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Fire and the origin of Table Mountain pine – pitch pine communities in the southern Appalachian Mountains, USA

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Abstract: The prevalence of stand-replacing fire in the formation of Table Mountain pine – pitch pine (*Pinus pungens* Lamb. and *Pinus rigida* Mill., respectively) communities was investigated with dendrochronological techniques. Nine stands in Georgia, South Carolina, and Tennessee were analyzed for age structure, species recruitment trends, and radial growth patterns to determine whether they had originated as a result of stand-replacing fires. The oldest pines date from the late 1700s or early 1800s. Continuous or frequent episodic pine regeneration from those times to the early to mid 1900s was evident at all sites. During the first half of the 20th century, all sites experienced large surges in pine regeneration. However, no clear evidence of stand-replacing wildfires could be definitively linked to these surges. Rather, the regeneration appeared to have been caused by noncatastrophic surface fires and canopy disturbances occurring together or by the cessation of a frequent fire regime. For the past 25–50 years, there has been little pine regeneration at any of the sites. Restoring the dual disturbance regime of periodic fires and canopy disturbances should help sustain Table Mountain pine – pitch pine communities in southern Appalachian Mountains landscapes.

Résumé : La prédominance des feux qui provoquent le remplacement des peuplements dans la formation des associations de pin à cônes piquants (*Pinus pungens* Lamb.) et de pin rigide (*Pinus rigida* Mill.) a été étudiée à l'aide de techniques dendrochronologiques. La structure d'âge, l'évolution du recrutement des espèces et les patrons de croissance radiale ont été analysés dans neuf peuplements situés en Georgie, en Caroline du Sud et au Tennessee pour déterminer si leur origine était due à un feu qui a provoqué la formation d'un nouveau peuplement ou non. Les plus vieux pins datent de la fin des années 1700 ou du début des années 1800. Depuis ce temps jusqu'au début et milieu des années 1900, toute les stations montrent des signes d'épisodes fréquents de régénération ou de régénération continue du pin. Durant la première moitié du 20e siècle, toutes les stations ont connu de fortes vagues de régénération du pin. Cependant, aucun indice clair ne permet de relier ces vagues à des feux qui auraient provoqué le remplacement des peuplements. Au contraire, des feux de surface non catastrophiques et des perturbations de la canopée survenues en même temps ou la cessation d'un régime de feux fréquents semblent avoir été responsables de la régénération. Il y a eu peu de régénération de pin dans toutes les stations au cours des 25 à 50 dernières années. La restauration du régime de double perturbation caractérisé par des feux périodiques et des perturbations du couvert devrait contribuer à maintenir les associations de pin à cônes piquants et de pin rigide dans le paysage des Appalaches méridionales.

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Introduction

The advent of ecosystem management has sparked interest in the restoration of uncommon plant communities for diversity. The Table Mountain pine (*Pinus pungens* Lamb.) – pitch pine (*Pinus rigida* Mill.) (TMPP) forests of the Appalachian Mountains region of eastern North America represent such a plant community. These unique forests provide a conifer component in an otherwise hardwood-dominated landscape. Zobel (1969) described TMPP sites as small (<20 ha), widely scattered (from southern Pennsylvania to northern Georgia), and restricted to dry, thin soils on south and west aspects at elevations between 300 and 1200 m a.s.l. These geographic and site restrictions place TMPP sites primarily on public lands, where ecosystem restoration can be pursued (Welch et al. 2000).

It is generally perceived that TMPP communities are largely dependent on infrequent, high-intensity crown fires for regeneration (Zobel 1969; Barden 1979; Sanders 1992; Williams 1998). This perspective is supported by several facts. The silvical characteristics of both species suggest evolution in a high-intensity fire regime. These characteristics include cone serotiny, dormant buds on bole and branches (pitch pine), black seeds (Table Mountain pine), shade intolerance, and the need for exposed seed beds for successful seedling establishment (Della-Bianca 1990; Little and Garrett 1990; Williams et al. 1990; Williams 1998). 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; Williams 1998). Research and postburn regeneration inventories indi-

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Table 1. Site characteristics of the nine Table Mountain pine – pitch pine study stands in Georgia, South Carolina, and Tennessee.

Site	Location (lat., long.)	Elevation (m a.s.l.)	Slope (%)	Aspect (°)	Soil series	Soil family
Georgia						
Big Ridge	34°52′00″N, 83°14′45″W	975–1100	10–40	90–225	Ashe sandy loam	Typic Dystrochrept
Lower Tallulah	34°51′30″N, 83°14′15″W	850–925	10–25	90–225	Ashe sandy loam	Typic Dystrochrept
Upper Tallulah	34°51′30″N, 83°14′15″W	975–1100	20–60	90–225	Ashe sandy loam	Typic Dystrochrept
South Carolina						
Buzzard Roost	34°46′00″N, 83°08′16″W	500–600	15–30	90–225	Walhalla sandy loam	Typic Hapludult
Poor Mountain	34°46′48″N, 83°08′50″W	500–600	5–20	90–270	Walhalla sandy loam	Typic Hapludult
Toxaway Ridge	34°42′00″N, 83°15′23″W	400–450	5–35	90–270	Evard sandy loam	Typic Hapludult
Tennessee						
Lower Gregory	35°32′62″N, 83°50′18″W	900–975	15–30	90–125	Ramsey silt loam	Mesic Dystrochrept
Middle Gregory	35°32′57″N, 83°50′45″W	925–1000	10–20	180–270	Ramsey silt loam	Mesic Dystrochrept
Upper Gregory	35°32′58″N, 83°50′51″W	975–1025	20–50	90–180	Ramsey silt loam	Mesic Dystrochrept

cated that the most abundant and successful pine seedlings occurred where intense fires had killed the overstory, removed the litter layer, and reduced the thickness of the O horizon (Williams et al. 1990; Williams and Johnson 1992; Groeschl et al. 1992, 1993; Sanders 1992).

