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RESEARCH NOTE

Fire History and Age Structure of an Oak-pine Forest on Price Mountain, Virginia, USA

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ABSTRACT: Fire history is an important aspect of the natural disturbance pattern of many types of forested ecosystems. Nonetheless, many forests and corresponding management plans lack quantitative information on fire interval, frequency, and seasonality. This project examined the fire history at Price Mountain, Virginia, using fire scar samples and tree-ring analyses from live tree chronologies. Additionally, this project investigated the fire scarring potential of two little-studied species, black gum (*Nyssa sylvatica*) and sourwood (*Oxydendrum arboreum*), as well as described the age-structure of the current stand. We hypothesized that fire frequency would be high prior to the fire suppression era, given the proximity to an historical railroad track at the base of the mountain and susceptibility to lightning due to elevation. Six major fire years occurred between 1861 and 1925 at an average interval of 14 years, followed by a period of no fires. Two-thirds of the fires burned early in the season. There was an initial establishment of sourwood and chestnut oak (*Quercus prinus*) from 1930-1940 as well as another establishment peak between 1950 and 1960 after a major logging event. Pine (*Pinus pungens* and *Pinus rigida*) species established between 1870 and 1930. Reconstructed fire history and age structure informs land managers that repeated fires occurred in this Appalachian ridge top forest and that modern forest structure is in part the legacy of historic fires and fire suppression.

Index terms: central Appalachians, dendrochronology, fire history, *Pinus pungens*

INTRODUCTION

Fire history is an important aspect of the natural disturbance and successional patterns of various types of forested ecosystems. Fire can act as a stand-replacing disturbance, or as a frequent lower-intensity disturbance, which may open small canopy gaps (White and Pickett 1985). Species composition depends greatly on this temporal variation in disturbance patterns. Some forest ecosystems develop a mix of species that are adapted to both stand-replacing and surface fires, though it has been widely agreed that hardwood species will dominate a site in the absence of fire (Harrod et al. 2000). Rhoades (2002) found that without a major disturbance, an oak (*Quercus* spp.) forest would eventually succeed to white pine (*Pinus strobus*) and red maple (*Acer rubrum*), two species that are considered fire intolerant. In contrast, nutrient-poor, sandy soils will maintain fire-adapted species such as table mountain pine (*Pinus pungens* Lamb.) and pitch pine (*Pinus rigida*) despite the absence of fire, as is seen in ridge-top forests of the Appalachian Mountains (Williams 1998). Ultimately, despite the maintenance of pine on these sites, continuous recruitment may not be possible without major disturbance events.

Previous fire history research in Appalachian ridge-top communities has shown that the disturbance regime in these areas includes both frequent low-intensity and infrequent severe fires (Aldrich et al. 2010), with a variety of ignition sources. Non-anthropogenic fires, typically originating from lightning strikes, occur less frequently than their anthropogenic counterparts (Lynch and Hessl 2010). Prior to the fire suppression era that began in the United States in the early 1900s, anthropogenic fires, from intentional land-clearing to those unintentionally ignited by railroad sparks, generated broader seasonality and higher frequency in fire regimes than has occurred previously (Fowler and Konopik 2007). Furthermore, the oak-pine communities found on these ridge-tops are resilient to both frequent and infrequent fire regimes (Barden 1977; Hessl et al. 2011), suggesting that periods of fire suppression will not eliminate the pine constituent from the forest. Waldrop and Brose (1999) similarly conclude that while fire plays a major role in pine regeneration, fire intensity does not need to be extreme to regenerate the pine component of the forest. Given the temporal and quantitative variability of these fire regimes, it is important to study fire history at small spatial scales to determine the disturbance regime for a particular forest tract. We investigated historical fire regimes of a ridge-top forest of southwestern Virginia by combining reconstructed fire history from scars on stumps, snags, and logs with tree age structure.

