Fire and the Ecology of Table Mountain Pine

Thomas A. Waldrop, Patrick H. Brose, and Nicole Turrill Welch

Waldrop, Thomas A.; Brose, Patrick H.; Welch, Nicole Turrill. 2007. Fire and the Ecology of Table Mountain Pine. Chapter for internet-based fire encyclopedia.
http://fire.forestencyclopedia.net/

Abstract

Table Mountain pine (*Pinus pungens*), a southeastern endemic, grows on ridge tops and south facing slopes of the Appalachian Mountains. Silvical characteristics, such as serotinous cones and shade intolerance, suggest that stands of this species were created by fire. Dendrochronology evidence suggests these stands were historically created by large-scale disturbances and maintained by frequent low-intensity fires. Today, most stands are entering later-seral stages with pines being replaced by oaks (*Quercus* sp.) in the overstory and mountain laurel (*Kalmia latifolia*) in the shrub layer. Recent research has focused on methods of using prescribed fire to restore these stands. High intensity stand replacement fires can be successful but frequent low-intensity fires may be equally successful and more practical. Future research should focus on ecological impacts of fires of varying intensity and impacts of continued fire exclusion.

Community

Table Mountain pine stands occur from central Pennsylvania to northeast Georgia. These stands are generally small, < 20 ha, and found on ridges with thin, dry soils with southern and western aspects at elevations ranging from 300 to 1200 m (Zobel 1969). Geographic and site requirements restrict Table Mountain pine stands primarily to public lands where prescribed burning for ecosystem restoration can be practiced (Welch et al. 2000). Williams (1998) stated that Table Mountain pine stands are in decline as a result of fire suppression and inadequate understanding of the species= regeneration biology.

Throughout the region, stands in which Table Mountain pine occur are entering later seral stages where pines are beginning to be dominated by oaks (particularly chestnut oak, *Quercus prinus*) and hickories (*Carya* spp.). 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). The most common pine associated with these stands is pitch pine (*P. rigida*.) but shortleaf pine (*P. echinata*.) and Eastern white pine (*P. strobus*) can be present. The shrub layer is predominately mountain laurel (*Kalmia latifolia*), while galax (*Galax* spp.), blueberries (*Vaccinium* spp.), and huckleberries (*Gaylusacia* spp.) are common in the herb layer (Zobel 1969, Williams 1998, Newell and Peet 1998, Turrill et al., 1997).

No threatened or endangered plants are strictly associated with Table Mountain pine stands. However, smooth coneflower (*Echinacea laevigata*), a federally-listed perennial herb, has been found to coexist with Table Mountain pine in South Carolina (Emanuel and Waldrop 1995). Rare plants restricted to xeric pine and pine/oak forests include round-leaved service berry (*Amelanchier sanquinea*), branched whitlow grass (*Draba ramosissima*) and witch-alder (*Fothergilla major*) (Hessl and Spakman 1996). Hessl and Spakman (1996) suggest that Heller's blazing star (*Liatris helleri*), Peter's Mountain mallow (*Iliamna corei*), white irisette (*Sisyrinchium dichotomum),* and running buffalo clover (*Trifolium reflexum*) depend upon xeric montane woods.

Table Mountain pine has numerous adaptations that allow it to survive a fire or to regenerate after a fire. The species is shade intolerant and has serotinous cones, which suggests that fire may be needed to regenerate this species. Microsite conditions needed for seedling establishment are similar to those created by fire. Adaptations include: serotinous cones, black-colored seed, prolific cone production, thick flaky bark, self pruning of lower limbs, and cone production at an early age. Cones persist in the crown with viable seed for 5 to 10 years.

Fire Ecology

Fire in the Appalachians.

Ecological and meteorological evidence suggests that lightning-caused fires were a major environmental force shaping the vegetation of the southern Appalachians for millions of years (Van Lear and Waldrop 1989). Lightning served as a mutagenic agent and as a factor in natural selection that forced species to adapt or perish. The frequency of fires increased dramatically upon the arrival of Native Americans in the southern Appalachians about 10,000 years ago. These early Native Americans were hunters and gatherers, using fire to improve food abundance. They began land clearing for agriculture around 800 to 1000 A.D., when corn and beans were first cultivated in the southeastern United States. Regular burning created large open meadows with widely spaced trees and abundant wildlife.

