CHANGES IN THE DISTURBANCE REGIME OF UPLAND YELLOW PINE STANDS IN THE SOUTHERN APPALACHIAN MOUNTAINS DURING THE 20TH CENTURY

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

Abstract—A dendrochronology study was conducted in four upland yellow pine communities in Georgia, South Carolina, and Tennessee to determine whether the number and frequency of stand-level disturbances had changed since 1900. Increment cores of Table Mountain pine (*Pinus pungens* Lamb.), pitch pine (*P. rigida* Mill.), shortleaf pine (*P. echinata* Mill.), and chestnut oak (*Quercus prinus* L.) were obtained from the stands and analyzed for major, moderate, and minor canopy releases. Cross sections of intermediate hardwoods were collected and examined for fire scars. Historical drought and hurricane records were obtained from the National Oceanic and Atmospheric Administration. These records and the data from the cores and cross sections were analyzed for changes in the number and frequency of canopy releases, droughts, fires, and tropical storms in 2 50-year increments, pre- and post-1950. The number of canopy releases, droughts, fires, and tropical storms decreased considerably after 1950. These disturbances are less common now than they were a century ago and no longer coincide in occurrence. This change may result in dramatic repercussions for sustaining these conifer communities.

INTRODUCTION

Disturbance events have been an integral part of Southern Appalachian forests for millennia (Yarnell 1998). Three important large-scale disturbances for this region are droughts, fires, and hurricanes. Singularly and interactively, these disturbances shape the composition and structure of upland forests. For example, a hurricane may predispose an area to burning by increasing fuel loadings, or a drought may increase fire intensity and severity, causing additional tree mortality. It is important that managers of upland yellow pine (UYP) forests understand how these disturbances are related on a temporal scale and how their occurrence has changed over time.

UYP forests are located throughout the Southern Appalachian Mountains on xeric, mid-elevational, south- and west-facing ridges (Zobel 1969). Their canopies are dominated by pitch, shortleaf, Table Mountain, and Virginia pines, while their midstories consist primarily of hardwoods, especially chestnut oak. Because of their position in the landscape and species mix, UYP forests offer an excellent opportunity to study droughts, fires, and hurricanes.

Dendrochronology can be used to identify past disturbances and how they have changed through time by combining radial-growth analysis, timelines for species establishment, and recorded history. Previous studies in UYP communities (Armbrister 2002, Williams and Johnson 1990) focused on the role of fire in establishing these stands and, to a lesser degree, the decline in fire occurrence after the onset of organized fire-control policies circa 1925 (Yarnell 1998). They did not investigate whether the frequency of other disturbances also may have changed as fire was becoming less common. For this study, we used dendrochronology in UYP stands to determine whether the number and frequency of canopy releases, droughts, fires, and hurricanes have changed over time.

METHODS

Study Stands

This study was conducted in four UYP stands (designated GA, SCI, SCII, and TN) on the Chattahoochee National Forest in northern Georgia, Sumter National Forest in western South Carolina, and Great Smoky Mountains National Park in eastern Tennessee. The stands were situated on the tops and upper side slopes of south- and west-facing ridges. Elevations ranged from 1,400 to 3,600 feet, and soils were well-drained sandy or silt loams formed in place by the weathering of gneiss, sandstone, and schist parent material (Carson and Green 1981, Davis 1993, Herren 1985). Consequently, soils were of low fertility and strongly acidic. Climate was warm, humid, and continental; average monthly high temperatures ranged from 25 °F in January to 85 °F in July. Mean annual precipitation ranged from 53 to 73 inches distributed evenly throughout the year.

Composition, structure, and size of the four UYP stands were similar. In general, they were 10 to 30 acres each and consisted of 10 to 20 woody species distributed in 3 distinct strata. The main canopy was 50- to 65-feet tall, broken and patchy, and consisted almost exclusively of 2 or more of the UYP species and chestnut oak. A ubiquitous midstory stratum (10- to 40-feet tall) generally lacked a pine component. It consisted almost exclusively of chestnut oak and other hardwood species such as blackgum (*Nyssa sylvatica* Marsh.), red maple (*Acer rubrum* L.), scarlet oak (*Q. coccinea* Muenchh.), and sourwood [*Oxydendrum arboretum* (L.) DC.]. Together, the main and sub canopies contained 1,100 to 1,400 stems and 130 to 175 square feet of basal area per acre. The understory stratum (3- to 10-feet tall) ranged 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.

