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Restoring Table Mountain Pine (*Pinus pungens* Lamb.) Communities With Prescribed Fire: An Overview of Current Research

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ABSTRACT

Table mountain pine (*Pinus* pungens Lamb.) communities of the southern Appalachian Mountains have been maintained historically by lightning- and human-caused fires. Characteristic stands have a table mountain pine overstory, a chestnut oak (*Quercus prinus* L.), scarlet oak (Q. *coccinea* Muenchh.) and blackgum (*Nyssa sylvatica* Marshall) understory, and a mountain laurel (*Kalmia latifolia* L.) shrub layer. Following more than sixty years of fire suppression, most stands have increased densities of oaks and mountain laurel as well as fire-intolerant species such as red maple (*Acer rubrum* L.) and white pine (I? *strobus* L.). Previous research suggests that restoration of these communities can only be accomplished with high intensity fires that open the forest canopy and expose mineral soil. Opportunities to conduct such burns, however, are limited under current prescribed burning guidelines. Two recent studies examined community response to prescribed burning. Fires of low and medium-low intensity gave rise to 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. Fires of medium-high intensity may have been most successful, they killed overstory trees and allowed abundant regeneration. Large numbers of these seedlings survived the first growing season as their roots penetrated duff to reach mineral soil. Hardwood rootstocks resprouted after all fire intensities and may out-compete pine seedlings for available resources. Fires of lower intensity than previously recommended may best provide conditions for table mountain pine regeneration but additional research is needed. Prescriptions calling for lower intensity fires may widen the burning window defined by current guidelines.

INTRODUCTION

Table mountain pine (*Pinus pungens*), an Appalachian endemic, historically was maintained by lightning- and human-ignited fires. Stands of table mountain pine present on the landscape today were established by the logging fires of the early twentieth century, the most recent landscape-scale, stand-replacing fires to occur in the region (Williams 1998). Since that time, seven to eight decades of fire prevention policies and suppression have allowed the majority of table mountain pine stands to succeed towards hardwood dominance and closed understories (Williams and Johnson 1990, 1992; Sutherland et al. 1995; Turrill 1998; Williams 1998). As a result of these changes in dominance and structure, table mountain pine woodlands are recognized by the Southern Appalachian Assessment as one of thirty-one rare communities in the southern Appalachian Mountains [Southern Appalachian Man and the Biosphere (SAMAB) 19961.

The majority of degraded table mountain pine stands are located on National Forest and National Park lands where prescribed burning is possible and encouraged [United States Department of the Interior (USDI) and United States Department of Agriculture (USDA) 19951. Previous studies of table mountain pine regeneration following wildfires suggest that prescribed fires need to be of high intensity to remove the forest canopy and expose mineral soil for successful regeneration (USDA 1965, Zobel 1969, Sanders 1992). Although many National Forests

and National Parks include high intensity prescribed fires in their management plans for table mountain pine, executing these burns is difficult (Turrill 1998). Prescriptions calling for high intensity fires narrow the window of opportunity for burning and raise questions about worker safety and smoke management. In addition, some federal land managers avoid using high intensity fires because of the perceived risk of damaging marketable hardwoods and the lack of ability to control such fires on steep slopes (Van Lear and Waldrop 1989). As a result, high intensity prescribed burning has had limited application in the southern Appalachian Mountains.

Williams (1998) states that table mountain pine stands are in decline as a result of fire suppression policies and inadequate understanding of the species regeneration biology. To date, only two studies, Turrill(1998) and Waldrop and Brose (1999), have conducted prescribed burns to better understand the conditions necessary for table mountain pine regeneration. These studies examine community response to varying degrees of fire intensity as well as seedling establishment under varying levels of shade and duff depth. This paper evaluates the accepted regeneration conditions of fully open canopy and exposed mineral soil based on the results of those studies. The objectives of this study are to synthesize current knowledge, analyze gaps in the current data, and formulate research needs for the future.

BACKGROUND

Table mountain pine has serotinous cones and is shade intolerant. Pure and mixed table mountain-pitch pine (*Pinus rigida* Miller) stands are located between 305–1220 m elevation on southwest-facing slopes from central Pennsylvania to northern Georgia (Zobel1969, Della-Bianca 1990, MacKenzie and White 1998, Newell and Peet 1998). Characteristic stands have a chestnut oak (*Quercus prinus*), scarlet oak (*Q. coccinea*), and blackgum (*Nyssa sylvatica*) understory and a mountain laurel (*Kalmia latifolia*) shrub layer. Galax (*Galax* spp.), blueberries (*Vaccinium* spp.), and huckleberries (*Gaylusacia* spp.) are common in the herb layer (Zobel1969, Williams 1998, Newell and Peet 1998).