Table Mountain pine communities were once maintained by frequent low intensity fires ignited by both lightning and anthropogenic sources. These fires burned on average every 10 to 12 years from the 1850's until the late 1930's (Harmon 1982). Sutherland et al. (1995) used dendrochronology techniques to develop the fire history of three Table Mountain pine stands in southwestern Virginia. They found that fires occurred periodically during the 1800's and the first half of the 20th century with a mean fire return interval of 9 to 11 years. Age distribution of the pines was bimodal. The vast majority of the trees were established in the mid-1850's and again in late-1930's, suggesting an intense fire in the early 1850's and early 1930's.

With frequent burning, Table Mountain pine stands were probably open with little understory development, which allowed pine regeneration. Since that time, fire suppression prevented pine regeneration and has allowed succession to oaks and other hardwoods. As the pines continue to die, fuel loading is increasing to levels of concern. Also, decomposition rates are slow allowing fuels on the forest floor to become as much as 6 to 8 inches deep (Robichaud and Waldrop 1994).

Prescribed burning was rarely used in the southern Appalachian Mountains until the mid 1980's. At that time, site preparation burns were being tested (Phillips and Abercrombie 1987). Other renewed interests have dealt with restoration of habitat for endangered species and declining communities. In the 1990's, s limited amount of prescribed burning was attempted to restore habitat for smooth coneflower (*Echinacea laevigata*) (Emmanuel et al. 1995), Table Mountain pine (*Pinus pungens*) (Waldrop and Brose 1999, Welch et al. 2000), pitch pine (*P. rigida*) (Elliott et al. 1999) and grassy balds (Barden 1978). Prescribed fires have also been tested to improve oak regeneration on mesic Appalachian sites (Loftis et al. 1993, Brose and Van Lear 1998).

Fire Effects

Vegetation

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) 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 (<4 cm) and where the canopy was more open than in surrounding stands. Such microsites were usually created by ice storms (Williams 1998). Also, Williams et al. (1990) found that hardwood litter creates barriers to pine seedling establishment.

Stand-replacement prescribed burning has been studied at 3 separate burn units in the southern Appalachian Mountains including the Grandfather Ranger District, Pisgah National Forest (Welch et al. 2000); Tallulah Ranger District, Chattahoochee National Forest (Waldrop and Brose 1999); 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 (Waldrop et al. 2002). These burn units will be referred to as the Grandfather, Tallulah, and Buzzard's Roost burns, respectively. The burns conducted for all 3 studies varied in their effects on opening the forest canopy and removing litter and duff. Impacts on vegetation were largely a function of fire intensity. The prescriptions applied in these studies produced 4 fire intensities defined by Waldrop and Brose (1999): low, medium-low, medium-high, and high. Briefly, these categories were described as subcanopy ground fires (low), subcanopy ground fires with hot spots where jackpot fuels occurred (medium low), flames reaching into overstory tree crowns (medium high), and flames equal to or exceeding tree height (high). All intensities were observed in the Tallulah burn and all but high intensity was observed in the Buzzard's Roost burn. Only the medium-low intensity was observed at the Grandfather burn.

High- and medium-high intensity fires were the only ones of sufficient intensity to kill enough of the overstory to achieve conditions of stand replacement. High-intensity fires in the Tallulah burn killed nearly all overstory trees, leaving only 1.0 m^2 of basal area per ha (Table 1). Medium-high intensity fires at Tallulah and Buzzard's Roost were also effective at killing overstory trees, leaving only 1.6 and 7.6 m^2 per ha of basal area, respectively. Mortality was high across 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 3 studies to allow sufficient pine regeneration. Medium-low-intensity fires reduced basal area to 11.1 m^2 per ha at the Tallulah burn 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.

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 the burn units, even in areas of low-intensity. Post-burn pine densities ranged from 3,448 to more than 22,500 stems per ha (Table 1) in these two units. 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.

Although plots in high-intensity burn areas had fewer seedlings, if they are well dispersed, the 3,448 seedlings per ha present in those areas should create pine-dominated stands. However, Table Mountain pine seedlings were found at only 51 % of the sampling points, indicating that portions of burned areas had no pine regeneration. Hardwoods will likely dominate such areas. Plots in areas burned at medium-high intensity also had low pine stocking (64 percent) and may become dominated by hardwood sprouts. Areas burned at medium low and low intensity should have sufficient numbers of seedlings to create pine-dominated stands if they receive sufficient sunlight.