[1] Research Silviculturist, USDA Forest Service, Northeastern Research Station, Irvine, PA; and Research Forester, USDA Forest Service, Southern Research Station, Clemson, SC 29634, respectively.

Citation for proceedings: Connor, Kristina F., ed. 2006. Proceedings of the 13th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–92. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 640 p.

Sampling Procedures

In each stand in the fall of 1999, 30 to 45 0.05-acre rectangular plots were located systematically to ensure uniform coverage or selected from an ongoing study (Waldrop and Brose 1999). From 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 1 foot above the ground to intersect hidden, internal scars. Cores with visible defects were retained, but others were extracted until a sound core was obtained. Typically, only one core was needed from most trees, and only several trees required more than two cores. It was not possible to obtain bole cross sections from these larger trees due to landowner restrictions, difficulty accessing some stands, or safety constraints. However, we did obtain six to eight cross sections from suppressed trees and shrubs on each plot.

Lab Procedures

Nearly 1,000 cores were collected from the four UYP 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. More than 900 cross sections collected from the stands were dried and sanded similarly. An initial establishment date for each core and cross section was determined by aging to the innermost ring or pith under a 40-power dissecting microscope.

The 18 oldest, best-quality (free of visible defects) cores from each stand were selected for radial growth analysis. These were skeleton-plotted to identify signature years for cross-dating to recognize false or missing rings (Stokes and Smiley 1996). After proper ages were verified for these cores, 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 in the International Tree-Ring Data Bank Program Library (Cook and others 1997) was used to verify the accuracy of the dating.

After dating and measuring, each core was examined for major, moderate, and minor releases 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-percent increase in average growth that lasted at least 15 years and a moderate release as a ≥50-percent increase lasting 10 to 15 years. These correspond to large, canopy-level disturbances that release residual trees from competition until crown closure reoccurs. Nowacki and Abrams (1997) defined a minor release as a ≥25-percent increase in average growth lasting 5 to 10 years. This criterion identifies partial crown releases that provide increased sunlight to adjacent canopy trees.

Dating of Disturbances

All cores and cross sections that contained an internal or external scar were skeleton-plotted and crossdated to assign an absolute date to each scar. Because scars can be caused by means other than fires, we determined that three or more scars had to occur in the same year in the same stand for a scar to be considered of fire origin.

The Palmer Drought Severity Index (PDSI), available for 1895 to 1999 from the National Oceanic Atmospheric Administration (NOAA 2000), provided monthly precipitation and temperature data for each stand on a State and sub-regional basis. Records of hurricanes and tropical storms since 1850 also were available (NOAA 2003) and showed the routes of these storms.

Statistical Analysis

We divided our timeline into 2 50-year periods: 1900 to 1949 and 1950 to 1999. This division corresponds to when organized fire control finally became effective in the region (Yarnell 1998). Analysis of variance with the Newman-Keuls mean separation test (SAS 2002) was used to test whether the number of major, moderate, and minor canopy releases differed between and within these periods. Data were analyzed as a randomized complete-block design with stand serving as the blocking factor, time period as the factor, and number of major, moderate, and minor releases as the dependent variable. Residuals were examined to ensure that model assumptions were met; α was 0.05 for the analysis.

The FHX2 program (Grissino-Mayer 2004) can be used to characterize the interval between successive canopy releases and to evaluate the goodness of fit between disturbance frequencies and normal and Weibull distributions. The frequency data were skewed so we used the Weibull distribution as a measure of central tendency. We tested the means of the transformed data with *T*-tests (unequal variances) to detect differences in mean disturbance interval of major, moderate, and minor releases among and within eras; α was 0.125 for these tests.

RESULTS

In all, 293 release events were identified from the 72 cores. These were distributed as 176 (60 percent) minor releases, 85 (29 percent) moderate releases, and 32 (11 percent) major releases. There were no differences in the number of major, moderate, and minor releases among the four stands, so we pooled the data to simplify reporting.