Restoration and maintenance of table mountain pine habitat is important since many animal and plant species are restricted to pioneer and mid-seral pine-oak forests of the southern Appalachian Mountains. Jeopardized wildlife limited to this habitat may include the northern pine snake (*Pituophis melanoleucus melanoleucus*) and the slender glass lizard (*Ophisaurus attenuatus*) (K. Langdon, pers. comm. 1997). Imperiled plants restricted to xeric pine and pine/oak forests include round-leaved service berry (*Amelanchier sanquinea* Pursh), branched whitlow grass (*Draba ramosissima* Desv.) and witch-alder [*Fothergilla major* (Sims) Lodd.] (Hessl and Spakman 1996). Hessl and Spakman (1996) also suggest that Heller's blazing star (*Liatris helleri* Porter), Peter's Mountain mallow (*Iliamna corei* Greene), and running buffalo clover (*Trifolium reflexum* L.) are limited to xeric montane woods.

Historically, stands of table mountain pine were maintained primarily by cultural burning (Buckner 1989, Van Lear and Waldrop 1989, Delcourt and Delcourt 1997, Buckner and Turrill 1998, Williams 1998). Lightning-ignited fires in the southern Appalachian region were, and remain, infrequent and restricted in location (ridge-top areas) and size (40 hectares or less) (SAMAB 1996). Cultural use of fire shaped the landscape until the early 1900s. Since that time, fire prevention and suppression practices have greatly reduced the frequency of fire in the southern Appalachian Mountains (Harmon 1982). As a result, table mountain pine stands are entering later seral stages where short-lived, shade-intolerant pines are replaced by longer-lived, shade-tolerant hardwoods including oaks (particularly chestnut oak) and hickories (*Carya* spp.) (Zobel 1969; Williams and Johnson 1990, 1992; Sutherland et al. 1995; Turrill et al. 1997; Turrill 1998).

The majority of the research addressing the role of fire in table mountain pine stands is limited to post-wildfire studies and often is contradictory. Zobel's (1969) monograph emphasized the need for intense fires in table mountain pine stands. Zobel (1969) found that seedlings survived only where fires killed enough overstory trees to allow direct sunlight on the forest

floor and erosion exposed mineral soil. Likewise, Sanders (1992) observed the greatest proportion of table mountain pine seedlings in high and moderate intensity burn areas, where the forest canopy was open and mineral soil was exposed.

In contrast, Barden (1977, 1978) indicated that fire may not be necessary to maintain populations of table mountain pine. He found that historical fires helped to establish many stands on xeric sites, but that these stands regenerate without fire and become uneven aged through gap-phase replacement. Similarly, Williams and Johnson (1992) found that seeds were abundant on the ground in lightly disturbed stands where no fire occurred. However, seedlings were successful only on microsites that had thin litter layers (<4 cm) and were more open than the surrounding stand. Such microsites were created most often by ice storms (Williams 1998).

Canopy gaps created by ice storms or other disturbances may not be sufficient to maintain table mountain pine. As the hardwood component of table mountain pine stands increases in the absence of fire, hardwood litter covering the forest floor increases. Hardwood litter creates barriers to pine seedling establishment (Williams et al. 1990). Many, stands with a significant component of table mountain pine also have thick litter and duff (the 0, and O_i horizons found below freshly fallen leaf litter and above the mineral soil) layers. Because fire is infrequent and because decomposition rates are slow, the litter and duff can reach depths of 15 to 20 cm on southern Appalachian sites (Robichaud and Waldrop 1994). Where this is the case, the litter and duff may prevent the roots of pine seedlings from reaching mineral soil.

CURRENT RESEARCH ON PRESCRIBED BURNING

Availability Days for Prescribed Burning in the Southern Appalachian Mountains

High-intensity prescribed burning has had limited application in the southern Appalachian Mountains due to the narrow burning window created by safety restrictions (USDA Forest Service 1989) and concerns of controlling fires on steep slopes (Van Lear and Waldrop 1989). Turrill (1998) estimated the number of days that was suitable for prescribed burning during Spring 1995 and 1996 for each of three sites where four high intensity burns to regenerate table mountain pine were planned. One burn was planned on both the George Washington and Jefferson National Forest (Wythe Ranger District), Virginia, and the Chattahoochee National Forest (Tallulah Ranger District), Georgia, and two burns were planned on the Pisgah National Forest (Grandfather Ranger District), North Carolina. Only one of these four burns was completed within the two year time period.

