Current Research on Restoring Ridgetop Pine Communities With Stand Replacement Fire

Thomas A. Waldrop[1], *Nicole Turrill Welch*[2], *Patrick H. Brose*[3], *Katherine J. Elliott*[4], *Helen H. Mohr*[1], *Ellen A. Gray*[5],
Frank H. Tainter[6], and *Lisa E. Ellis*[6]

Abstract

Ridgetop pine communities of the Southern Appalachian Mountains historically have been maintained by lightning- and human-caused fires. With fire suppression for several decades, characteristic stands are entering later seral stages. They typically have an overstory of Table Mountain (*Pinus pungens*) and/or pitch pine (*P. rigida*), a midstory of chestnut oak (*Quercus prinus*), scarlet oak (*Q. coccinea*) and blackgum *(Nyssa sylvatica*), and a shrub layer of dense mountain laurel (*Kalmia latifolia*). Previous research suggests that restoration of these communities can be accomplished with high-intensity fires that open the forest canopy and expose mineral soil. Three recent studies examined plant-community response to high-intensity prescribed fires. A series of corollary studies help to 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. Post-burn duff was deep and did not vary by fire intensity. We observed sufficient seedling densities to restore pine-dominated stands after all but the highest intensity fires. Many seedlings survived the first growing season as their roots penetrated duff to reach mineral soil. Hardwood rootstocks resprouted on sites treated with all fire intensities and may out-compete pine seedlings for available resources. 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, but additional research is needed.

Introduction

Table Mountain pine (*Pinus pungens*) and pitch pine (*P. rigida*) are ridgetop Appalachian endemics that historically were maintained by lightning- and human-ignited fires. Stands of Table Mountain and pitch pines present on the landscape today were established by fires, logging, insects, and diseases that occurred in the early twentieth century, the most recent landscape-scale disturbances. Stand-replacing fires have been nearly absent in the region since then (Williams 1998). Sutherland and others (1995) found a Table Mountain pine community in Virginia that was maintained by major fires occurring approximately every 10 years until the 1940's. Fire suppression and lack of other disturbance have allowed ridgetop pine communities to succeed to hardwood dominance and closed understories (Williams and Johnson 1992, Sutherland and others 1995, Turrill 1998, Williams 1998). As a result of these changes in dominance and structure, Table Mountain/pitch pine woodlands are recognized by the Southern Appalachian Assessment as one of thirty-one rare communities in the Southern Appalachian Mountains (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 that remove the forest canopy and expose mineral soil will help ensure successful regeneration. Zobel (1969) found that serotinous cones opened in lightly burned areas, but that seedlings survived only where fires killed overstory trees 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 canopy was open and mineral soil exposed. 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 with thin litter layers (<1.5 in.) and where the canopy was more open than in surrounding stands. Such microsites usually were created by ice storms (Williams 1998).

Many ridgetop pine stands are located on National Forest System land and National Parks, where prescribed burning is possible and encouraged. Although many National Forest and National Park land management plans prescribe high-intensity fire for ridgetop pine communities, carrying out such burns is difficult (Turrill 1998). Such prescriptions provide a narrow window of opportunity and raise questions about worker safety and smoke management (Waldrop and Brose 1999). In addition, some land managers avoid using high-intensity fires because of the perceived risk of damaging marketable hardwoods and the inability 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) suggested that Table Mountain/pitch pine stands are in decline as a result of fire suppression policies and inadequate understanding of the species regeneration biology. To date, only three studies have conducted prescribed burns to better understand the conditions necessary for pine regeneration. Together, these three studies examine community response to varying degrees of fire intensity, as well as seedling establishment in varying types of microhabitat. This paper examines the results of

---

[1] USDA Forest Service, Southern Research Station, Clemson, SC

[2] School of Public and Environmental Affairs, Indiana University, Bloomington, IN

[3] USDA Forest Service, Northeastern Research Station, Warren, PA

[4] USDA Forest Service, Southern Research Station, Otto, NC

[5] Department of Forestry, Wildlife and Fisheries, University of Tennessee, Knoxville, TN

[6] Clemson University, Department of Forest Resources, Clemson, SC

those studies to evaluate the fully open canopy and exposed mineral soil conditions generally accepted as necessary to regenerate ridgetop pines.