Prolific hardwood sprouting was observed following fires of all intensities (Table 1). Under all fire intensities there were over 20,000 rapidly growing stems per ha one year after burning. Competition from these sprouts may eliminate any pine regeneration after a fire of any intensity. This result suggests that multiple, low-intensity fires may be necessary to reduce hardwood abundance while maintaining a seed source among large pines. Continued measurement of the stands created in these studies is needed to provide management recommendations for post-burn cultural treatments.

Table 1. Characteristics of Table Mountain pine stands during the year following stand-replacement prescribed burning.

Variable	Fire Intensity Level: Low	Med-Low	Med-High	High	Fire
Pine basal	5.9	6.0	1.1	0.0	Tallulah[1]
area (m^2/ha)	8.4	6.4	0.0		Buzzard's Roost[2]
		21.6			Grandfather[3]
Hardwood	16.8	5.1	0.5	1.0	Tallulah
basal area	11.8	4.2	7.6		Buzzard's Roost
(m^2/ha)		4.3			Grandfather
Total basal	22.7	11.1	1.6	1.0	Tallulah
area (m^2/ha)	19.2	10.8	7.6		Buzzard's Roost
		25.9			Grandfather
Hardwood	32,150	37,371	26,590	31,537	Tallulah
sprouts	20,553	25,582	17,505		Buzzard's Roost
(num/ha)		2,295			Grandfather
Pine seedlings	13,852	22,551	9,016	3,448	Tallulah
(num/ha)	551	995	961		Buzzard's Roost
		7,699			Grandfather

[1]Waldrop and Brose (1999)
[2]Waldrop et al. (2002)
[3]Welch et al. (2000)

Soil and Water

No studies have been completed that directly address the impacts of fire in Table Mountain pine stands on soil and water quality. Studies by Zobel (1969), Williams and Johnson (1992), and Williams et al. (1990) document that wildfires exposed mineral soil and caused erosion in some areas. However, other areas had a duff layer thick enough to interfere with Table Mountain pine regeneration. Waldrop and Brose (1999) examined differences in forest floor characteristics by fire intensity after a prescribed fire. Post-burn duff depth was not related to fire intensity and averaged about 5 cm throughout the burn unit. Soil exposure was minimal. Rainfall the day after burning probably prevented smoldering of duff and prevented erosion.

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. Ellis et al. (2002) examined the relationship of fire intensity to mycorrhizal development on Table Mountain pine roots. *Pisolithus tinctorius*, *Suillus granulatus*, and *Cenococcum* spp. were the predominant symbionts that formed 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 %) as did seedlings from sites burned at high intensities (22 %), 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^{o}C and almost absent after exposure to temperatures up to 80^{o}C. These results suggest that poor pine regeneration could result from poor formation of mycorrhizal root tips after high intensity fires. Frequent low-intensity burning would be one means of avoiding loss of mycorrhizal fungi.

Effects of Fire Suppression

Shifts in Species Composition

Dendrochronology studies initiated by Sutherland et al. (1995), Armbrister (2002), and Brose et al. (2002) show that many contemporary Table Mountain pine stands originated after major disturbances such as fire, tropical storms, and clearcutting throughout the 19th and early 20th centuries. Many were maintained by frequent low-intensity fires that kept stands open and allowed frequent regeneration of Table Mountain pine. Fire exclusion and the cessation of grazing began in the 1930's to 1950's which allowed succession to hardwood-dominated stands. Turrill et al. (1997) and Brose et al. (2002) found that pines were being replaced by oaks, particularly chestnut oak (*Quercus prinus*). In many areas, chestnut oak became the dominant species as pines died. The shrub layer is dominated by mountain laurel (*Kalmia latifolia*) which originated in the 1950's and, now, is often too thick to allow pine regeneration. Both studies failed to find pine regeneration. Turrill et al. (1997) found that pine-hardwood stands covered 66 percent of a sample area in the southern Appalachians, suggesting that pine stands are succeeding to hardwood-dominated stands throughout the southern end of the species' range.