There were significant differences in the mean number of major, moderate, and minor releases among and within time periods (fig. 1). Regardless of the period, the number of minor

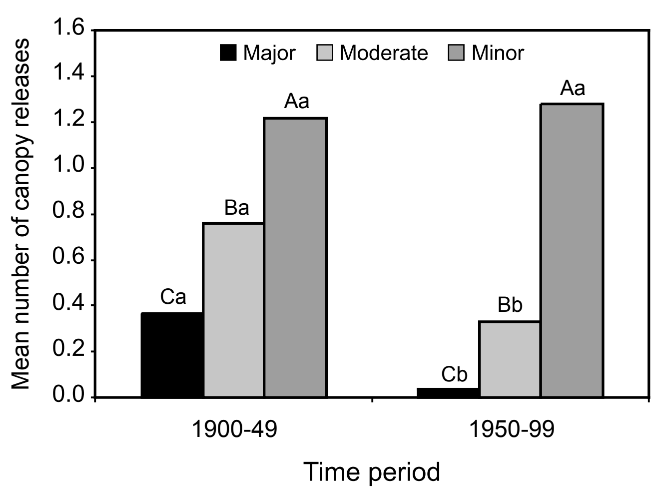

Figure 1—The mean number of major, moderate, and minor canopy releases for the time periods 1900-1949 and 1950-1999. Columns with different uppercase letters are statistically different within a time period at α = 0.05. Columns with different lowercase letters are statistically different between time periods at α = 0.05.

canopy releases always exceeded the number of moderate releases. Similarly, the number of moderate canopy releases was always greater than the number of major releases. The number of major and moderate releases decreased from the early 1900s to the late 1900s. The number of minor releases did not differ among time periods.

The frequency of major and moderate canopy releases in each time period did not differ by stand so these data were combined to simplify reporting (table 1). Events varied in frequency of occurrence during the early 1900s from 6.3 to 13.6 years depending on stand. Major and moderate canopy releases were too infrequent during the late 1900s for analysis. Minor canopy releases were much more frequent than major or moderate releases for both periods and all stands. Minor releases tended to increase in frequency from the early 1900s, but this change was not significant except at the GA stand.

The number and frequency of droughts, fires, and hurricanes in the southern Appalachian Mountains changed in a similar pattern during the 20th century (fig. 2). During the first half of the 20th century, 10 to 13 droughts occurred, and these were usually singular events except from 1925 to 1935. The numbers of droughts during 1950 to 1999 was the same as during the preceding period, but most were concentrated in the early 1950s and late 1980s. Detectable fires at each stand numbered two to six between 1900 and 1949 and one or two after 1950. Hurricanes showed the same numeric distribution as fires: four to seven from 1900 to 1950 and two after 1950.

DISCUSSION

There have been dramatic changes in the disturbance regime of the southern Appalachian Mountains during the 20th century. Between 1900 and 1950, the occurrence of stand-level disturbances was 1 every 6 to 13 years, as was the case throughout the southern Appalachians (Yarnell 1998). These

Table 1—The Weibull median return interval and confidence interval in years for major, moderate, and minor crown releases at the four study stands during 1900-49 and 1950-99 time periods

Time period	Major/moderate crown releases[a] Median	CI	Minor crown releases[a] Median	CI
GA				
1900-49	13.6	5.5–26.6	5.2a	3.0 – 8.6
1950-99	na[b]	na	2.1b	1.2 – 3.0
SCI				
1900-49	6.3	1.0–12.9	1.4a	0.7 – 2.1
1950-99	na	na	1.5a	0.9 – 2.5
SCII				
1900-49	7.8	6.9–13.1	2.2a	0.9 – 3.8
1950-99	na	na	1.8a	1.1 – 4.2
TN				
1900-49	6.7	2.0–16.3	2.3a	0.9 – 4.4
1950-99	na	na	1.5a	0.8 – 2.4

[a] Medians with different lowercase letters are significantly different within that site at $\alpha = 0.125$.
[b] Insufficient number of releases for analysis.