Daily fine fuel moisture, maximum daily temperature, minimum daily temperature, and minimum daily relative humidity data were obtained from the National Interagency Fire Management Integrated Data Base, Fire Weather Observation files for each site. The data collected between March 1 to May 31, 1995 and March 1 to May 31, 1996 were reviewed to see how many days met all of the following criteria: fine fuel moisture greater than or equal to 10 percent but less than or equal to 20 percent, maximum daily temperatures greater than or equal to 156°C [an air temperature at which internal tree tissues likely would reach or exceed lethal temperatures (63°C) during the fire (USDA Forest Service 1989)], minimum daily temperature greater than or equal to 0°C, and minimum daily relative humidity greater than or equal to 30 percent but less than or equal to 55 percent.

The number of days per month for which all data were available varied between sites (Table 1). Fine fuel moisture data were not available for Pisgah National Forest. The number of days per month meeting the four burning conditions on each site ranged from one to fourteen. In both 1995 and 1996, the total number of burning days per three month period was highest on the Pisgah National Forest. Burning days were most numerous during the month of May in both years.

Days meeting this subset of prescribed burning parameters were limited. If all of the required variables outlined by USDA Forest Service (1989) were considered, the number of days suitable for prescribed burning in 1995 and 1996 would be less, More importantly, these data were summarized after the fact. Predicting good days for burning is difficult. Regardless,

Table 1. Number of days meeting prescribed burning parameters for Spring 1995 and 1996. Values in parentheses are the number of days with complete data for the month

National Forest	State	Month		
		March	April	May
1995				
George Washington and Jefferson	VA	2 (31)	6 (30)	5 (15)
pisgah	NC	2 (31)	7 (30)	10 (14)
Chattahoochee	GA	0 (31)	1 (30)	7 (31)
1996				
George Washington and Jefferson	VA	1 (31)	3 (30)	3 (15)
Pisgah	NC	2 (25)	6 (30)	14 (29)
Chattahoochee	GA	1 (31)	3 (30)	8 (30)

executing high-intensity burns in table mountain pine stands is difficult under current burning guidelines.

Effects of Fire Intensity on Table Mountain Pine Regeneration

Two studies have examined the response of table mountain pine stands to prescribed fire, Turrill (1998) and Waldrop and Brose (1999). The burns conducted for these studies varied in their effects on opening the forest canopy and removing litter and duff. Comparisons of these field studies allow evaluation of the amount of pine regeneration under natural conditions.

The prescribed burn observed by Waldrop and Brose (1999) was on the War Woman Wildlife Management Area of the Tallulah Ranger District of the Chattahoochee National Forest. Prior to burning, mean total basal area in the study stands was 30.3 m^2/ha. Hardwoods made up 21.3 m^2 of this total and pines the remaining 8.9 m^2. Chestnut oak was the predominant hardwood and almost all of the pines were table mountain pine. USDA Forest Service personnel conducted a stand-replacement prescribed fire on a 350-ha unit in April 1997. The burn area covered sharp ridgetops and steep slopes with northeastern or southwestern aspects. The fire was ignited by hand and by helicopter to create a ring fire that reached greatest intensity within ridgetop table mountain pine stands.. The resulting fire was large enough and fire intensity varied enough to allow comparisons of regeneration success between areas burned at different intensities.

Turrill (1998) observed a 3-ha prescribed fire on the Grandfather Ranger District of the Pisgah National Forest. Prior to burning, the mean total basal area of the stand was 32.3 m^2/ha. Hardwoods comprised 8.7 m^2/ha of this total and pines the remaining 23.6 m^2/ha. Blackgum was the predominant hardwood. The pine component of this stand was 51 percent table mountain pine, 39 percent pitch pine and 10 percent Virginia pine (*P. virginiana* Miller). USDA Forest Service crews used a combined ring and head fire technique to burn the stand in May 1996. Stands burned for both Waldrop and Brose (1999) and Turrill (1998) contained dense mountain laurel shrub layers. Waldrop and Brose (1999) and Turrill (1998) completed post-burn observations in the first growing season after burning.

The prescriptions applied in these studies produced four fire intensities defined by Waldrop and Brose (1999): low, medium-low, medium-high, and high. Waldrop and Brose (1999) observed all four fire intensities and Turrill (1998) observed a medium-low intensity fire. Flames of low intensity fires never reached into the crowns of trees and uniformly burned the area. Medium-low intensity fires had flames slightly taller than those of low intensity fire, burned less uniformly, and produced hot spots that killed large trees. Flames of medium-high intensity fires typically reached into the crowns of overstory trees. Flames of high intensity fires reached, and often exceeded, the crown of overstory trees and carried from crown to crown.