However, recent research questions the necessity of an intense crown fire to initiate a TMPP community. Waldrop and Brose (1999) found that Table Mountain pine regenerated better in areas that had experienced a moderate-intensity surface fire (partial canopy removal) than it did in the full sunlight created by a high-intensity crown fire. Mohr et al. (2002) reported that Table Mountain pine seedlings survived better in partial shade on a 5 cm O horizon than they did in full sunlight on mineral soil.

A pine stand originating from a catastrophic fire has certain physical characteristics (Heinselman 1973; White 1985; Taylor 1993; Huff 1995; Taylor and Skinner 1998; Brown et al. 2000). It exhibits a unimodal age distribution: that is, most or all of the pine stems originated within a few years of each other. Few, if any, hardwood stems predate the fire. Residual pines, that is, those that predate the fire and survived it, show a strong moderate or major radial growth increase after the fire. However, they are likely scarred on the uphill side of the lower bole.

TMPP communities arising from stand-replacing fire should have these same characteristics, and dendrochronology can be used to test for this relationship. Armbrister (2002) found that the pine component of five TMPP stands in eastern Tennessee originated en masse (unimodal age structure) in the 1930s, suggesting stand-replacing wildfire. Williams and Johnson (1990) reported a unimodal age distribution for dominant Table Mountain pine in three TMPP stands in southwestern Virginia. Subsequently, Sutherland et al. (1995) found fire scars preceding establishment of these cohorts.

Our hypothesis was that infrequent, intense crown fires, not periodic, low- to moderate-intensity surface fires, were the key disturbance to initiating TMPP stands. To test this hypothesis, we conducted a dendrochronology study in 1999 that consisted of (1) determining the age structure of the pines and hardwoods; (2) documenting their recruitment dates; and (3) ascertaining whether fires coincided with the establishment of pine cohorts. Understanding how TMPP stands originated will aid resource professionals in managing southern Appalachian ecosystems to maintain and restore this unique forest community.

Methods

Study sites

Nine TMPP stands located in northern Georgia, western South Carolina, and eastern Tennessee were selected for the study. Stand selection criteria were as follows: (1) basal area of the main canopy was >50% Table Mountain pine; (2) site was capable of supporting hardwoods; and (3) fire scars were present. Because we were seeking evidence for past stand-replacing fires, we were not concerned about dissimilar disturbance histories (insect outbreaks, grazing, logging, or storms).

Three of the TMPP stands, Big Ridge, lower Tallulah, and upper Tallulah, were south of Rabun Bald, in the Chattahoochee National Forest, Georgia. Three more (upper, middle, and lower Gregory) were southeast of Cades Cove, in the Great Smoky Mountains National Park, Tennessee. Two stands, Buzzard Roost and Poor Mountain, were northwest of Walhalla, South Carolina, and the remaining one, Toxaway Ridge, was west of Holly Springs, South Carolina, in the Sumter National Forest.

The nine stands had similar physical characteristics (Table 1). All were ridges or hilltops with a southerly aspect. The accompanying side slopes were quite steep (20%–60% slope) and rocky. Elevations varied from 400 m a.s.l. at Toxaway Ridge to 1100 m a.s.l. at Big Ridge. Soils at all the sites were well-drained sandy or silt loams formed in place by weathering of gneiss, sandstone, and schist parent material (Carson and Green 1981; Herren 1985; Davis 1993). Consequently, they were moderately fertile and strongly acidic. Climate was warm, humid, and continental, with average monthly high temperatures ranging from –3 °C in January to 28 °C in July. Mean annual precipitation ranged from 135 to 185 cm, distributed evenly throughout the year.

Composition, structure, and size of the nine TMPP stands were also similar. In general, they were 5–12 ha and consisted of 10–20 woody species distributed in three distinct strata. The main canopy was 15–20 m tall, broken, and patchy

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and consisted almost exclusively of pitch pine, Table Mountain pine, and mixed oaks (*Quercus* spp.), especially chestnut oak (*Quercus montana* Willd.). The main canopy of the South Carolina stands also contained some shortleaf pine (*Pinus echinata* Mill.) and Virginia pine (*Pinus virginiana* Mill.). A few loblolly pines (*Pinus taeda* L.) were found at Toxaway Ridge. A ubiquitous midstory stratum (3–15 m tall) was present in all stands. This stratum generally lacked a pine component, consisting almost exclusively of intermediate oaks and several other hardwood species, such as blackgum (*Nyssa sylvatica* Marsh.), red maple (*Acer rubrum* L.), and sourwood (*Oxydendrum arboreum* (L.) DC.). Together, the main canopy and the subcanopies contained approximately 1100–1400 stems and had a basal area of 30–40 m^2/ha. The understory stratum (1–3 m tall) varied from absent to impenetrably dense. When present, it was dominated by ericaceous shrubs, especially mountain laurel (*Kalmia latifolia* L.), and lacked hardwood and pine seedlings, as well as herbaceous plants.

Field procedures

In fall 1999, at each stand 12–15 rectangular 0.02 ha plots were either systematically located to ensure uniform coverage or selected from an ongoing study (Waldrop and Brose 1999) on the basis of the previously mentioned selection criteria. We wanted to determine whether stand-replacing crown fires coincided with the origin of these TMPP communities, but obtaining bole cross sections was not possible because of landowner restrictions, difficult accessibility to some sites, or safety constraints. Therefore, in each plot at least one increment core was extracted from the uphill side of six to eight randomly selected dominant and intermediate trees at a height of 0.3 m above the ground to intersect hidden, internal scars. If a core contained a visible defect it was kept, but others were extracted until a sound core was obtained. Usually, one core was needed from most trees, and only a few trees required more than two cores. We were able to obtain six to eight cross sections from suppressed trees and shrubs in each plot.