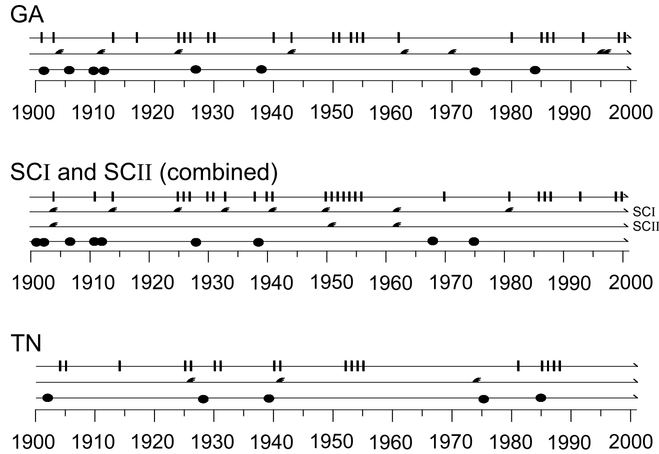

Figure 2—The number and temporal distribution of droughts, fires, and hurricanes in the GA, SCI, SCII, and TN study stands since 1900. Severe droughts (PDSI < -2.0) are denoted by short vertical bars, fires by diagonal slashes, and hurricanes by black dots.

major and moderate crown releases were most likely widespread fires, large-scale weather events, chestnut blight, and timber harvesting. From 1900 to 1950, at least 15 fires burned some or all of the 4 stands. Intermixed with the fires were 11 tropical storms. Chestnut blight moved through the region in the late 1920s (Keever 1953), and all stands had a significant chestnut component, especially GA. SCI and SCII experienced at least one logging operation.

There were several minor releases per decade during the first half of the 20th century. These events likely were lightning strikes, natural mortality of old trees, outbreaks of southern pine bark beetle (*Dendroctonus frontalis* Zimmermann), isolated fires, and thunderstorm downbursts.

Reoccurring droughts probably augmented the effects of all these disturbances. During the first half of the 20th century, 34 years were drier than average with 19 experiencing severe droughts. Fires occurring in drought years, e.g., the 1925 drought, and fires likely were more intense, severe, and widespread than those during non-drought years.

Since the mid-1950s, there have been virtually no major and moderate canopy releases while the frequency and number of minor releases have remained unchanged. Stand-level disturbances now are the exception. There were only four fires and six tropical storms. Logging occurred once at SCI and SCII and not at all at GA and TN. There have been no major disease epidemics like chestnut blight. Outbreaks of the bark beetle and minor weather events probably are the only disturbances that were similar in frequency between the first and second halves of the 20th century. The background disturbance of drought also was less common after the mid-1950s.

The tandem occurrence of tropical storms and surface fires may be a key event for perpetuating UYP stands. When a canopy-level disturbance occurs first, an ideal high-light environment is created for pine and oak regeneration. The stand also is predisposed to fire due to increasing fuel loads and insolation. A lightning strike or fire of human origin probably would burn more intensely in the aftermath of the preceding canopy disturbances than otherwise, opening sealed cones and reducing hardwood competition. Table Mountain pine seedlings that established in the aftermath of the initial canopy disturbance would be killed but would be replaced rapidly by new germinants. Pitch and shortleaf pine seedlings would sprout from the root collar. After several years of initial slow height growth, pine seedlings grow quickly and overtake competing hardwoods to form a new pine-dominated stand.

If the disturbance order were reversed, i.e., the fire occured first, understory hardwoods would be top-killed, and the sealed cones of Table Mountain pine would open. Although the canopy remains largely intact, there is sufficient sunlight for pine seedlings to survive. The following tropical storm, beetle infestation, or blight creates gaps in the canopy that ensure the young pines sufficient long-term light for some to eventually reach the canopy, ensuring perpetuation of a UYP community.