The objectives of our study were threefold: (1) to determine the fire history of Price Mountain in southwestern Virginia,

(2) to use the age structure of the current forest to interpret the impacts of historical fire regimes on forest structure, and (3) to investigate the potential of hardwood species such as black gum (*Nyssa sylvatica*) and sourwood (*Oxydendrum arboreum*) to serve as records of past fire events by maintaining datable scars in their wood structure. We hypothesized that Price Mountain was subjected to numerous fires in the past, and that the establishment dates of the trees in the current stand correspond to burns in the past. The results from this study can help inform management and provide insight into the effects of fire on ridgetop pine forest ecosystems.

METHODS

Study Area

The study was conducted on Price Mountain, in the Fishburn Forest, southwest of Blacksburg, VA (37° 11.19' N, 80° 28.86' W). The mountain is elliptical in shape, with an east-west trending ridge at approximately 730 m above sea level (Figure 1). Soils are composed of well-drained silty loams derived from shale, siltstone, and sandstone parent material (Creggar et al. 1985). Average annual precipitation is 1016 mm and average monthly temperatures are between -2 and 26 °C (NCDC 2005). The study was conducted on the southern aspect of the Price Mountain ridge staying within 30 m of the ridge trail, beginning approximately 100 m east of the VT/NPR radio tower and ending approximately 1000 m east of the tower. Slope ranged from approximately 0% at the ridge-top trail to 35% at 30 m down slope.

The mountain is now surrounded by development and farmland. A railroad, built in the early 1900s, skirts the southern and western sides of the mountain (Figure 1). Several mines once extracted anthracite coal, but were closed by the mid-twentieth century. Virginia Tech acquired the study