Laboratory procedures

A total of 888 cores and 871 cross sections were collected from the nine study stands. These were air dried for several weeks, mounted, and sanded with increasingly finer sandpaper (120, 220, 320, and 400 grit) to expose the annual rings (Phipps 1985). Cores and cross sections were sorted by species, and an initial establishment date for each was determined by aging them to the innermost ring or pith under a 40× dissecting microscope. The age structure of the pine and hardwood component at each site was determined by grouping these cores and cross sections into 10-year intervals (e.g., 1841–1850) on the basis of their pith dates. A pith estimator (Villalba and Veblen 1997) was prepared from cores that intersected the pith and was then used to date cores that did not intersect the pith. Finally, 5 years was added to each pith date to account for the time needed by the seedlings to grow to the coring height.

Radial growth analysis was done by selecting the pine species with the oldest trees in each stand. The 10 oldest cores of that species that were free of visible defects were cross-dated with skeleton plots to identify signature years so that false or missing rings would be recognized (Stokes and Smiley 1996). After proper ages were verified for these cores, their annual rings were measured to the nearest 0.002 mm with a UniSlide TA tree ring measurement system (Velmex Inc., Bloomfield, New York). The COFECHA 2.1 quality assurance program (Holmes 1983; Grissino-Mayer 2001*b*) in the International Tree-Ring Data Bank Program Library (Grissino-Mayer et al. 1992; Cook et al. 1997) was used to verify the accuracy of the cross-dating.

The ARSTAN program (Cook 1985) in the Data Bank Program Library was used to detrend cores with a negative exponential curve. Detrending removes the effects of tree age and microsite variability, allowing trees of different growth rates to be combined in a single chronology (Fritts 1976). The detrended chronologies of each pine core were averaged to create a master chronology for each pine species at each site.

The major and moderate releases in each master chronology were identified by using the JOLTS program (Holmes 1999) in the International Tree-Ring Data Bank Program Library, based on criteria established by Lorimer and Frelich (1989). A major release was defined as a ≥100% increase in average growth lasting at least 15 years; a moderate release, as a ≥50% growth increase lasting 10–15 years. These correspond to large disturbances that release residual trees from competition until crown closure occurs again.

Determination of fires

All cores and cross sections that contained an internal or external scar, regardless of species, were cross-dated with skeleton plots, in the same manner as the pine cores used for the radial growth analysis, so that an absolute date could be assigned to each scar. Because scars can be caused by other means in addition to fires, we decided that three or more scars had to occur in the same year at the same stand to be considered of fire origin. The resultant data were entered into the FHX2 program (Grissino-Mayer 2001*a*, 2004) to graphically illustrate the temporal distribution of the fires.

Results

Age structure

The nine TMPP sites exhibited three markedly different age structures (Fig. 1). The three Georgia stands displayed a polymodal age structure. The oldest trees were all Table Mountain pines that originated about 1769, 1804, and 1808. From these initial establishment dates, pines regenerated successfully in all three stands on a continuous or frequent periodic basis for nearly 150 years. Pine recruitment increased modestly from 1850 to 1900, with small cohorts being established in the 1850s and 1870s. Between 1900 and 1930, pine regeneration rose considerably, with a large cohort forming between 1925 and 1930. From that time, pine regeneration declined until the 1950s, when it ceased. There has been no pine recruitment in any of the three Georgia TMPP stands for the past 40–50 years.

The three Tennessee stands and Toxaway Ridge, South Carolina, had a unimodal age distribution (Fig. 1). Toxaway Ridge was the youngest site, with the vast majority of the trees originating between 1955 and 1970. However, there were 21 residual trees (13 shortleaf pines, 5 Table Mountain

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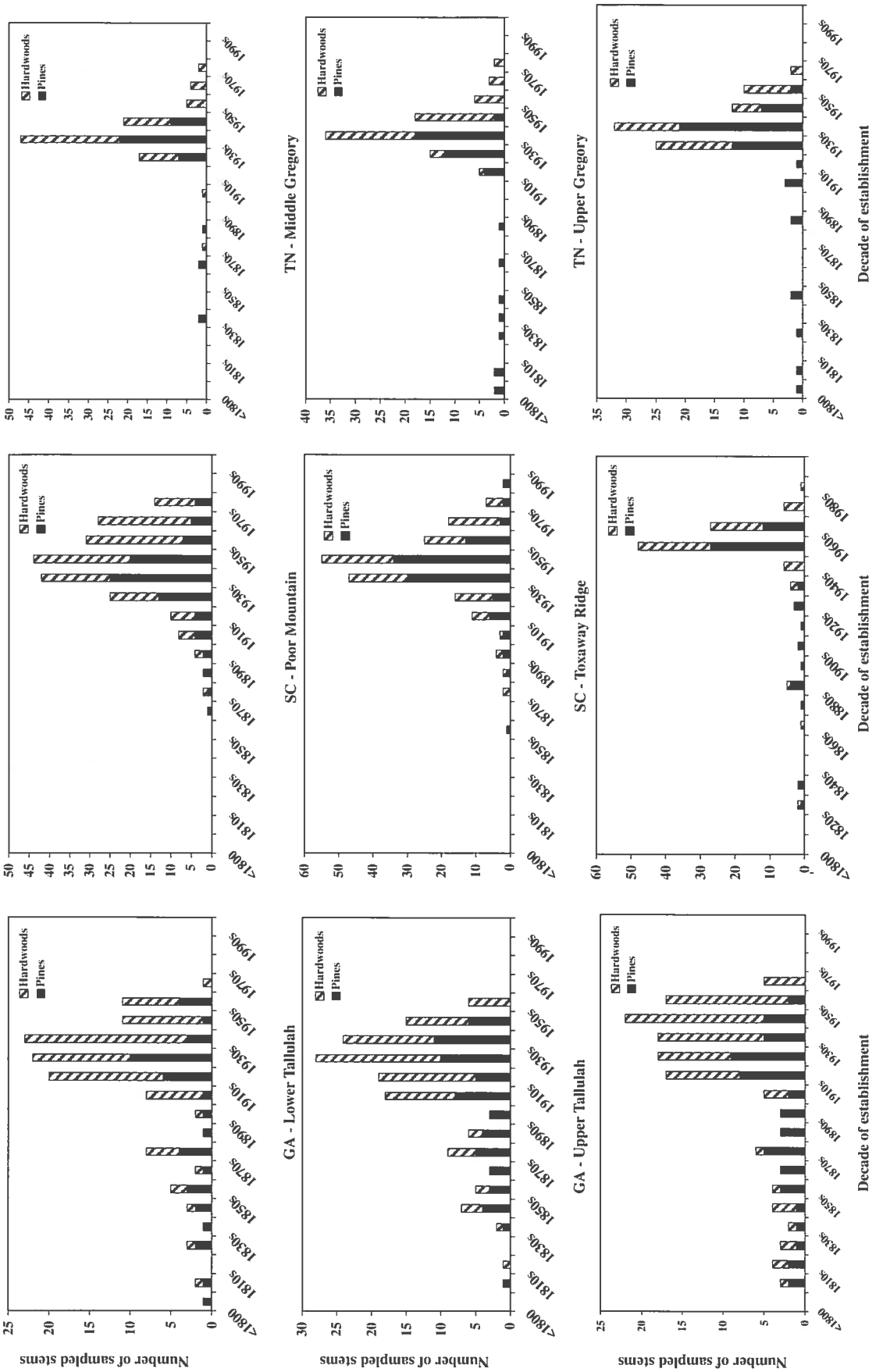

