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FIRE AND THE ORIGIN OF TABLE MOUNTAIN PINE – PITCH PINE COMMUNITIES IN THE SOUTHERN APPALACHIAN MOUNTAINS, USA

Patrick H. Brose[1*] and Thomas A. Waldrop[2]

[1]USDA Forest Service

Northeastern Research Station

Forestry Sciences Lab

PO Box 267

Irvine, PA 16329

[2]USDA Forest Service

Southern Research Station

233 Lehotsky Hall

Clemson University

Clemson, SC 29634

* Corresponding author: Phone (814) 563-1040, Fax (814) 563-1048, Email: pbrose@fs.fed.us

ABSTRACT

The prevalence of stand-replacing fire in the formation of Table Mountain pine – pitch pine (*Pinus pungens* and *P. rigida*, respectively) communities was investigated using 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 or not they had originated because of stand-replacing fires. The oldest pines dated to the late 1700s or early 1800s. From those times to the early to mid 1900s, all sites showed evidence of continuous or frequent episodic pine regeneration. 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 non-catastrophic surface fires and canopy disturbances occurring together or by the cessation of a frequent fire regime. For the past 25 to 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 Mountain landscapes.

Keywords: dendrochronology, disturbance history, fire regime, Pinus echinata, Pinus pungens, Pinus rigida, radial growth analysis, uneven-aged forest, xeric soils.

INTRODUCTION

The advent of ecosystem management has sparked interest in the restoration of uncommon plant communities for diversity. The Table Mountain pine – pitch pine (*Pinus pungens* and *P. rigida*, respectively) forests of the Appalachian Mountain region of eastern North America represent such a plant community. These unique forests, hereafter referred to as TMPP, 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. 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. Both species possess silvical characteristics suggesting evolution in a high-intensity fire regime such as 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 post-burn regeneration inventories found the most abundant and successful pine seedlings occurred where intense fires 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 experienced a moderate-intensity surface fire (partial canopy removal) than it did in the full sunlight created by a high-intensity crown fire. Also, 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 in that most or all the pine stems originate within a few years of each other. There are few, if any, hardwood stems predating the fire. Residual pines, i.e., those that predated 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 and has been 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 of dominant Table Mountain pine in three TMPP stands in southwestern Virginia. Subsequent research by 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 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 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 if the stands had dissimilar disturbance histories for insect outbreaks, grazing, logging, or storms.

Three of the TMPP stands, Big Ridge, Lower Tallulah, and Upper Tallulah, were south of Rabun Bald on the Chattahoochee National Forest in 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 were quite similar to each other in physical characteristics (Table 1). All were ridges or hilltops with a southerly aspect. The accompanying sideslopes were quite steep (20 to 60% slope) and rocky. Elevations varied from 400 m at Toxaway Ridge to 1100 m 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 also were quite similar. In general, they were 5 to 12 hectares in size and consisted of 10 to 20 woody species distributed in three distinct strata. The main canopy was 15 to 20 m tall, broken and patchy, and consisted almost exclusively of pitch pine, Table Mountain pine, and mixed oaks (*Quercus* spp.), especially chestnut oak (*Q. montana*). The main canopy of the South Carolina stands also contained some shortleaf pines (*P. echinata*) and Virginia pine (*P. virginiana*). A few loblolly pines (*P. taeda*) were found at Toxaway Ridge. A ubiquitous midstory stratum (3 to 15 m tall) was present in all stands. It generally lacked a pine component, consisting almost exclusively of intermediate oaks and several other hardwood species such as blackgum (*Nyssa sylvatica*), red maple (*Acer rubrum*), and sourwood (*Oxydendrum arboreum*). Together, the main and sub canopies contained approximately 1100 to 1400 stems and 30 to 40 m^2 of basal area per hectare. The understory stratum (1 to 3 m tall) varied from absent to impenetrably dense. When

present, it was dominated by ericaceous shrubs, especially mountain laurel (*Kalmia latifolia*), and lacked hardwood and pine seedlings as well as herbaceous plants.

Field Procedures

At each stand in fall 1999, 12 to 15 0.02-ha rectangular plots were either systematically located to ensure uniform coverage or selected from an ongoing study (Waldrop and Brose 1999) based on the previously mentioned selection criteria. We wanted to determine if stand-replacing crown fires coincided with the origin of these TMPP communities but obtaining bole cross-sections of the trees was not possible due to landowner restrictions, difficult accessibility to some sites, and 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 to the innermost ring or pith under a 40x dissecting microscope.

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, based on their pith dates. A pith estimator (Villalba and Veblen 1997) was prepared from cores that intersected the pith and was then used to age cores that did not intersect the pith. Finally, five years were 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 skeleton plotted to identify signature years for crossdating to recognize false or missing rings (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, NY). The COFECHA 2.1 quality assurance program (Holmes 1983; Grissino-Mayer 2001a) 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 crossdating.

