher than for germinants growing without shade or under the two highest shade levels.

survival rates under hlgh shade in the greenhouse and tow density under high shade in the field emphasize me lack of shade tolerance of Table Mountain pine. The species may be unable to survive without some direct sunlight. Moderate levels of shade. represented by 30-percent shade cloth in me greenhouse or 30- to 60-percent insolation in the field, may provide the best balance of moisture and light. Waldmp and Brose (1999) found that a prescribed fire that was of sufficient intensity to kill understory trees and shrubs but leave me overstory alive would create insolation levels similar to the moderate shade categories. This pattern suggests that high-intensity crown fires are not necessary for Table Mountain pine regeneration.

Duff and Shade Interactions

Figure 1 shows the total number Of seedlings per pot at me end of me 90-day greenhouse study for all combinations of duff and shade. Stem density was typically greater in 2-i". duff than in bare soil or 4-i". duff. This pattern remained constant for all shade categories except 0 shade. In 0 shade. stem densities in pots with 2 in. of doff were equal to stem densities in pots without duff. Without shade, the mulching effect of a 2-in. duff layer may not have bee" adequate to prevent moisture deficit and seedling *death.*

Lack of shade reduced seed germination and the survival of germinants. while heavy shade reduced survival. These

Table 2—Germination, survival, and stem density by shade level in greenhouse and field studies

Greenhouse				Field	
Shade level	Germination[a]	Survival[b]	Density	Shade category	Density
	Percent		Stems/pot	Percent	Stems/acre
0	49.9c[c]	51.8b	8.5b		
30	64.0ab	71.3a	10.2a	Low (l-39)	3,942.3ab
63	69.8a	31.2c	6.0c	Medium (40-69)	6,665.2a
65	62.2b	44.4bc	4.7c	High (70-99)	232.6b

[a] Percentage of 25 seeds that germinated at any time throughout the 90-day study,
[b] Percentage of germinants that survived to the end of he 90-day study.
[c] Means followed by the same letter within a column an not significantly different at the 0.05 level.

Differences in greenhouse germination and survival rates caused significant differences in pot seedling density after 90 days (table 2). At the end of the study. pots placed under 30-percent shade had significantly more seedlings than did pots without shade or those under higher levels of shade. TNS Pattern closely resembled the pattern observed in the field (table 2). There, stem density under medium shade was higher than under low shade and significantly higher than under high shade. Stem density at low and medium shade was probably higher than necessary for successful stand regeneration. However, areas under high shade had only 233 seedlings per acre, a stocking level that would probably not generate Table Mountain pine dominance.

Reduced germination and survival rates observed without shade were likely caused by less available moisture. Poor factors typically allowed more seedlings to become established under 30-percent shade than under full liiht or higher levels of shade. This pattern was constant among pots with 2 and 4 in. of duff but differed among pots with no duff (fig. 1). With no duff, fewer seedlings per pot occurred under 30-percent shade than under no shade. although this difference was not significant. Without the mulching effect of duff. 30-percent shade may not be adequate to prevent moisture deficit.

If germination and survival under field conditions follow the same patterns as in the greenhouse. these data provide a partial description of seedbed conditions necessary to establish Table Mountain pine. Because of differences in study designs. field results shown here do not provide a direct comparison to greenhouse results. However, results

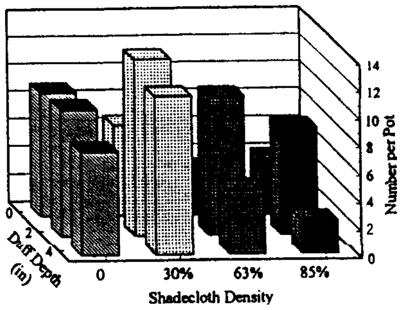

Figure 1—Seedling density per Pot by shade level and duff depth after the so-day greenhouse study.

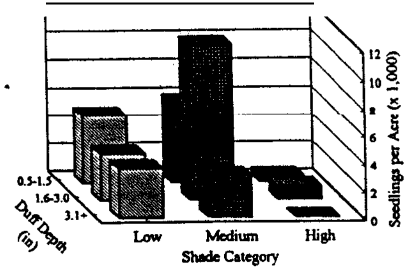

Figure 2—Seedling density by shade level end duff depth at the end of one growing season in Georgia and South Carolina bum units.

of the two studies are similar. In the field. stem numbers did not vary significantly at different duff depths within a shade category (fig. 2). Seedling numbers were not significantly different between low- and medium-shade categories but both had significantly more stems man did me high-shade category. Under high shade. stem density was less then 1,000 seedlings per acre at all duff depths. These seedlings are probably too few to adequately regenerate a stand. Stem numbers in medium and low shade ranged from 3.024 per acre for medium shade with > 3 in. of duff to over 11,000 stems per acre under medium shade and 1.6 to 3.0 in. of duff. Each of these stem densities probably exceeds the minimum needed to regenerate the stand.

Seedling Height

Height growth of seedlings in the greenhouse was affected by duff depth and shade levels (table 3). Seedlings growing in bare soil were significantly shorter than those growing in 2 or 4 in. of duff. In addition, seedlings were significantly shorter when grown under 63 or 65 percent shade than

Table 3—Seedling height after 90 days by duff and shade level In the greenhouse study

Duff depth	Height
	Inch
0	1.6b
2	2.4a
4	2.1a
Shade level	**Height**
Percent	*Inch*
0	2.3a
30	2.3a
63	1.7b
65	1.8b

those grown under 30 percent shade or without shade. These patterns give additional evidence that seedlings endure moisture stress without a duff layer and light stress under shade levels over 60 percent.

CONCLUSIONS

Previous research indicated that successful regeneration of Table Mountain pine required a thin forest floor (Williams and Johnson 1992) and abundant insolation (Zobel 1969). Results of the greenhouse and field studies verify these findings and indicate that high-severity, stand-replacement fires, which was the goal of the prescription for fires studied, will produce those seedbed conditions. Such fires provide abundant sunlight by killing all overstory trees and they consume the duff to expose mineral soil. This study showed adequate stem density for regeneration when the duff was thin or missing and shade levels were low.

This study also suggests that fires of lower intensity than crown fires can produce as many or more seedlings. Stem density was highest where moderate levels of shade (30-percent shade in the greenhouse and 30- to 60-percent insolation in the weld) were combined with a duff layer less man 3 in. thick. Also. seedling growth was reduced where there was no duff. Moderate levels of shade and duff may help prevent moisture stress in young seedlings. Duff > 3 in. thick appears to reduce seedling survival. Shade levels > 60 percent may inhibit photosynthesis. At high shade levels, seedlings were fewer in number and height growth was reduced.

Additional research is needed to document the relationship of fire intensity to postburn shade level and duff depth over a range of conditions in Table Mountain pine stands. Also, seedling survival must be followed for more than one growing season. During the second growing season, pine numbers may increase with additional germination or decrease if that season is dry. Nonetheless, this study indicates that fires of extreme intensity, such as crown fires, may not be necessary to regenerate the species. One fire of moderate intensity or a series of low-intensity fires may be adequate. Such fires would maintain a duff layer to prevent erosion on steep slopes and help to reduce risks. Because of the limited number of days with weather conditions appropriate to produce controllable crown fires, prescriptions for lower-intensity fires would help expand the burning window. This would not only make burning less risky but allow more areas to be treated for regeneration of Table Mountain pine.

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