Altered Fire Behavior

The largest source of fuel in table-mountain-pitch pine stands is the shrub layer, consisting almost entirely of mountain laurel (*Kalmia latifolia*). This species occurs in dense thickets, with cover almost always over 50% (Whittaker 1956) and commonly reaching 100%. Presence of heavy mountain laurel cover creates two problems for regenerating table mountain-pitch pine stands. First, light levels below the mountain laurel canopy are approximately 2% of full sunlight, well below optimum levels for seedling growth (Chapman 1950). Removal of this shrub layer by fire would allow sunlight to reach the forest floor. Second, fire intensity is difficult to control where mountain laurel density is high. Because of the heavy shade created by mountain laurel, the forest floor is often too moist to burn. Fires which have been prescribed for open stand conditions generally extinguish when entering a mountain laurel thicket. On days when fuels are dry enough to ignite mountain laurel, fire intensities can become extreme. These thickets act as vertical fuels, which carry flames into and above the crowns of overstory trees. While intense fires may be necessary to kill overstory pines and hardwoods, these fires have a narrow burning window and raise concerns about worker safety and smoke management.

Waldrop and Brose (1999) found that mountain laurel cover strongly affected the intensity of a prescribed fire and limited successful pine regeneration. Where mountain laurel cover was high, flame lengths reached approximately twice the height of overstory trees but pine regeneration was significantly reduced. High intensity fires may have killed seeds, reduced mycorrhizal abundance, or promoted overland water flow which washed much of the seed source down slope. However, these factors have not been studied. These results suggest that wildfires, which historically maintained Table Mountain pine, could reach dangerously high intensities because of heavy mountain laurel cover, thus reducing table mountain pine and pitch pine abundance. Prescribed burning at low or moderate intensities may be necessary to reduce heavy fuel loads and successfully regenerate these fire dependent pines.

Research Gaps

Numerous researchers and managers have recognized that Table Mountain pine stands are disappearing throughout the Appalachian Mountains. However, the exact number, size, and location of remaining stands are unknown. A detailed inventory of Table Mountain pine stands, including a description of the successional stage, would help managers to determine priorities for restoration. In addition, no research has been conducted to identify ecosystem components, such as vegetation, wildlife or soil biota, that require the presence of Table Mountain pine. Each of these components may be impacted as overstory dominance changes from Table Mountain pine to hardwoods. Mountain laurel abundance is likely increasing in the absence of fire. This change has been shown to decrease pine regeneration and increase fire intensity (Waldrop and Brose 1999) but no information is available about how mountain laurel impacts other components of this community.

Prescribed Fire

Ecosystem Maintenance and Restoration

Vegetation

After decades of fire suppression, ridgetop pine communities of the Southern Appalachians are entering later seral stages and disappearing. They typically have Table Mountain pines (*Pinus pungens*) and pitch pines (*P. rigida*) in the overstory, which are being replaced by more shade-tolerant oaks. Previous research suggests that high-intensity stand-replacement fires are needed to restore these communities because they will open the forest canopy and expose mineral soil. However, this work was based on observations made after wildfires.

In a comparison of regeneration success after prescribed fires of varying intensity, high and medium-high intensity fires killed most overstory trees and provided adequate sunlight for pine seedlings (Waldrop and Brose 1999). Medium-low and low intensity fires did not kill overstory trees and left too much shade on the forest floor. Post-burn duff was deep and did not vary by fire intensity. Sufficient seedling densities to restore pine-dominated stands (< 9,000 per ha) occurred after all but the highest intensity fires. Many seedlings survived the first growing season as their roots penetrated duff up to 7.5 cm deep to reach mineral soil. Hardwood rootstocks sprouted on sites treated with all fire intensities and may out-compete pine seedlings without repeated fires.

Poor regeneration after high-intensity fires was unexpected because these fires were suggested by previous research. However, greenhouse and field studies of seedbed habitat showed that pine seedlings had better survival in the presence of low shade and thin duff than in full sunlight and with no duff (Mohr et al. 2002, Waldrop et al. 2000). These results suggest that high intensity fires reduce seedbed habitat quality by drying the site. Another study showed that high-intensity fires reduced mycorrhizal abundance and, therefore, limited moisture availability for germinants (Ellis et al. 2002). A study of seed biology showed that poor regeneration after high-intensity fires was not likely caused by a poor seed source (Gray et al. 2002). Rather, the fires may have consumed cones or killed seed.