Canopy cover was reduced following high and medium-high intensity fires (Table 2). Only 1.0 m^2 per hectare of basal area remained after high intensity burning. Medium-high intensity

Table 2. Characteristics of table mountain pine stands following p&scribed burning

Variable	Fire Intensity				Source
	Low	Medium-Low	Medium-High	High	
Pine basal area (m²/ha)	5.9	6.0 21.6	1.1	0.0	Waldrop and Brose (1999) Turrill (1998)
Hardwood basal area (m²/ha)	16.8	5.1 4.3	0.5	1.0	Waldrop and Brose (1999) Turrill (1998)
Hardwood sprouts (#stems/ha)	32,150	37,371 2,295	26,590	31,537	Waldrop and Brose (1999) Turrill (1998)
Pine seedlings (#/ha)	13,852	22,551 7,700	9,015	3,448	Waldrop and Brose (1999) Turrill (1998)
Insolation Category (% of forest floor receiving direct sunlight)	30-60	30-60	61-100	61-100	

fires showed similar reductions in basal area with only 1.6 m² per hectare remaining after burning. Mortality was high in all diameter breast height (dbh) size classes following both high and medium-high intensity fires. Direct sunlight reaching the forest floor was at levels up to 100 percent which may have been adequate for seedling survival following fires of both intensities.

Medium-low and low intensity fires were ineffective at reducing canopy cover (Table 2). Medium-low intensity fires reduced basal area to 11.1 m² per hectare in Waldrop and Brose (1999) and to 25.9 m² per hectare in Turrill(1998). Low intensity fires had little effect on canopy basal area and 23.0 m² per hectare remained. Mortality was greatest in the lower dbh size classes (less than 15 cm dbh) following fires of medium-low and low intensity. These fires may not have killed enough overstory trees to allow adequate light for pine seedlings. Insolation was significantly lower in areas burned at low and medium-low intensity than in areas burned at medium-high and high intensity.

Prolific hardwood sprouting was observed following fires of all intensities (Table 2). The mountain laurel shrub layer was top-killed by the low intensity fire observed by Waldrop and Brose (1999) and the medium-low intensity fire observed by Turrill (1998). The shrub layer was removed by medium-low, medium-high, and high intensity prescribed fires observed by Waldrop and Brose (1999).

Post-burn counts of pine seedlings suggest that fires were of sufficient intensity to open serotinous cones throughout the burn unit including areas burned at low intensity. Post-burn pine density ranged from 3,448 stems per ha to more than 22,000 stems per ha (Table 2). An unexpected result was that the lowest pine densities were in plots burned at the highest intensity levels. This pattern suggests that cones were consumed by fire or seeds were killed by intense heat where flames reached into the crowns of the trees.

Even though plots burned at high intensity had fewer seedlings than other plots, the 3,448 seedlings per ha present should create pine-dominated stands where seedlings are well dispersed. However, pine seedlings were found at only 51 percent of the sampling points. This indicates that portions of the burned areas had no pine regeneration and may be dominated by hardwoods. Plots burned at the medium-high intensity level also had low pine stocking (64 percent). Stocking levels for plots burned at low (77 percent) and medium-low (94 percent) intensities should be adequate to develop into pine-dominated stands if the seedlings receive adequate sunlight.

Competition from hardwoods and shrubs that sprouted after the fire may inhibit the development of a pine-dominated stand. There were no significant differences in the number of sprouts per ha by fire intensity category for any species or for the total. This suggests that

most hardwood rootstocks survived even high-intensity fires and resprouted. The total number of sprouts per ha was high in all intensity levels, ranging from 26,590 to 37,371.

Pine seedlings regenerated on thick litter and duff following all fire intensities. The total depth of litter and duff remaining after the prescribed fires was 5.3, 3.8, 7.6, and 6.6 cm for the low, medium-low, medium-high, and high intensity fires, respectively, of Waldrop and Brose (1999). The percentage of those seedlings with roots penetrating into mineral soil was 71.1, 94.6, 63.0, and 56.1 for the same order of fire intensities (Waldrop and Brose 1999). Turrill (1998) observed pine regeneration on approximately 9.2 cm of combined litter and duff. Waldrop and Brose (1999) found that root systems of over 80 percent of the sampled seedlings were able to penetrate duff of up to 7.5 cm thick, indicating that duff removal may not be as critical as once thought. However, survival of these seedlings was not followed beyond the first growing season after the burn in either study.