Current Research on Stand-replacement Prescribed Burning

Effects of Fire Intensity on Table Mountain/ Pitch Pine Regeneration

Three studies have examined the response of Table Mountain pine and pitch pine stands to stand-replacement prescribed fire: Turrill (1998), Waldrop and Brose (1999), and Elliott and others (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 an evaluation of the amount of pine regeneration under natural conditions.

Several corollary 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 shade and duff on seedling establishment. Ongoing studies include the dendrochronology of ridgetop pine stands across the Southern Appalachians, seed biology of Table Mountain Pine, and mycorrhizal associations in burned Table Mountain pine stands. We will discuss the preliminary results of each.

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 study stands was 123.0 ft^2 per ac. Hardwoods made up 98.8 ft^2 of this total and pines the remaining 38.8 ft^2. Chestnut oak was the predominant hardwood and almost all pines were Table Mountain pine. USDA Forest Service personnel conducted a stand-replacement prescribed fire on a 850-ac unit in April 1997. The burn area included 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 fire was large enough and its intensity varied enough to allow comparisons of regeneration success among areas burned at different intensities. This ongoing study will include four additional burns: in Georgia, South Carolina, and Tennessee during late winter 2000 or the winter of 2000-2001.

Turrill (1998) studied a 7.5-ac prescribed fire on the Grandfather Ranger District of the Pisgah National Forest. The stand's mean total basal area was 140.7^2 ft per ac prior to the burn. Hardwoods comprised 37.9 ft^2 per ac, and pines 102.8 ft^2 per ac. Blackgum was the predominant hardwood. The pine component was 51 percent Table Mountain pine, 39 percent pitch pine, and 10 percent Virginia pine (*P. virginiana*). USDA Forest Service crews used a combined ring and head fire technique to burn the stand in May 1996.

Elliott and others (1999) studied a roughly 750-ac burn on Wine Springs Creek on the Nantahala National Forest in western North Carolina. The ridgetop community was dominated by pitch pine, chestnut oak, scarlet oak, and red maple, which comprised 49, 19, 8, and 8 percent of the total basal area, respectively. This south-facing burn unit was ignited by helicopter in April 1995 in a pattern to create a mosaic of fire intensities. Low intensity fire occurred on the lower slopes and flames reached into the crowns of trees along the ridgetop.

Stands burned for Turrill (1998), Waldrop and Brose (1999), and Elliott and others (1999) contained dense mountain laurel shrub layers. Post-burn observations in both study areas were completed 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, while Turrill (1998) and Elliott and others (1999) observed only medium-low intensity. Waldrop and Brose (1999) give a detailed description of the discriminant functions used to classify fire intensity, which generally can be described 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- and medium-high-intensity fires reduced canopy cover, leaving only 4.4 ft^2 and 7.0 ft^2 per acre of basal area, respectively (table 1). 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.

Medium-low- and low-intensity fires reduced canopy cover (table 1), but residual basal area may be too high in all three studies to allow stand replacement. Medium-low-intensity fires reduced basal area to 48.3 ft^2 per acre in Waldrop and Brose (1999), 112.8 ft^2 per acre in Turrill (1998), and to 82.1 ft^2 per acre in Elliott and others (1999). Low-intensity fires had little effect on basal area, leaving 98.9 ft^2 per acre. Mortality was greatest in lower d.b.h. classes (< 6 in. d.b.h.) following fires of medium-low and low-intensity. Shade from surviving trees may have prevented pine seedling survival.