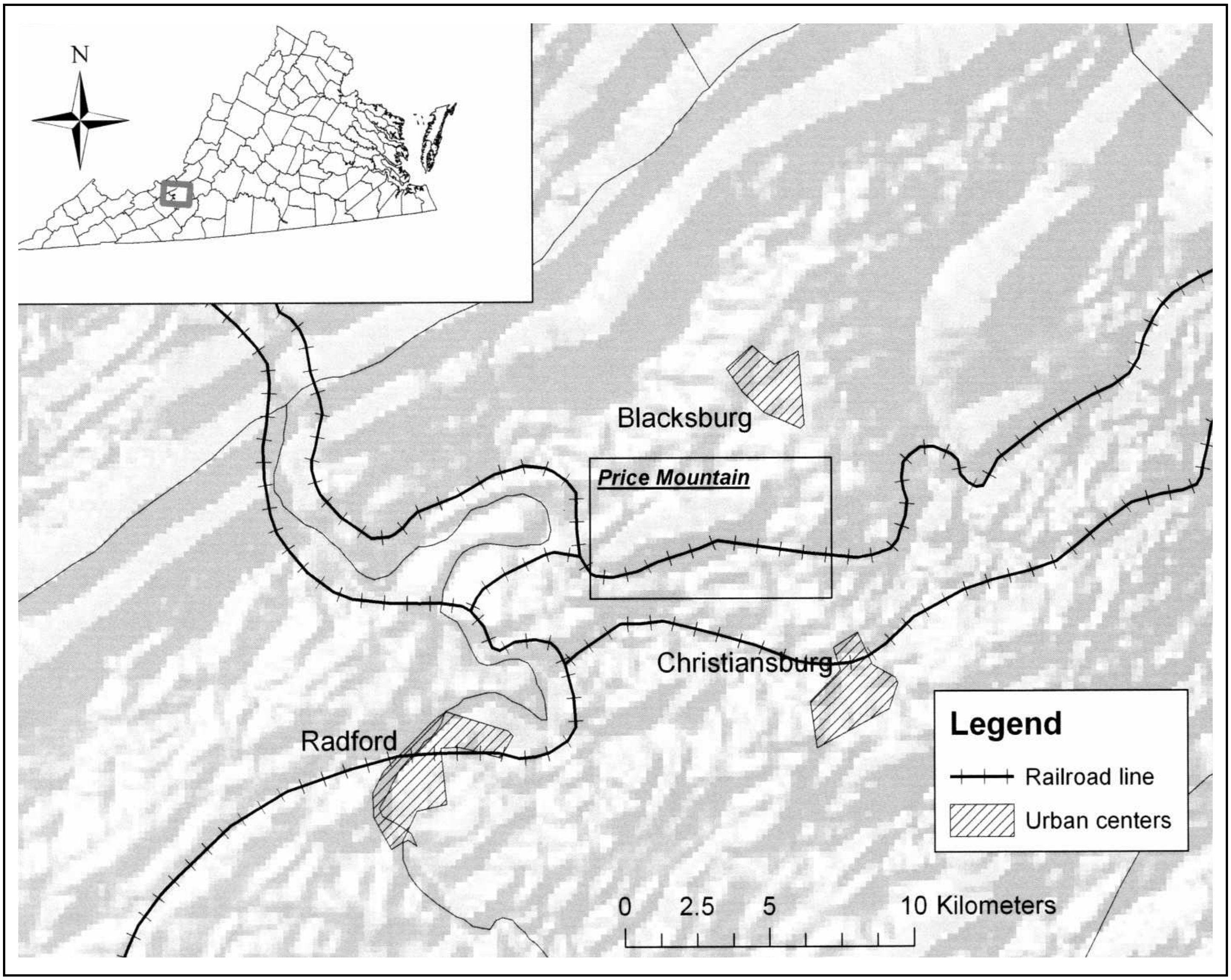

Figure 1. Map of Price Mountain, Virginia. Samples were collected from the south-facing slope.

area in 1929, and during the 1960s, the forest was logged for high-value timber (C. Copenheaver, Virginia Tech, pers. comm., 2011). The forest is now composed of a mix of *Quercus* spp, *P. rigida*, *P. pungens*, *N. sylvatica*, and other hardwoods. Since the 1930s, Virginia Tech has used the Price Mountain property for science labs, research projects, and, since the mid-2000s, has conducted prescribed surface burns (Harrell 2006).

Field Methods

Age structure data were collected in a randomly located 10-m radius circular plot. Within the plot, two increment cores were extracted from every tree ≥ 5 cm in diameter at breast height (dbh), and species, dbh (cm), and notable features such as crown damage were recorded. Cores were extracted 30 cm from the ground, parallel to the contour of the slope to avoid reaction wood in leaning trees.

To reconstruct fire events, cross sections were collected from both living and dead trees of pitch pine, table mountain pine, chestnut oak, black gum, and sourwood with basal scars in a study area of approximately 500 m long and 50 m wide. Basal sections were collected with a chainsaw from 30 cm above the ground surface when possible. On living, large-dbh trees with basal scars, one side of the basal scar was sectioned, leaving the tree standing. Dead individuals on the forest floor and standing dead snags were fully sampled. Species (or genus) of dead wood was recorded if known. Additional cores were collected in the study area from pitch pine, table mountain pine, and chestnut oak stems at a height of 30 cm to develop master tree-ring chronologies needed to date the fire-scarred samples; and dbh was recorded for each tree as well as the slope and aspect of their position.

Laboratory Methods and Data Analysis

Cores and cross-sections were sanded to maximize wood structure and ring boundary visibility. The ring of apparent fire scars and other injuries was noted. The seasonality of fire scars and injuries was noted as follows: dormant season, early earlywood, middle earlywood, late earlywood, latewood, or unknown (Speer 2010). The presence of pith or bark was also noted.

Skeleton plots of each species were assembled into master chronologies and the master chronology was used to assign calendar years to rings on each living and dead sample (Stokes and Smiley 1968). Fire scars for each sample were dated by recording the year in which they occurred; for samples taken from dead trees, scar dates were established by cross-dating samples to live tree chronologies. Several samples contained embedded scars of undetermined origin, which were recorded as injuries. Ring widths of dated tree ring series were measured to the nearest 0.001 mm using a dissecting microscope with a Velmex Measuring System and MeasureJ2X software (East Bloomfield, New York, USA). Chronologies were statistically verified using COFECHA (Holmes 1983). When a sample did not contain the pith, we overlaid concentric circles on the sample to estimate the number of rings between the inner-most ring and the pith (Applequist 1958).