The ARSTAN program (Cook 1985) in the International Tree-Ring Data Bank Program Library (Grissino-Mayer et al. 1992; Cook et al. 1997) was used to detrend cores with a negative expotential 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 and a moderate release as a ≥50% growth increase lasting 10 to 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, regardless of species, that contained an internal or external scar were skeleton plotted and crossdated in the same manner as the pine cores used for the radial growth analysis to assign an absolute date to each scar. Because scars can be caused by means other than fires, we decided that three or more scars had to occur in the same year at the same stand for them to be considered of fire origin. The resultant data were entered into the FHX2 program (Grissino-Mayer 2001b, 2004) to graphically illustrate the temporal distribution of the fires.

RESULTS

Age Structure

The nine TMPP sites exhibited three markedly different age structures (Figure 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 to 50 years.

The three Tennessee stands and Toxaway Ridge, SC had a unimodal age distribution (Figure 1). Toxaway Ridge was the youngest site with the vast majority of the trees originated between 1955 and 1970. However, there were 21 residual trees (13 shortleaf pines, 5 Table Mountain 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 (Figure 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 50 Table Mountain pine, 30 pitch pine, and 10 shortleaf pine. The

Table Mountain pines were from the three Georgia stands and Buzzard Roost and Poor Mountain in South Carolina. The other SC stand, Toxaway Ridge, provided the shortleaf pine while 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 (Figure 2). Initially, all showed wide fluctuations in radial growth due to their small sample size. Once sample size was sufficiently large ($n \geq 5$ cores), radial growth trends stabilized and exhibited less fluctuation. All chronologies contained from 5 to 8 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 (Figure 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's in 1866, 1903, 1924, 1946, 1971, and 1981; and Toxaway Ridge's 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 from three to eight fires since the 1850s (Figure 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 (Figure 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 nor the belief that current TMPP stands arose primarily from stand-replacing wildfires.

The three Georgia stands and two more in South Carolina were all-aged. Each one exhibited frequent periodic or continuous pine and hardwood regeneration and

recruitment for 100 to 150 years. This type of age distribution cannot be created nor 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 due, at least in part, to 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 less than 30 cm dbh at the time of the fires. A periodic surface fire regime also explains why pitch pine and Table Mountain pine have some of their silvical characteristics. Both species have thick, flaky bark, self-pruning of lower branches, basal sprouting (pitch pine only), precocious cone maturation, opening of sealed cones at temperatures as low as 30°C, and resin degradation of sealed cones within a few years (McIntyre 1929; Andresen 1957; Della-Bianca 1990; Little and Garrett 1990;

Fraver 1992; Williams 1998; Gray et al. 2002). Some of these fires were probably of anthropogenic origin but others may have been caused by lightning. Barden and Woods (1974) reported that most lightning fires in the southern Appalachian Mountains occurred in pine-hardwood stands below 1200 m elevation during the summer months and usually burned a hectare with a creeping fire

While 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/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*) 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 have 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 of 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 < 20 cm basal diameter at the time and located on steep sideslopes where an intense fire would have surely killed them. Also about 1951, a timber harvest occurred at the site. All of the trees predating 1950 were on steep sideslopes that likely prevented their harvesting 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 (pers. comm. Paul Burris, silviculturist, Sumter NF). Given that timber harvests are capable of initiating TMPP sites (McIntyre 1929), it is unclear the exact contribution of the 1951 fire 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 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 several times a decade for more than a century for numerous reasons (Shields 1977; Dunn 1988). During that same period, they grazed livestock in mountain pastures during the summer months. The three stands were grazed annually and burned frequently for more than a century. Fires would have been low-intensity due to 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-origin 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 immigration was fostered by the imminent formation of Great Smoky Mountains 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 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 lack of appropriate weather conditions to conduct such burns. Even when conditions arise, the intermix of private and public land ownership and rough terrain make operational burns dangerous and difficult to implement. Periodic surface fires will not have 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 type of canopy disturbances.

While this study contributed to our understanding of TMPP ecology, it was not without some shortcomings. While the cores indicated some fire dates, 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 dependant on high-intensity fires as we hypothesized. While they can and have formed after catastrophic fire, it is 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 causal, or at least contributory, 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 than infrequent, intense fires to sustain TMPP communities.

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Figure Captions

Figure 1. Age structure of the pine and hardwood components of the nine TMPP stands. In each graph the horizontal axis is decade of establishment and the vertical axis is the number of sampled stems.

Figure 2. Master growth chronology for the ten oldest pines in each of the nine TMPP stands. In each graph, the horizontal axis is time in years and the vertical axis is the ring width index (average growth = 1.0). The "M" and "m" signify when major and moderate canopy releases occurred in the chronology. The "N" indicates the number of cores in the chronology.

Figure 3. Year of fire occurrence for the nine TMPP stands. The solid vertical bars on each stand's timeline mark the year at least three scars on the lower bole of sampled trees were found. Note the abundance and consistency of fires between the late 1800s and 1950s and their relative scarcity after the 1950s.