Prolific hardwood sprouting was observed following fires of all intensities (table 1). Waldrop and Brose (1999) reported that all intensities top-killed the mountain laurel shrub layer; Turrill (1998) and Elliott and others (1999) reported that medium-low intensity fires did so. Generally, under all fire intensities there were over 10,000 stems per acre, and they 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

Table 1.—Characteristics of Table Mountain and pitch pine stands one year following stand replacement prescribed burning

	Fire Intensity Level				
Variable	Low	Medium Low	Medium High	High	Source
Pine basal area (ft^2/ac)	25.7	26.1 94.1 42.1	4.8	0.0	Waldrop and Brose (1999) Turrill (1998) Elliott and others (1999)
Hardwood basal area (ft^2/ac)	73.2	22.2 18.7 40.0	2.2	4.4	Waldrop and Brose (1999) Turrill (1998) Elliott and others (1999)
Total basal area (ft^2/ac) 82.1	98.9	48.3 112.8	7.0	4.4	Waldrop and Brose (1999) Turrill (1998) Elliott and others (1999)
Hardwood sprouts (num/ac)	13,016	15,130 929 12,354	10,765	12,768	Waldrop and Brose (1999) Turrill (1998) Elliott and others (1999)
Pine seedlings (num/ac)	5,608	9,130 3,117 ~300	3,650	1,396	Waldrop and Brose (1999) Turrill (1998) Elliott and others (1999)

may be necessary to reduce hardwood abundance while maintaining a seed source among large pines.

Post-burn counts of Table Mountain pine seedlings reported by Waldrop and Brose (1999) and Turrill (1998) suggest that fires were of sufficient intensity to open serotinous cones throughout the burn unit, even in areas of low-intensity burns. Post-burn pine density ranged from 1,400 to more than 9,000 stems per acre (table 1). An unexpected result was that the lowest pine densities 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.

Although plots in high-intensity burn areas had fewer seedlings, if they are well dispersed, the 1,396 seedlings per acre present in those areas should create pine-dominated stands. However, Table Mountain pine seedlings were found at only 51 percent of the sampling points, indicating that portions of burned areas had no pine regeneration. Hardwoods may dominate such areas. Plots in areas burned at medium-high intensity also indicated low pine stocking (64 percent). If seedlings receive enough sunlight, pine density and stocking levels in those areas burned at low and medium-low intensities should be sufficient to create pine-dominated stands.

Pitch pine does not have serotinous cones in the region studied by Elliott and others (1999). Therefore, managers were concerned that a winter or spring burn would consume seeds already on the ground. In this study, over 1,100 pitch pine seedlings per acre were present the year after burning, indicating that the seed source was still viable. Among those seedlings, however, fewer than 300 per acre survived. The authors suggested that mortality was due to shading by the surviving overstory, competition from sprouts, and a thick duff layer that prevented seedling roots from reaching mineral soil.

Pine seedlings regenerated on relatively thick duff following all fire intensities in the Waldrop and Brose (1999) study. Total litter and duff depth remaining after fires was 2.1, 1.5, 2.5, and 2.6 in. for the low-, medium-low-, medium-high-, and high-intensity fires, respectively. The percentage of seedlings with roots penetrating 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 3.6 in. 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 up to 3.0 in., indicating that duff removal may not be as critical as once thought. However, seedling survival was not tracked beyond the first growing season in either study.

Corollary Studies

Dendrochronology

Little is known about the disturbance history of Table Mountain/pitch 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. The dendrochronology study of Sutherland and others (1995) provides valuable insight to fire frequency and stand dynamics for one Virginia site. A similar study is being done by Brose, Tainter, and Waldrop

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

Age Class (yrs)	n	Pct of Sampled Trees
1-50	0	0
51-75	9	33
76-100	9	33
101-125	3	11
125-158	6	22

(unpublished study plan) in conjunction with the study sites reported by Waldrop and Brose (1999). Cores have been extracted from overstory trees and understory trees and shrubs in two burn units in Georgia, two in South Carolina, and one in Tennessee.