Fire history was analyzed using FHX2 software (Grissino-Mayer 2001). We limited our analysis to fire events that scarred at least two trees and at least 25% of the recorder trees in a given year. Once trees had experienced fire, we considered them recorder trees. After identifying fire dates with these criteria, we assessed the dates of injuries on samples that we were not able to conclusively attribute to fire. Injuries that coincided with fire dates were added to the fire history data with the assumption that they were created by fire events. We generated a plot of fire dates using FHAES software, and used FHX2 to statistically analyze the dataset (Grissino-Mayer 2001). We calculated the following descriptive statistics: percent of fires in each season class, percent of early vs. late season fires, years with ≥ 2 fire scarred trees, percent of scarred trees in each fire year, and mean fire return interval. The sample size was too small to fit a Weibull distribution for calculated fire return interval. We conducted a Super Posed Epoch Analysis (SEA) (Haurwitz and Brier 1981) to compare fire years to a seven-year window of average spring and average fall Palmer Drought Severity Index (PDSI; Cook et al. 1999). PDSI values for the four years preceding the fire year, the fire year itself, and two years following the fire year were compared to simulated average PDSI values to identify if fire events were associated with abnormal moisture conditions. Simulated average PDSI and 95% confidence intervals were generated by 1000-seed boot strapping drawing from PDSI data between 1895 and 2011.

RESULTS

A total of 47 trees were sampled in the stand age structure plot, 29 cross sections sampled with fire scars and 33 trees sampled to develop master dating chronologies (Table 1). Chronology length varied between species with long chronologies (approximately 150 years) for *Q. prinus* and *P. rigida* and shorter chronologies (approximately 70 years developed for *O. arboreum* and *P. pungens*). A preliminary American chestnut (*Castanea dentata)* chronology was created and aligned with *Q. prinus* but could not be statistically confirmed due to short chronologies within a small sample size (N=8). The mean fire interval was 14 years and fire years with two or more injured trees were 1861, 1882, 1892, 1896, 1916, and 1925 (Figure 2), based on 15 of the 29 cross-sections collected. Early season fires were detected for 67% of the fire scars whereas 33% were late season fires. We ran two Super Posed Epoch Analyses but found no significant correlation with spring or fall PDSI (Figure 3).

Age structure indicated a period of establishment between 1930 and 1950 and continued establishment through 1980 (Figure 4). The pulse of establishment beginning in 1930 follows the last known date of fire from our fire scarred trees (1925). There was no *Pinus* spp. in the age structure plot, and thus we do not have establishment dates for pine, although the master chronologies contained individuals with establishment dates in the 1870s to 1930s for *P. pungens* and *P. rigida*, indicating continuous establishment prior to the inception of fire suppression.

Table 1. List of species sampled on Price Mountain, VA. Plot samples were collected from a 10-m radius age-structure plot. Fire scars represents cross-section collected for fire history reconstruction. Chronology samples were taken along the southern slope of Price Mountain. Number of scars and injuries, as well as fire season, are indicated for the fire scarred individuals.

Species	Plot	Fire Scars	Chronology	No. of scars/injuries	Fire season (Early/Dormant)	Total No. of trees
Quercus prinus	19	0	14			33
Nyssa sylvatica	11	3	0			14
Pinus rigida	0	0	14			14
Pinus spp	4	9	0	28	E/D	13
Oxydendrum arboreum	5	2	0	2	D	7
Castanea dentata	0	8	0			7
Acer rubrum	6	0	0			6
Pinus pungens	0	0	5	7		5
Quercus spp	0	5	0	2		5
Quercus rubra	1	0	0			1
Quercus coccinea	1	0	0			1
Robinia pseudoacacia	0	1	0			1
Carya glabra	0	1	0			1
Study totals	47	29	33			108

Within the age structure plot and along the hillside, we were able to collect samples from black gum and sourwood to evaluate the fire scarring potential of these species. We were able to date the fire scars for sourwood based on a master chronology generated from sourwood cores, but could not date the black gum samples due to complacent rings and short chronologies.