Fig. 1. Age structure of the pine and hardwood components of the nine Table Mountain pine – pitch pine stands. GA, Georgia; SC, South Carolina; TN, Tennessee.

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pines, and 3 chestnut oaks) from the previous stand. These dated from 1828 to 1936 and indicated that pine regeneration had been periodic or continuous. The pines at the Tennessee site originated primarily between 1925 and 1950, but there were 29 residual trees (21 pitch pines, 6 Table Mountain pines, and 2 chestnut oaks) from the previous stands. These older trees dated from 1789 to 1924 and indicated that periodic pine regeneration had occurred in these stands for those years.

The remaining two South Carolina stands, Buzzard Roost and Poor Mountain, contained elements of both age structures (Fig. 1). The oldest trees were Table Mountain pines dating to 1862 and 1874, with periodic pine recruitment occurring until 1890. After that date, pines became established on a continuous basis until 1980, with the pronounced peak occurring in the 1930s and 1940s.

Radial growth

A total of 90 pine cores were analyzed for radial growth and used to develop a master chronology for the oldest pine species in each stand. Cores were distributed among species as follows: 50 Table Mountain pine, 30 pitch pine, and 10 shortleaf pine. The Table Mountain pines were from the three Georgia stands and from Buzzard Roost and Poor Mountain in South Carolina. The other South Carolina stand, Toxaway Ridge, provided the shortleaf pine, and the pitch pine came from the three Tennessee stands. The master chronologies show stand-level periods of growth suppression, release events, and growth acceleration relative to a mean tree-ring index of 1.0.

All chronologies shared certain characteristics (Fig. 2). Initially, all showed wide fluctuations in radial growth because of small sample size. Once sample size was sufficiently large (n = 5 cores), radial growth trends stabilized and exhibited less fluctuation. The chronologies contained five to eight prolonged surges in radial growth, indicating stand-level major or moderate canopy releases.

The master chronologies from Georgia showed that these three stands all had major or moderate canopy releases in 1835, 1873, 1902, and 1926 (Fig. 2). Individually, Big Ridge had major or moderate releases in 1800, 1817, and 1971; lower Tallulah in 1941; and upper Tallulah in 1823 and 1987. The South Carolina master chronologies showed no common releases for the three stands. Rather, release years varied by stand, with Buzzard Roost having major or moderate canopy releases in 1875, 1892, 1914, 1944, and 1986; Poor Mountain, in 1866, 1903, 1924, 1946, 1971, and 1981; and Toxaway Ridge, in 1852, 1875, 1892, 1909, 1923, 1953, and 1986. The three Tennessee stands shared a common release in 1927 and 1983. Otherwise, release years varied by stand. Lower Gregory had major or moderate canopy releases in 1843, 1864, 1901, and 1965; middle Gregory, in 1797, 1837, 1856, and 1894; and upper Gregory, in 1822, 1848, 1876, 1903, and 1953.

Fires

From all sites, 173 cross sections and 214 cores, almost exclusively chestnut oak, contained external or internal scars. From these scars, a minimum of 24 fires were apparent, with the individual stands experiencing 3–8 fires since the 1850s (Fig. 3). Fire scars were quite synchronous among stands within the same state but generally not synchronous among states. The three Georgia stands all experienced fire in 1872, 1898, 1905, 1912, 1925, and 1944 (Fig. 3). The two Tallulah stands also burned in 1963, and single stand fires occurred in 1971 on lower Tallulah and 1996 on Big Ridge. In South Carolina, Buzzard Roost and Poor Mountain had fires in 1894, 1904, 1914, 1925, 1933, and 1941. Buzzard Roost also had a fire in 1962, and Poor Mountain burned in 1950 and 1982. Toxaway Ridge had only three detectable fires, and these occurred in 1904, 1951, and 1962. The three Tennessee stands had fire scars for the years 1872, 1926, and 1941. Upper Gregory also had a small fire in 1974.

Discussion

Understanding the disturbance regime that historically maintained unique forest communities in the landscape is a critical part of ecosystem restoration. Stand-replacing fire is widely held as the keystone of the disturbance regime that perpetuated TMPP stands throughout the southern Appalachian Mountains and was our research hypothesis. However, our data do not support our hypothesis or the belief that current TMPP stands arose primarily from stand-replacing wildfires.