A preliminary analysis of stand dynamics in the two Georgia units suggests a history of frequent disturbance that lasted until the 1950's (table 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 (table 2) indicates that pines were regenerating from the 1850's through the 1950's, and that these stands were relatively open. Well-established fire suppression policies in the 1950's allowed the shrub layer to become dominant and prevent continuing pine regeneration. Restoration of these stands will likely require some means to remove shrubs and competing hardwoods.

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, Rennie, and Waldrop (unpublished study plan) will help identify stands that have an adequate seed source for regeneration. Such studies will help managers determine the abundance and viability of seed from a range of tree ages, as well as from cones of different ages. Preliminary results for seed viability are given in table 3. Seed viability was moderate, generally between 20 and 50 percent, from cones of all ages and from trees older than 10 years. 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 considered as 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.

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. Both ectomycorrhizae and vesicular-arbuscular mycorrhizae may be necessary for survival of Table Mountain pine seedlings, but their respective roles in Table Mountain pine regeneration and their responses to high-intensity fires have not been considered. Neary and others (2000) suggested that fire intensity strongly affects the degree and duration of reduced soil microbial activity. Neary and others (2000) also suggested that after a period of low activity, microbial populations increase in areas burned at high intensity to a level much higher than in unburned areas, or in areas burned at low intensity. This pattern may suggest that Table Mountain pine seedlings will not develop for some time after high-intensity burning; but that they may eventually benefit from increased microbial populations. If so, prescribed burns should be conducted far enough in advance of spring germination to allow these populations to recover.

An ongoing study by Ellis, Tainter, and Waldrop (unpublished study plan) is examining the relationship of fire intensity to mycorrhizal development on Table Mountain pine roots. First- and second-year seedlings were collected on 22 plots established for the Waldrop and Brose (1999) study. Seedling root biomass was quantified, ectomycorrhizal root tips were characterized, and their presence compared by seedling age, slope aspect, and microsite. Sites burned at low and medium-low intensities had twice as many mycorrhizal root tips (40 percent) than sites burned with medium high and high intensities (22 percent). Two-year-old seedlings had twice as many mycorrhizal root tips than one-year-old seedlings. Seedlings on slopes of western aspect had twice as many mycorrhizal root tips than those on

Table 3.—Percent viability of Table Mountain pine seed by tree age and cone age within a tree

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

eastern aspects. Based on morphological and histological examinations of mycorrhizal root tips, *Pisolithus tinctorius*, *Suillus granulatus*, and *Cenococcum* spp. were identified as the predominant symbionts. Although these results are preliminary, they may indicate that the very high-intensity fires had adverse effects on mycorrhizal development, thus reducing pine regeneration success.

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, 2, and 4 in.; and shade levels included 0, 30, 63, and 85 percent shade. Table Mountain pine seeds were collected on the Chattahoochee National Forest in Georgia. Soil and duff were collected from a recently burned Table Mountain pine stand on the Sumter National Forest, South Carolina. Seeds were germinated and allowed to grow under these conditions for 3 months. We compared survival of seedlings grown in the greenhouse to field seedling survival in the burn described by Waldrop and Brose (1999).

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 2-in. duff than in bare soil or 4-in. duff. This pattern remained constant for all except the 0-shade category. In 0 shade, stem densities in pots with 2 in. of duff were equal to stem densities in pots without duff. Without shade, the mulching effect of a 2-in. 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 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.