DISCUSSION

Fire dates indicate that fire suppression went into effect on Price Mountain around 1930 and only recently ended through prescribed burnings initiated by Virginia Tech in 2005-2006. Fire has been absent from the landscape since at least 1925 for many reasons including a change in land ownership, change in railroad fuel (coal to diesel), the advent of better fire fighting technologies, and growth in population near the study site. The mean fire interval of 14 years falls within the range of previous studies in the area (Schuler and McClain 2003; Aldrich et al. 2010; Hessl et al. 2011). Most of the fire scars occurred in the earlywood rather than during dormancy, which indicates that circa 1850-1930, fire disturbance occurred during spring in our study area. Fire years in our study site were not notably wet or dry, indicating that, for the fire years we identified, fire occurred independently of climate. This result was not surprising, given that the causes of fire during most of

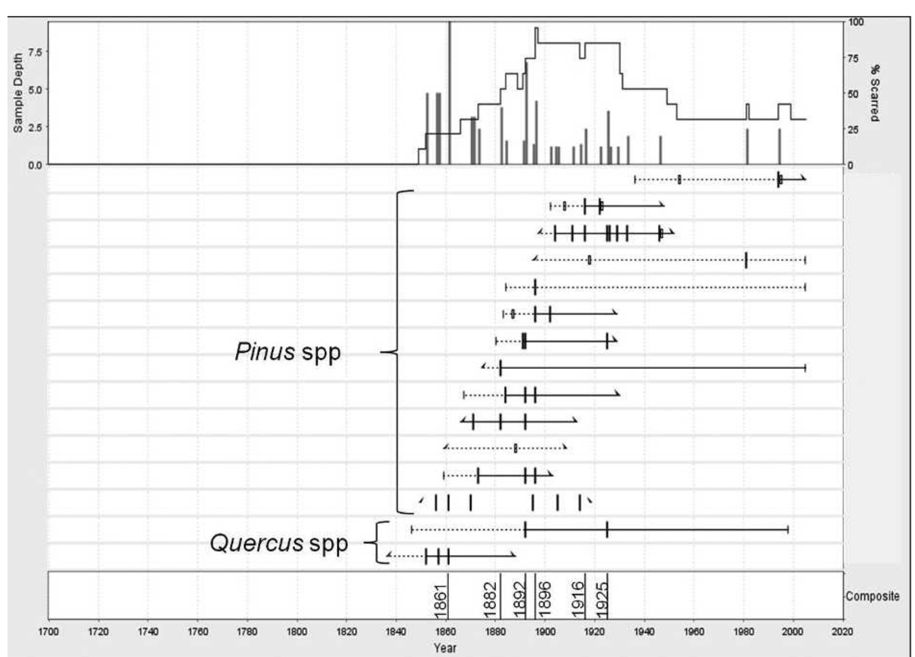

Figure 2. Graphical representation of Price Mountain fire chronology from FHAES and FHX2. Each horizontal line segment represents one sample with vertical lines representing fire and injury dates. Recorder trees are solid lines and non-recorders are dashed. Vertical lines at the bottom represent the composite fire history, including only dates with 2 or more fire scars and 25% of the scarred samples.