The three Georgia stands and two in South Carolina were all-aged. Each one exhibited frequent periodic or continuous pine and hardwood regeneration and recruitment for 100–150 years. This type of age distribution cannot be created or maintained by stand-replacing fire. Nor were these five stands amalgamations of several smaller, even-aged TMPP cohorts, as it was common for any given plot to have pines of drastically different ages.

The finding that five of the nine TMPP stands were all-aged surprised us. This age structure for a TMPP community had only been reported for one stand in the southern Appalachian Mountains (Barden 1977, 1988, 2000). However, that site was so xeric that it was incapable of supporting hardwoods on a long-term basis, thus permitting episodic to continual regeneration and recruitment of Table Mountain pine. None of the five all-aged stands in this study occurred on such harsh sites, as evidenced by the abundance of hardwoods. The occurrence of all-aged TMPP stands on sites capable of supporting hardwoods suggests that a different disturbance regime was in operation.

The continuous regeneration of pines in these five stands appears to be due to, at least in part, periodic surface fires. Seven to eight such fires burned in each stand between 1870 and 2000, with most happening from 1900 to 1950 — the primary pine regeneration decades. These were surface fires, because their scars were found in cores and cross sections taken from living chestnut oaks. They were likely low- to moderate-intensity fires, as the chestnut oaks were generally of <30 cm basal diameter at the time of the fires. A periodic surface fire regime also explains why the pitch pine and Table Mountain pine have certain silvical characteristics. Although only pitch pine exhibits basal sprouting, both species have thick, flaky bark, self-pruning of lower branches, precocious cone maturation, opening of sealed cones at temperatures as low as 30 °C, and degradation of sealed cone resin within a few years (McIntyre 1929; Andresen 1957; Della-Bianca 1990; Little and Garrett 1990; Fraver 1992;

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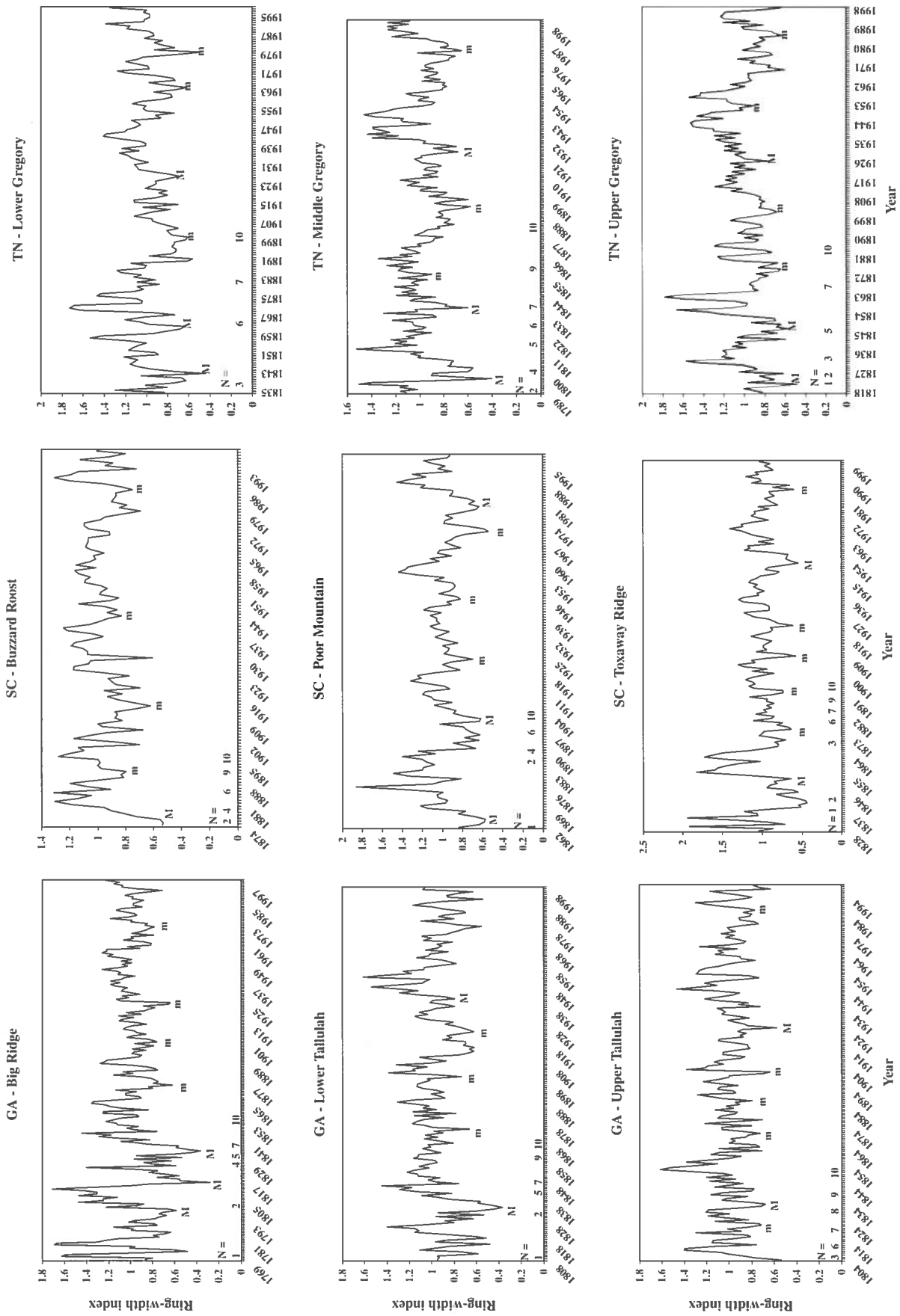

Fig. 2. Master growth chronology for the 10 oldest pines in each of the nine Table Mountain pine – pitch pine stands. For the vertical axis, average growth is 1.0. M, major canopy release; m, moderate canopy release; N, number of cores in the chronology. GA, Georgia; SC, South Carolina; TN, Tennessee.