In order to assess seedling establishment, Waldrop et al. (1999) conducted a greenhouse study that used similar shade and duff treatment combinations as observed in the field. Duff categories included depths of 0, 5, and 10 cm and shade levels included 0, 30, 63, and 85 percent shade. Table mountain pine seeds were collected on the Chattahoochee National Forest. Soil and duff were collected from a recently burned table mountain pine stand on the Sumter National Forest, South Carolina. The seeds were germinated and allowed to grow under these conditions for three months. Germination, mortality, and seedling height were compared between seedlings grown in the greenhouse and those observed by Waldrop and Brose (1999) in the field.

Stem densities were highest where moderate levels of shade (30 percent in the greenhouse and 30 to 60 percent shade in the field) were combined with a duff layer no more than 7.5 cm. Also, seedling growth was reduced where there was no duff. Moderate levels of shade and duff may help to prevent moisture stress in young seedlings. However, duff over 7.5 cm thick and shade levels over 60 percent appeared to reduce seedling survival.

CONCLUSIONS

Results of Turrill (1998), Waldrop and Brose (1999) and Waldrop et al. (1999) suggest that fires of lower intensity than crown fires may successfully regenerate table mountain pine in this study area. Insolation levels to the forest floor were increased by medium-high and high-intensity fires because of high mortality of trees and shrubs. Low and medium-low intensity fires probably did not kill enough of the overstory trees to ensure seedling survival. In medium-high intensity plots, flames reached into the canopies of overstory trees but probably did not carry from crown to crown. In plots burned at this intensity level, overstory mortality was near 100%, insolation to the forest floor was abundant, and seedling density was adequate for stand regeneration.

These results contradict the suggestions of Zobel (1969) and Sanders (1992) and increase the number of days available for prescribed burning. Zobel (1969) and Sanders (1992) emphasized that table mountain pine seedlings germinate and survive in areas where the forest canopy was opened and mineral soil was exposed following high and moderate intensity fires. High intensity fires are difficult to conduct under current burning guidelines. Medium-high intensity prescribed fires, demonstrated to be successful at regenerating stands by Turrill (1998) and Waldrop and Brose (1999), are less dangerous and can be achieved within a larger burning window than high intensity fires.

Competition and shading from hardwoods and shrubs that sprouted after burning may inhibit the development of a pine-dominated stand. Rootstocks survived all fire intensities and resprouted. Post-fire sprouting occurred more frequently in hardwood tree species (red maple, chestnut oak, and scarlet oak) than in shrub species (mountain laurel). McGee et al. (1995) demonstrated that such post-burn increases in understory and shrub densities may persist for more than twelve years. However, Waldrop (1997) indicated that post-burn hardwood competition was not sufficient to inhibit pine survival on xeric and subxeric sites. Fires that expose the regenerative basal buds of hardwoods and shrubs to lethal temperatures may be necessary to reduce post-burn sprouting (Armour et al. 1984, Kauffman and Martin 1990).

Total consumption of the forest floor may not be required for table mountain pine regeneration. Post-burn duff depth did not differ with fire intensity. Large numbers of seedlings survived the first growing season on duff that was nearly twice as thick as the 4 cm maximum suggested by Williams and Johnson (1992). The studies described here will be continued to observe post-burn canopy cover, seedling density, seedling rooting depth, and seedling survival over several growing seasons.

There is still much to learn about restoring table mountain pine stands. The results presented here suggest that medium-high intensity fires may be sufficient. However, these results were drawn from only two studies and from data from only one growing season after burning. More research is necessary before definitive fire plans can be developed for table mountain pine. Future studies should apply prescriptions to achieve medium-high intensity burns and observe post-burn canopy cover, seedling density, seedling rooting depth, and seedling survival over several growing seasons. Additional research also is needed to test fires in other seasons and multiple low-intensity burns.

Many questions remain about the ecology of table mountain pine. In particular, the competitive ability of this species is unknown. If it is able to overtop hardwood and shrub sprouts at an early age, intense fires may not be necessary. Furthermore, work is needed on seed biology. Information about the relationship of seed viability to tree age and the age of cones within a tree would help identify stands that have the highest priority for regeneration. Physical, chemical, and biological properties of soils in table mountain pine stands also are likely to be affected by regeneration burns. These properties may affect seedbed conditions but they have not been studied. Finally, natural disturbances, other than fire, may have played an historical role in perpetuating the species. This information could suggest management alternatives to fire that could be used for regeneration.

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