The intermixing of disturbances also means that no single disturbance need be catastrophic, that is, driving initial stand dynamics by itself. Canopy disturbances make low-and moderate-intensity fires more effective in controlling hardwoods and stimulating pine regeneration. It is easier for a surface fire in a partially-open stand to generate the necessary heat to girdle stems, consume leaf litter, and burn during the growing season than it is for a fire in a closed stand. Likewise, periodic fires keep the forest understory open, making the gaps that form more conducive to maintaining a pine component in a potentially hardwood-dominated stand. In the absence of the fire or canopy disturbance, continuous pine and oak recruitment ceases, as evidenced by the single fire and storm events after 1950. Additional research is needed on the effects of combined canopy and forest-floor disturbances on forest regeneration processes.

ACKNOWLEDGMENTS

Funding for this research was provided by the Joint Fire Science Program. We thank the Chattahoochee National Forest, Great Smoky Mountains National Park, and Sumter National Forest for permission to conduct research on their lands and guidance in locating the study stands. We are indebted to Jamie Browning, Kelly Irwin, and Helen Mohr for their hard work in collecting the cores and cross-sections from rugged stands under inhospitable conditions; Wendy Bish and Greg Sanford for preparing the cores and cross-sections for analysis; and Bryan Black, Bob Ford, and Jim Speer for guidance in cross-dating and conducting the analyses.

LITERATURE CITED

Armbrister, M.R. 2002. Changes in fire regimes and the successional status of Table Mountian pine (*Pinus pungens* Lamb.) in the southern Appalachians, USA. Knoxville, TN: University of Tennessee. 51 p. Masters thesis.

Carson, W.S.; Green, T.W. 1981. Soil survey of Rabun and Towns Counties, Georgia. Athens, GA: U.S. Department of Agriculture, Soil Conservation Service. 97 p.

Cook, E.R.; Holmes, R.L.; Bosch, O. [and others]. 1997. International tree-ring data bank program library. Version 2.1. http://www.ngdc.noaa.gov/paleo/treering.html [Date accessed: unknown].

Davis, H.A. 1993. Soil survey of Blount County, Tennessee. Knoxville, TN: U.S. Department of Agriculture, Soil Conservation Service. 121 p.

Grissino-Mayer, H.D. 2004. FHX2 user's manual: software for analyzing temporal and spatial patterns in fire regimes from tree rings. Knoxville, TN: University of Tennessee. 101 p.

Herren, E.C. 1985. Soil survey of Oconee County South Carolina. Columbia, SC: U.S. Department of Agriculture, Soil Conservation Service. 78 p.

Holmes, R.L. 1999. Program JOLTS: finding growth surges or suppressions in trees. Tucson, AZ: The University of Arizona, Laboratory of Tree-Ring Research. 65 p.

Keever, C. 1953. Present composition of some stands of the former oak-chestnut forest in the southern Blue Ridge Mountains. Ecology. 34: 44-55.

Lorimer, C.G.; Frelich, L.E. 1989. A method for estimating canopy disturbance frequency and intensity in dense temperate forests. Canadian Journal of Forest Research. 19: 651-663.

National Oceanic and Atmospheric Administration (NOAA). 2000. Temperature-precipitation data. www.ncdc.noaa.gov/oa/climate/onlineprod/drought/. [Date accessed unknown].

National Oceanic and Atmospheric Administration (NOAA). 2003. Historic hurricanes. www.hurricane.csc.noaa.gov/hurricane/index.html. [Date accessed unknown].

Nowacki, G.J.; Abrams, M.D. 1997. Radial growth averaging criteria for reconstructing disturbance histories from presettlement-origin oaks. Ecological Monographs. 67: 225-249.

SAS Institute. 2002. User's guide. Cary, NC: SAS Institute. 754 p.

Stokes, M.A.; Smiley, T.L. 1996. An introduction to tree-ring dating. Tucson, AZ: University of Arizona Press. 73 p.

Waldrop, T.A.; Brose, P.H. 1999. A comparison of fire intensity levels for stand replacement of Table Mountain pine (*Pinus pungens* Lamb.). Forest Ecology and Management. 113: 155-166.

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

Yarnell, S.L. 1998. The Southern Appalachians: a history of the landscape. Gen. Tech. Rep. SRS-18. Asheville, NC: U.S. Department of Agriculture, Forest Service. 45 p.

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