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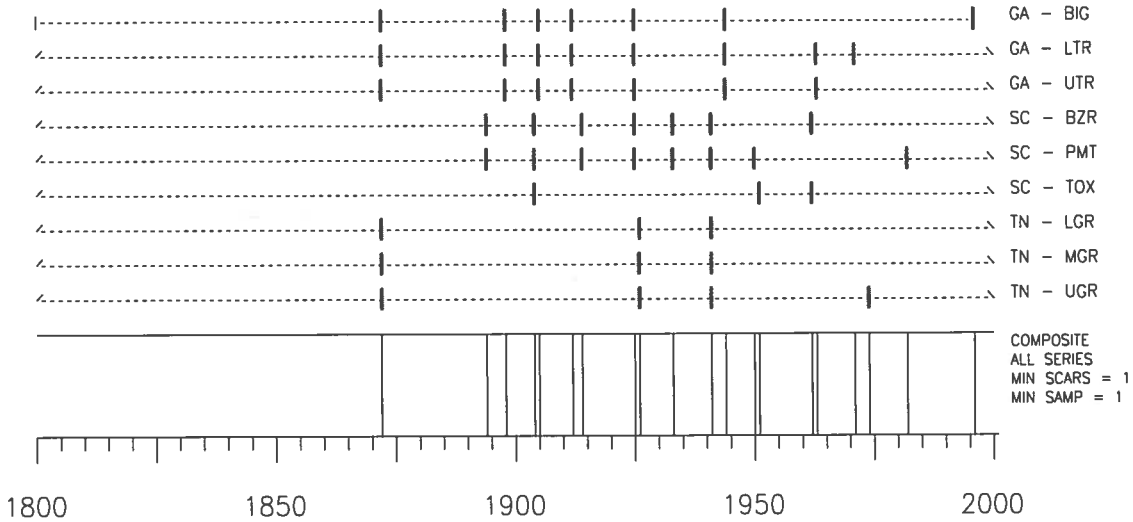
Fig. 3. Year of fire occurrence for the nine Table Mountain pine – pitch pine stands. The solid vertical bars on each stand's time line mark the year for which at least three scars were found on the lower bole of sampled trees. Note the abundance and consistency of fires between the late 1800s and the 1950s and their relative scarcity after the 1950s. GA, Georgia; SC, South Carolina; TN, Tennessee.



Williams 1998; Gray et al. 2002). Some of these fires were probably anthropogenic, but others may have been caused by lightning. Barden and Woods (1974) reported that most lightning fires in the southern Appalachian Mountains occurred during the summer months in pine–hardwood stands at elevations below 1200 m a.s.l. and usually burned 1 ha with a creeping fire.

Although the periodic surface fires explain some of the regeneration process of these all-aged TMPP stands, they don't coincide with the timing of all the major or moderate canopy releases. These events may be the result of non-fire disturbances. The southern Appalachian Mountains have a long history of other disturbances (Yarnell 1998). Droughts, hurricanes, ice storms, insect outbreaks, and thunderstorms all create canopy gaps of various sizes. Chestnut blight moved through the entire region in the 1920s, and American chestnut (*Castanea dentata* (Marsh.) Borkh.) was quite common in the Georgia stands. Logging was also a disturbance at the two South Carolina stands. Any of these canopy disturbances occurring shortly before or after a periodic surface fire would perpetuate TMPP stands and give them an all-aged structure.

The three Tennessee stands and the one at Toxaway Ridge in South Carolina had a unimodal age distribution, suggesting they did originate from a stand-replacing event. However, closer examination of all their data showed that they did not solely arise from intense crown fires.

The TMPP site at Toxaway Ridge was even-aged, with most trees dating to the early 1950s and with a few residual oaks and pines predating 1950. These residual trees originated throughout the 1800s, suggesting the previous stand was all-aged. All the residual trees showed a major release in 1953, and some had internal scars dating to 1951. This disturbance was likely a low- to moderate-intensity surface fire, as all the scarred trees were oaks of <20 cm basal diameter at the time and located on steep side slopes, where an intense fire would have surely killed them. Also about 1951, a timber harvest occurred at the site. All the trees predating 1950 were on steep side slopes that likely prevented their being harvested, even though several of them were clearly of merchantable size and quality at the time. Also, the loblolly pines we encountered at this site dated to the early 1950s. This species is outside its native range in this part of South Carolina but was routinely planted following clearcuts on federal lands at that time (P. Burris, silviculturist, Sumter National Forest, personal communication, 1999). Given that timber harvests are capable of initiating TMPP sites (McIntyre 1929), it is unclear how exactly the 1951 fire contributed to creating the current even-aged TMPP site.

The TMPP sites in Tennessee have a unimodal age structure, with most pines establishing between 1926 and 1945. Those that predate 1926 originated throughout the 1800s, indicating that the previous stands were all-aged. A fire occurred in 1926, but it was probably a low- to moderate-intensity surface fire, rather than a stand-replacing disturbance. Only eight trees were scarred, and all were small chestnut oaks. The sustained increase in radial growth that started in the late 1920s was most likely the result of the abandonment of Cades Cove in the valley below the site. The inhabitants of this community burned the surrounding forests, including the three stands, several times a decade for more than a century for numerous reasons (Shields 1977; Dunn 1988). During the same period, they grazed livestock in mountain pastures during the summer months. Fires would have been of low intensity because of light fuel loads. Such fires rarely scar large thick-barked pines (Waldrop and Brose 1999; Welch et al. 2000), explaining why the only cores extracted from pre-1925 origin oaks contained internal scars. Also, a grazing – low-intensity fire disturbance regime would have created an open, park-like forest, preventing most oak and pine establishment but creating ideal understory conditions for their widespread regeneration once the fires and grazing ceased.