Four studies provide evidence that ridgetop pine communities were historically created and maintained by multiple low-intensity fires rather than a single stand-replacement fire. A dendrochronology study shows that these stands are uneven aged with trees ranging from 50 to 150 years old (Brose et al. 2002). Pines regenerated frequently from approximately 1850 to 1950, probably due to open conditions maintained by low-intensity fires. Mountain laurel (*Kalmia latifolia*) became more common after 1950, probably due to fire exclusion. The seed biology study indicates that viable seed occur on trees as young as 5 years, suggesting an adaptation to frequent burning (Gray et al. 2002). A study of multiple low-intensity fires shows that ridgetop sites have open understories and begin to support pine regeneration after three low-intensity prescribed fires (Randles et al. 2002).

Pine regeneration can become established by single fires of relatively high intensity or multiple low-intensity fires, indicating that crown fires are too hot because they potentially damage the site. Medium-high intensity fires, which reach into the lower crowns of pines, are safer and provide abundant regeneration. Multiple low-intensity fires require a greater investment of time but better mimic historic burning regimes. This knowledge will allow a wider burning window and increase worker safety because severe weather conditions are not required for low-intensity fires. Because prescription guidelines developed by the above studies work are more conservative and safer, there will be a greater opportunity for prescribed burning to be accepted by the community and by land managers. Regeneration of these stands by means other than prescribed burning is unlikely because most stands are in remote locations and inaccessible to equipment.

Implementation

It is generally perceived that contemporary Table Mountain pine communities are legacies of the intense wildfire era of the early 20th century and are dependent on high-intensity crown fires for regeneration (Zobel 1969, Barden and Woods 1974, Sanders 1992, Williams 1998). This perspective is supported by several facts. Their almost exclusive occurrence on steep, dry, south- and west-facing ridges and upper slopes places them where fires moving uphill would reach their highest intensities (Zobel 1969, Sanders 1992, Williams 1998). The species has silvical characteristics, such as black seeds, cone serotiny, need for a mineral soil seed bed, and shade intolerance, indicative of pines that evolved under such conditions (Della-Bianca 1990). Some post-burn regeneration evaluations support this hypothesis as the most abundant and successful pine seedlings occurred where intense fires killed all the overstory and understory and removed the duff layer (Groeschl et al. 1992, Sanders 1992, Groeschl et al. 1993). Conversely, low-intensity fires that did not open the canopy and reduce duff thickness failed to adequately regenerate pitch and Table Mountain pine (Williams et al. 1990, Groeschl et al. 1993, Elliott et al. 1999, Welch et al. 2000).

However, evidence exists indicating that intense crown fires are not necessary and frequent, low-intensity surface fires may be the correct fire regime for this forest type. Table Mountain pine has characteristics such as thick, flaky bark, self-pruning of lower branches, and cone production at young age, that suggests the species evolved in a frequent, low-intensity surface fire regime (Della-Bianca 1990, Little and Garrett 1990). Cones of Table Mountain pine will open at temperatures as low as 30°C and the resins that seal the cones degrades after a few years (McIntyre 1929, Fraver 1992). Williams and Johnson (1992) reported that Table Mountain pine released seeds throughout the year with peak dissemination occurring in the spring and summer. The topographic location of Table Mountain pine stands would make them susceptible to lightning strikes and subsequent small, isolated fires (Barden and Woods 1974). Waldrop and Brose (1999) studied a variable-intensity prescribed fire conducted in 1997. They found that Table Mountain pine regenerated better in areas experiencing a moderate-intensity surface fire (partial canopy removal) than it did in the full sunlight created by a high-intensity crown fire. Also, roots of the new pine seedlings were capable of penetrating duff up to 7.5 cm thick. In a related study, Mohr et al. (2002) reported that Table Mountain pine seedlings survived better in partial shade on a 5 cm duff layer than they did in full sunlight on mineral soil.

Research Gaps

Several research projects have been completed to determine the type and intensity of prescribed fires that are needed to regenerate Table Mountain pine at the southern end of its range. These projects suggest that either a single stand replacement fire or multiple low intensity fires can be successful though both methods have limitations when relied upon solely. However, different prescribed burning techniques have not been tested in the central or northern portion of the species' range. Also, there are no guidelines for selecting stands for burning that have a high probability of producing successful regeneration. Factors such as cone production, seed viability, stand successional stage, overstory density, and shrub density may determine whether or not a particular stand can be regenerated with prescribed fire. This information would allow managers to prioritize stands for burning by identifying which are at the greatest risk.