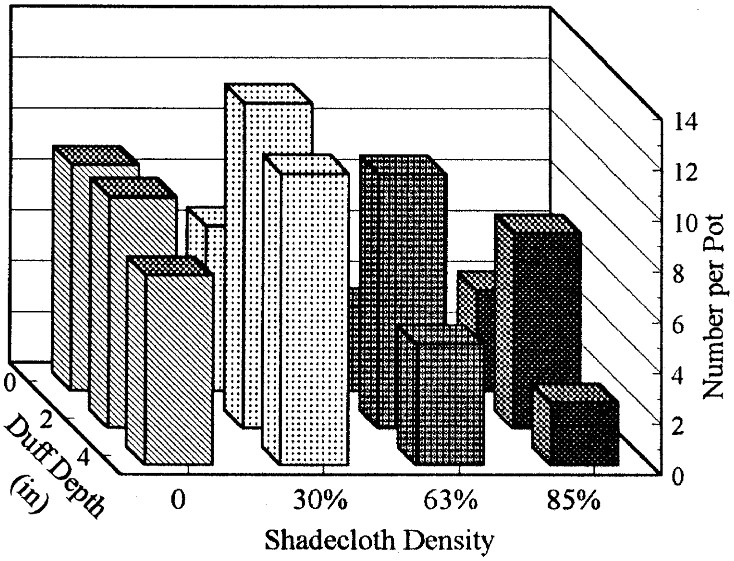

Figure 1.—Seedling density per pot after the 90-day greenhouse study for all combinations of shade level and duff depth.

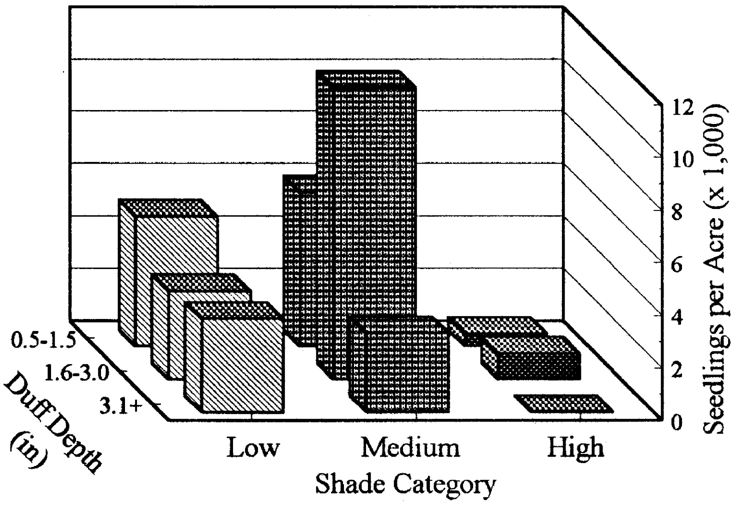

Figure 2.—Seedling density in Georgia and South Carolina burn units at the end of one growing season for all combinations of shade and duff depth categories.

If germination and survival in the field 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 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 than did the high-shade category. Under high shade, stem density was less than 1,000 seedlings per acre at all duff depths, 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 over 3 inches of duff to over 11,000 stems per acre under medium shade and 1.6 to 3.0 inches of duff. Each of these stem densities probably exceeds the minimum needed to regenerate the stand.

The moderate levels of shade and duff that this study suggests are 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 could maintain an overstory and seed source while reducing the duff without exposing mineral soil.

Conclusions

The three studies described here represent the first attempts to restore ridgetop pine communities in the Southern Appalachians with prescribed stand replacement fires. Such fires have been 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 needed to open serotinous cones; and they reduce thick duff layers or expose mineral soil. However, none of the fires observed in these studies should be considered successful for replacing older stands of mixed pines and hardwoods with newly regenerated stands of pines. Low-intensity fires observed by Waldrop and Brose (1999) and medium-low intensity fires observed in all three studies failed to kill more than a few overstory trees. High intensity fires killed most overstory trees but had few pine seedlings. Medium-high fires provided abundant overstory mortality and pine regeneration. However, fires of all intensities failed to control competition from hardwood and shrub sprouts.

