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

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

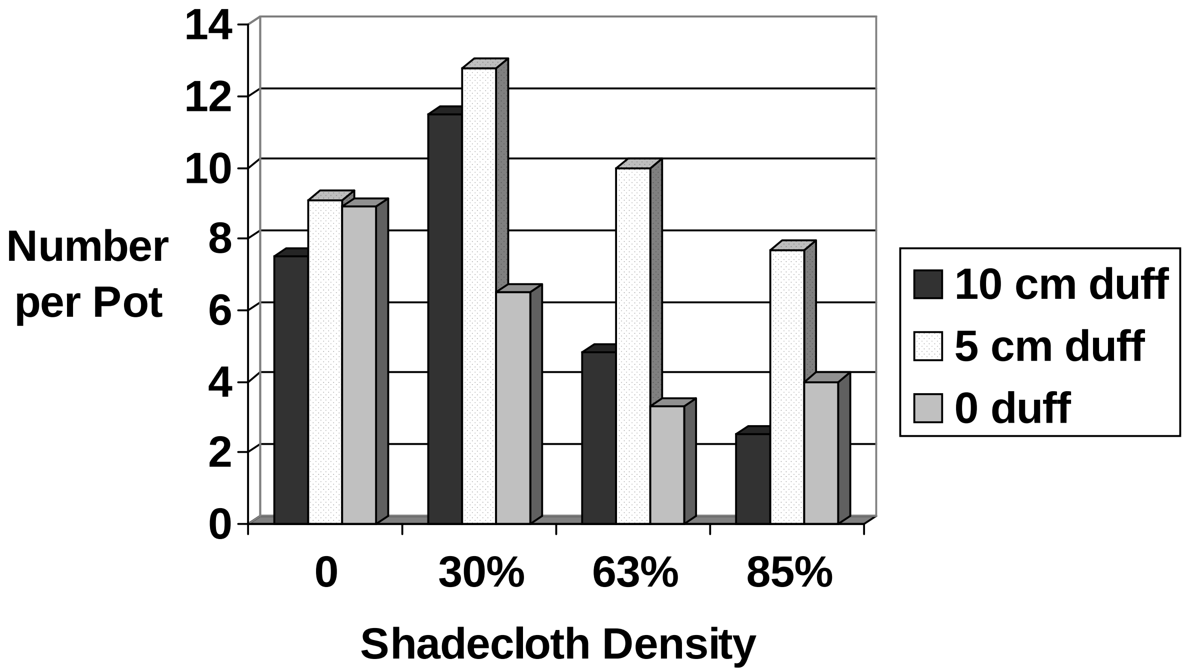

Figure 1—Seedlings per pot after the 90-day greenhouse study for all combinations of shade level and duff depth.

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

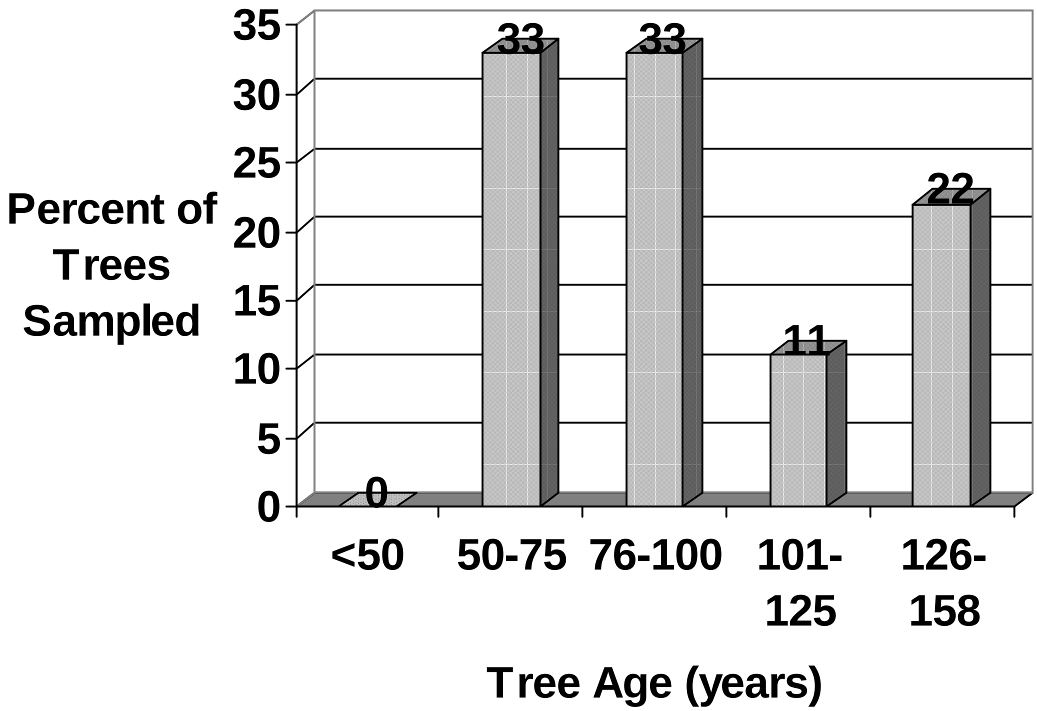

Figure 2—Age distribution of Table Mountain pines sampled on two north Georgia sites.

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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