This anthropogenic disturbance regime began changing during the 1920s (Shields 1977; Dunn 1988; Yarnell 1998). Numerous Cades Cove residents moved elsewhere in pursuit of better economic opportunities. This out-migration was fostered by the imminent formation of Great Smoky Moun-

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tains National Park, especially during the latter part of that decade. The reduction in human population decreased grazing pressure and fire starts. Creation of the park in 1936 forced the relocation of the last Cades Cove residents and their livestock. Wildfire control also began, finishing the rapid change to the disturbance regime. Ending frequent fire and grazing allowed oaks and pines to regenerate en masse in the open forest conditions and grow unimpeded into the canopy, forming the current TMPP sites. Thus, the 1926 burn was not a site-replacing conflagration but rather the last fire of a frequent fire and grazing regime.

Restoring a dual disturbance regime of canopy releases coupled with periodic surface fires will be easier than recreating a crown fire regime. Opportunities to conduct prescribed crown fires are limited in the southern Appalachian Mountains by the lack of appropriate weather conditions for conducting such burns. Even when the conditions are right, the mix of private and public land ownership and the rough terrain make operational burns dangerous and difficult to implement. Periodic surface fires will not be hampered by these restrictions to the same degree as prescribed crown fires, giving managers more opportunities to implement them. The operational window for low- to moderate-intensity surface fires can also be widened by using herbicides and timber harvesting to mimic the different types of canopy disturbance.

Although this study contributed to our understanding of TMPP ecology, it was not without some shortcomings. The cores indicated some fire dates, but obviously others were missed because full cross sections were not obtainable. Also, our conservative approach of defining a fire by three or more scars in the same year at the same stand probably caused us to miss some smaller fires. Consequently, the importance of fire's role in TMPP site origin may be understated. Also, the relationship between surface fires and other disturbances is speculative at this time and merits further research.

Conclusions

TMPP sites are not nearly as dependent on high-intensity fires as we hypothesized. Although they can form after catastrophic fire and have done so, such fires are not essential for their perpetuation. Rather, it appears that periodic surface fires supplemented by canopy-level disturbances may well have been the historical means for sustaining uneven-aged TMPP sites on xeric sites capable of supporting hardwoods. The reduction in fire frequency and extent since the 1950s appears to have caused, or at least contributed to, the cessation of pine regeneration and recruitment. A periodic, multiple disturbance regime that includes canopy openings and surface fires may be a more appropriate and manageable means of sustaining TMPP communities than infrequent, intense fires are.

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References

Andresen, J.W. 1957. Precocity of *Pinus rigida* Mill. Castanea, **22**: 130–134.

Armbrister, M.R. 2002. Changes in fire regimes and the successional status of Table Mountain pine (*Pinus pungens* Lamb.) in the southern Appalachians, USA. M.S. thesis, University of Tennessee, Knoxville, Tenn.

Barden, L.S. 1977. Self-maintaining populations of *Pinus pungens* in the southern Appalachian Mountains. Castanea, **42**: 316–323.

Barden, L.S. 1979. Serotiny and seed viability of *Pinus pungens* in the southern Appalachians. Castanea, **44**: 44–47.

Barden, L.S. 1988. Drought and survival in a self-perpetuating *Pinus pungens* population: equilibrium or nonequilibrium? Am. Midl. Nat. **119**: 254–257.

Barden, L.S. 2000. Population maintenance of Table Mountain pine (*Pinus pungens* Lamb.) after a century without fire. Nat. Areas J. **20**: 227–233.

Barden, L.S., and Woods, F.W. 1974. Characteristics of lightning fires in southern Appalachian forests. *In* A Quest for Ecological Understanding: Proceedings of the 13th Tall Timbers Fire Ecology Conference, Tallahassee, Fla., 14–15 October 1973. Proc. Tall Timbers Fire Ecol. Conf. **13**: 345–361.

Brown, P.M., Ryan, M.G., and Andrews, T.G. 2000. Historical surface fire frequency in ponderosa pine stands in research natural areas, central Rocky Mountains and Black Hills, USA. Nat. Areas J. **20**: 133–139.

Carson, W.S., and Green, T.W. 1981. Soil survey of Rabun and Towns counties, Georgia. USDA Soil Conservation Service, Athens, Ga.

Cook, E.R. 1985. A time series analysis approach to tree ring standardization. Ph.D. dissertation, University of Arizona, Tucson, Ariz.

Cook, E.R., Holmes, R.L., Bosch, O., Varem-Sanders, T., Grissino-Mayer, H.D., and Krusic, P.J. 1997. International Tree-Ring Data Bank Program Library. Version 2.1. Available from http://www.ngdc.noaa.gov/paleo/treering.html [accessed in 2001 and 2002].

Davis, H.A. 1993. Soil survey of Blount County, Tennessee. USDA Soil Conservation Service, Knoxville, Tenn.

Della-Bianca, L. 1990. Table Mountain pine (*Pinus pungens* Lamb). *In* Silvics of North America. Vol. I: Conifers. *Technical coordinators* R.M. Burns and B.H. Honkala. USDA For. Serv. Agric. Handb. 654. pp. 425–432.

Dunn, D. 1988. Cades Cove: the life and death of a southern Appalachian community. University of Tennessee Press, Knoxville, Tenn.

Fraver, S. 1992. The insulating value of serotinous cones in protecting pitch pine (*Pinus rigida*) seeds from high temperatures. J. Pa. Acad. Sci. **65**(3): 112–116.

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Fritts, H.C. 1976. Tree rings and climate. Academic Press, London, UK.

Gray, E.A., Rennie, J.C., Waldrop, T.A., and Hanula, J.L. 2002. Patterns of seed production in Table Mountain pine. *In* Proceedings of the 11th Biennial Southern Silvicultural Research Conference, Knoxville, Tenn., 20–22 March 2001. *Edited by* K.W. Outcalt. USDA For. Serv. Gen. Tech. Rep. SRS-48. pp. 302–305.