Competition and shading from hardwoods and shrubs that sprout after burning may inhibit the development of a pine-dominated stand. Post-fire sprouting occurred more frequently in hardwood tree species (red maple, chestnut oak, and scarlet oak) than in shrub species (mountain laurel). The ability of Table Mountain and pitch pine seedlings to compete with the regeneration of other species is unknown. Frequent burning may be necessary to reduce hardwood sprout vigor.

The corollary studies presented here provide indirect evidence that ridgetop pine communities may be restored by frequent burning. 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. This study also shows that very young trees produce viable seed, suggesting an adaptation to frequent burning. 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. Moderate levels of shade with some duff present were optimum for seedling survival, both in the greenhouse and in the field. These conditions may have been common in pre-1950's stands that burned often. Thick duff was a barrier to seedling development in all field studies but seedling roots can penetrate duff up to 3 inches thick.

The 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 stand 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. Low-intensity fires also decrease erosion potential on steep slopes and loss of site productivity.

There is still much to learn about restoring ridgetop pine stands. If seedlings continue to survive among sprout competition, a single medium-high intensity fire may prove sufficient. However, these results were drawn from studies which tracked seedling survival and overstory mortality for only one growing season. More research is necessary before definitive fire plans can be developed for ridgetop pine communities. These 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. Such fires should be conducted so as to control hardwood and shrub sprouting while maintaining healthy overstory pines as a seed source. Serotinous cones can open with the low-intensity fires (Zobel 1969, Waldrop and Brose 1999), indicating that the reduced fuel loads after multiple burns would not reduce fire intensity too much to allow cones to open.

Many questions remain about the ecology of Table Mountain and pitch pines. In particular, the competitive ability of these species is unknown. Physical, chemical, and biological properties of soils in ridgetop stands 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; so alternative management strategies may also improve regeneration.

Acknowledgment

Partial funding for the research described here was awarded by the Department of Interior/Department of Agriculture, Forest Service Interagency Joint Fire Science Program.

Literature Cited

Elliott, Katherine J.; Hendrick, Ronald L.; Major, Amy E.; Vose, James M.; Swank, Wayne T. 1999. **Vegetation dynamics after a prescribed fire in the southern Appalachians.** Forest Ecology and Management. 114: 119-213.

Neary, D.G.; DeBano, L.F.; Ffolliott, P.F. 2000. **Fire impacts on forest soils: a comparison to mechanical and chemical site preparation.** In: Moser, W. Keith., ed. Proceedings of the 21st Tall Timbers Fire Ecology Conference; 1998 April 14-16; Tallahassee, FL. Tall Timbers Research, Inc. (In press).

Sanders, Greg L. 1992. **The role of fire in the regeneration of Table Mountain Pine in the Southern Appalachian Mountains.** Knoxville, TN: The University of Tennessee, Knoxville. 123 p. Thesis.

Southern Appalachian Man and the Biosphere (SAMAB). 1996. **The Southern Appalachian Assessment Terrestrial Technical Report.** Report 5 of 5. Atlanta: USDA Forest Service, Southern Region.

Sutherland, E.K.; Grissino-Mayer, H.; Woodhouse, G.A.; Covington., W.W.; Horn, S.; Huckaby, L.; Kerr, R.; Kush, J.; Moore, M.; and Plumb, T. 1995. **Two centuries of fire in a southwestern Virginia *Pinus pungens* community.** In: Inventory and management techniques in the context of catastrophic events: altered states of the forest. Hypertext Proceedings, University Park, Pennsylvania State University, Center for Statistical Ecology and Environmental Statistics.

Turrill, Nicole L. 1998. **Using prescribed fire to regenerate *Pinus echinata*, *P. pungens*, and *P. rigida* communities in the Southern Appalachian Mountains.** Knoxville, TN: The University of Tennessee, Knoxville. 207 p. Dissertation.

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

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

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

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

Williams, Charles E.; Johnson, W. Carter. 1992. **Factors affecting recruitment of *Pinus pungens* in the southern Appalachian Mountains.** Canadian Journal of Forest Research. 22: 878-887.

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