Studies of prescribed fire impacts in Table Mountain pine communities have been limited to regeneration success. Prescribed fires have dramatic impacts on numerous components of other ecosystems including wildlife, soils, insects, diseases, and nutrient cycling. Impacts of prescribed fires should be studied for all ecosystem components in Table Mountain pine communities over a range of fire intensities.

Research to date has not has not been able to address management needs in the regenerated stands. Competition from sprouts of hardwoods or shrubs may become a major concern. Pines may need to be released from this competition by cutting, herbicide application, or understory burning. The techniques or need for these practices have not been addressed. Also, sites with Table Mountain pine regeneration are usually xeric and may not support rapid sprout growth. Study sites where Table Mountain pine regeneration has been successful should be followed for several years to address these questions.

Literature Cited

Barden, L.S. 1978. Regrowth of shrubs in grassy balds of the southern Appalachians after prescribed burning. Castanea 8(1-3):1-64.

Barden, L.S. and Woods, F.W. 1974. Characteristics of lightning fires in southern Appalachian forests. Tall Timbers Fire Ecology Conference 13: 345-361

Brose, Patrick H.; Tainter, Frank; Waldrop, Thomas A. 2002. Regeneration history of Table Mountain/pitch pine stands in two locations in the southern Appalachians. Pp. 296-301. In: Outcalt, Kenneth, ed. Proceedings eleventh biennial southern silvicultural research conference. 2001 March 20-22; Knoxville, TN: Gen. Tech. Rep. SRS-48; Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 pp.

Brose, P.H. and D.H. Van Lear. 1998. Responses of hardwood advance regeneration to seasonal prescribed fires in oak-dominated shelterwood cuts. Canadian Journal of Forest Research 28(1998): 331-339.

Chapman, G.L. 1950. The influence of mountain laurel undergrowth on environmental conditions and oak reproduction. Ph.D. Dissertation, Yale University, New Haven, Conn.

Della-Bianca, L. 1990. *Pinus pungens* Lamb., Table Mountain Pine. In: R.M. Burns and B.H. Honkala (Eds.), Silvics of North America. Volume 1, Conifers. U.S.D.A. Forest Service Agriculture Handbook 654.

Elliott, K.J., R.L. Hendrick, A.E. Major, J.M. Vose, and W.T. Swank. 1999. Vegetation dynamics after a prescribed fire in the southern Appalachians. Forest Ecology and Management 114:119-213.

Ellis, Lisa E.; Waldrop, Thomas A.; Tainter, Frank H. 2002. Ectomycorrhizae of Table Mountain pine (*Pinus pungens*). Pp. 128-131. In: Outcalt, Kenneth, ed. Proceedings eleventh biennial southern silvicultural research conference. 2001 March 20-22; Knoxville, TN: Gen. Tech. Rep. SRS-48; Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622pp

Emanuel, C.M.; T.A. Waldrop, J.L. Walker, and D.H. Van Lear. 1995. Silvicultural options for recovering the endangered smooth coneflower: preliminary results. pp. 32-35 In: Edwards, M. Boyd, ed. Proceedings of the eighth biennial southern silvicultural research conference. 1994 November 1-2; Auburn, AL: Gen. Tech. Rep. SRS-1; Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station.

Fraver, S. 1992. The insulating value of serotinous cones in protecting pitch pine (Pinus rigida) seeds from high temperatures. Journal of the Pennsylvania Academy of Science 65(3): 112-116.

Gray, Ellen; Rennie, John; Waldrop, Thomas. 2002. Patterns of seed production in Table Mountain pine *(Pinus pungens*). Pp. 302-305. In: Outcalt, Kenneth, ed. Proceedings eleventh biennial southern silvicultural research conference. 2001 March 20-22; Knoxville, TN: Gen. Tech. Rep. SRS-48; Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622pp.

Groeschl, D.A., Johnson, J.E., Smith, D.W. 1992. Early vegetative response to wildfire in a Table Mountain – pitch pine forest. International Journal of Wildland Fire 2(4): 177-184.

Groeschl, D.A., Johnson, J.E., Smith, D.W. 1993. Wildfire effects on forest floor and surface soil in a Table Mountain pine – pitch pine forest. International Journal of Wildland Fire 3(3): 149-154.

Harmon, M.E. 1982. Fire history of the westernmost portion of the Great Smoky Mountains National Park. Bulletin of the Torrey Botanical Club 109:74-79.