Grissino-Mayer, H.D. 2001*a*. FHX2 — software for analyzing temporal and spatial patterns in fire regimes from tree rings. Tree-Ring Res. **57**(1): 115–124.

Grissino-Mayer, H.D. 2001*b*. Evaluating crossdating accuracy: a manual and tutorial for the computer program COFECHA. Tree-Ring Res. **57**(2): 205–221.

Grissino-Mayer, H.D. 2004. FHX2 user's manual: software for analyzing temporal and spatial patterns in fire regimes from tree rings. University of Tennessee, Knoxville, Tenn.

Grissino-Mayer, H.D., Holmes, R.L., and Fritts, H.C. 1992. User's manual for the International Tree-Ring Data Bank Program Library. Laboratory of Tree-Ring Research, The University of Arizona, Tucson, Ariz. Available from http://www.ngdc.noaa.gov/paleo/treering.html [accessed in 2001 and 2002].

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

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

Heinselman, M.L. 1973. Fire in the virgin forests of the Boundary Waters Canoe Area, Minnesota. Quat. Res. **3**: 329–382.

Herren, E.C. 1985. Soil survey of Oconee County South Carolina. USDA Soil Conservation Service, Columbia, S.C.

Holmes, R.L. 1983. Computer-assisted quality control in tree-ring dating and measurement. Tree-Ring Bull. **43**: 69–78.

Holmes, R.L. 1999. Program JOLTS: finding growth surges or suppressions in trees. Laboratory of Tree-Ring Research, The University of Arizona, Tucson, Ariz.

Huff, M.H. 1995. Forest age structure and development following wildfires in the western Olympic Mountains, Washington. Ecol. Appl. **5**: 471–483.

Little, S., and Garrett, P.W. 1990. Pitch pine (*Pinus rigida* Mill.). *In* Silvics of North America. Vol. I: Conifers. *Technical coordinators* R.M. Burns and B.H. Honkala. USDA For. Serv. Agric. Handb. 654. pp. 456–462.

Lorimer, C.G., and Frelich, L.E. 1989. A method for estimating canopy disturbance frequency and intensity in dense temperate forests. Can. J. For. Res. **19**: 651–663.

McIntyre, A.C. 1929. A cone and seed study of the mountain pine (*Pinus pungens* Lambert). Am. J. Bot. **16**: 402–406.

Mohr, H.H., Waldrop, T.A., and Shelburne, V.B. 2002. Optimal seedbed requirements for germination of Table Mountain pine. *In* Proceedings of the 11th Biennial Southern Silvicultural Research Conference, Knoxville, Tenn., 20–22 March 2001. *Edited by* K.W. Outcalt. USDA For. Serv. Gen. Tech. Rep. SRS-48. pp. 306–309.

Phipps, R.L. 1985. Collecting, preparing, crossdating, and measuring tree increment cores. USGS Water Resour. Invest. Rep. 85-4148. pp. 41–48.

Sanders, G.L. 1992. The role of fire in the regeneration of Table Mountain pine in the southern Appalachian Mountains. M.S. thesis, University of Tennessee, Knoxville, Tenn.

Shields, A.R. 1977. The Cades Cove story. Great Smoky Mountains Natural History Association, Gatlinburg, Tenn.

Stokes, M.A., and Smiley, T.L. 1996. An introduction to tree-ring dating. The University of Arizona Press, Tucson, Ariz.

Sutherland, E.K., Grissimo-Mayer, H.D., Woodhouse, C.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* Hypertext Proceedings: IUFRO Conference on Inventory and Management Techniques in the Context of Catastrophic Events: Altered States of the Forest, University Park, Penn., 21–24 June 1993. Pennsylvania State University, Center of Statistical Ecology and Environmental Statistics, University Park, Penn.

Taylor, A.H. 1993. Fire history and structure of red fir (*Abies magnifica*) forests, Swain Mountain Experimental Forest, Cascade Range, northeastern California. Can. J. For. Res. **23**: 1672–1678.

Taylor, A.H., and Skinner, C.N. 1998. Fire history and landscape dynamics in a late-successional reserve, Klamath Mountains, California, USA. For. Ecol. Manage. **111**: 285–301.

Villalba, R., and Veblen, T.T. 1997. Improving estimates of total tree ages based on increment core samples. Ecoscience, **4**: 535–542.

Waldrop, T.A., and Brose, P.H. 1999. A comparison of fire intensity levels for site replacement of Table Mountain pine (*Pinus pungens* Lamb.). For. Ecol. Manage. **113**: 155–166.

Welch, N.T., Waldrop, T.A., and Buckner, E.R. 2000. Response of southern Appalachian Table Mountain pine (*Pinus pungens*) and pitch pine (*Pinus rigida*) sites to prescribed burning. For. Ecol. Manage. **136**: 185–197.

White, A.S. 1985. Presettlement regeneration patterns in a southwestern ponderosa pine stand. Ecology, **66**: 589–594.

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

Williams, C.E., and Johnson, W.C. 1990. Age structure and the maintenance of *Pinus pungens* in pine–oak forests of southwestern Virginia. Am. Midl. Nat. **124**: 130–141.

Williams, C.E., and Johnson, W.C. 1992. Factors affecting recruitment of *Pinus pungens* in the southern Appalachian Mountains. Can. J. For. Res. **22**: 878–887.

Williams, C.E., Lipscomb, M.V., Johnson, W.C., and Nilsen, E.T. 1990. Influence of leaf litter and soil moisture regime on early establishment of *Pinus pungens*. Am. Midl. Nat. **124**: 142–152.

Yarnell, S.L. 1998. The southern Appalachians: a history of the landscape. USDA For. Serv. Gen. Tech. Rep. SRS-18.

Zobel, D.B. 1969. Factors affecting the distribution of *Pinus pungens*, an Appalachian endemic. Ecol. Monogr. **39**(3): 303–333.

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