Hessl, A. and S. Spakman. 1996. Effects of fire on threatened and endangered plants: an annotated bibliography. USDI NBS Information and Technology Report 2.

Loftis, D.L., C.E. McGee, eds. 1993. Proceedings of Oak regeneration: serious problems, practical recommendations; 1992 September 8-10; Knoxville, TN: Gen. Tech. Rep. SE-84. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station.

McIntyre, A.C. 1929. A cone and seed study of mountain pine (Pinus pungens Lambert). American Journal of Botany 16:402-406.

Mohr, Helen H.; Waldrop, Thomas A.; Shelburne, Victor B. 2002. Optimal seedbed requirements for the regeneration of Table Mountain pine. Pp. 306-309. In: Outcalt, Kenneth, ed. Proceedings eleventh biennial southern silvicultural research conference. 2001 March 20-22; Knoxville, TN: Gen. Tech. Rep. SRS-48; Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622pp.

Newell, C.L. and R.K. Peet. 1998. Vegetation of Linville Gorge Wilderness, North Carolina. Castanea 63:275-322.

Phillips, D.R. and J.A. Abercrombie. 1987. Pine-hardwood mixtures-a new concept in regeneration. Southern Journal of Applied Forestry. 11(4)192-197.

Randles, R.B.; Van Lear, D.H.; Waldrop, Thomas A. 2002. Multiple low-intensity fires in Table Mountain and pitch pine communities: effects on vegetation and wildlife habitat. Pp. 114-118. In: Outcalt, Kenneth, ed. Proceedings eleventh biennial southern silvicultural research conference. 2001 March 20-22; Knoxville, TN: Gen. Tech. Rep. SRS-48; Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622pp.

Robichaud, P.R and T.A. Waldrop. 1994. A comparison of surface runoff and sediment yields from low- and high-severity site preparation burns. Water Res. Bull. 30:27-34.

Sanders, G.L. 1992. The role of fire in the regeneration of Table Mountain Pine in the southern Appalachian Mountains. Master's Thesis, The University of Tennessee, Knoxville, Tennessee.

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, C.A., Covington, W.W., Horn, S., Huckaby, L., Kerr, R., Kush, J., Moorte, M., 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. Hypertext Proceedings. 1993 June 21-24. University Park, PA. Pennsylvania State University, Center of Statistical Ecology and Environmental Statistics.

Turrill, N.L., E.R. Buckner, and T.A. Waldrop. 1997. *Pinus pungens* Lamb. (Table mountain pine): a threatened species without fire? In: J. Greenlee (Editor), Proceedings, Effects of Fire on Threatened and Endangered Species and Habitats. International Association of Wildland Fire. pp. 301-306.

Van Lear, D.H. and T.A. Waldrop. 1989. History, use, and effects of fire in the southern Appalachians. USDA Forest Service, Southeastern Forest Experiment Station, Gen. Tech. Rep. SE-54. 20 pp.

Waldrop, T.A. and P.H. Brose. 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.; Brose, Patrick H.; Welch, Nicole Turrill; Mohr, Helen H. 2002. Prescribed crown fires for regenerating Table Mountain pine stands: extreme or necessary? pp. 137-142. In: Outcalt, Kenneth, ed. Proceedings eleventh biennial southern silvicultural research conference. 2000 March 20-22; Knoxville, TN: Gen. Tech. Rep. SRS-48; Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 pp.

Waldrop, Thomas A.; Mohr, Helen H.; Brose, Patrick H.; and Baker, Richard B.. 1999. Seedbed requirements for regenerating Table Mountain pine with prescribed fire. pp 369-373. In: James D. Haywood, 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. 618 pp

Welch, N.T., T.A. Waldrop, and E.R. Buckner. 2000. Response of southern Appalachian Table Mountain pine (*Pinus pungens*) and pitch pine (*P. rigida*) stands to prescribed burning. Forest Ecology and Management 136(2000) 185-197.

Williams, C.E. 1998. History and status of Table Mountain pine - pitch pine forests of the southern Appalachian Mountains (USA). Natural Areas Journal 18(1): 81-90.

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

Williams, C.E. and W.C. Johnson. 1990. Age structure and the maintenance of Pinus pungens in pine-oak forests of southwestern Virginia. American Midland Naturalist 124:130-141.

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