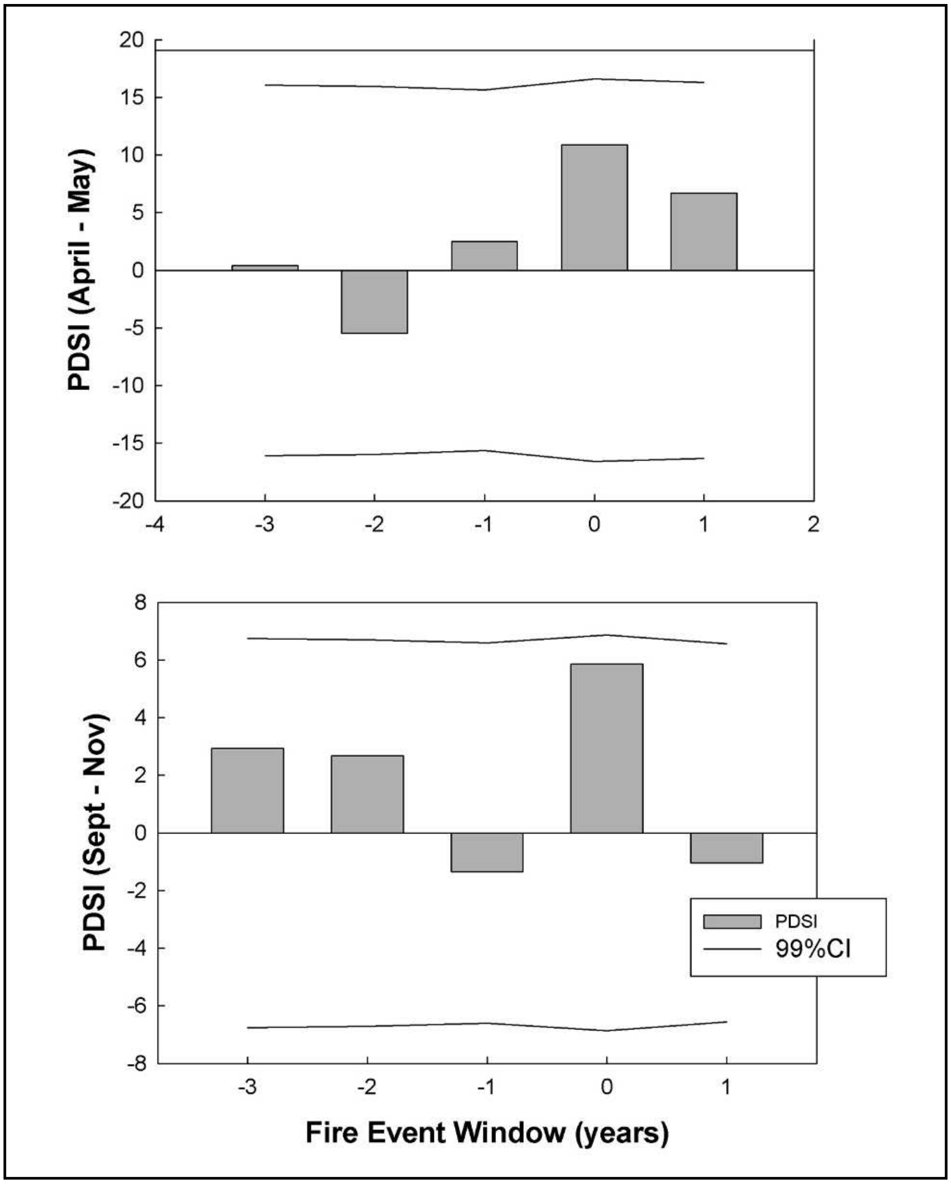

Figure 3. Super Posed Epoch analysis of fire events and the Palmer Drought Severity Index (PDSI) for the spring months (April – May) and fall months (September – November) averaged. Year zero represents fire events and no significance between PDSI and fire events was found (PDSI stayed within the bounds of the 99% confidence interval (CI) as shown by the solid lines above and below the bars).

our study period were anthropogenic. The seasonality of historical fires suggests that prescribed burns could be planned for the spring if managers hoped to approximate circa 1850-1930 regimes.

Our age structure plot was very similar to that of Copenheaver et al. (2006) indicating a pulse of establishment in the 1930s and 1940s, with another pulse beginning in the 1960s of similar species (Figure 4). Pulses of tree establishment on Price Mountain in the 1930s, 1940s, and 1960s coincided with the end of historical fires in the 1930s, the chestnut blight in the late 1930's, and the release from forest harvesting in the 1960s. These establishment pulses occurred for oak, maple, and other hardwoods, but we were not able to reconstruct age structure for *P. rigida* and *P. pungens* due to their absence from the sampled plot. *Pinus rigida* has been shown to be less drought-tolerant than *P. pungens*, but both may be able to survive on dry sandy exposed ridgetops despite fire suppression (Zobel 1969). Samples from pine trees dating to the late 1800s document a long-term presence of these species on the ridge-top, but a more detailed analysis of regeneration is necessary to confirm their persistence despite more recent fire suppression. The results suggest that the historically mixed severity and frequency fire-regime has not excluded pine species, but also provided regeneration opportunities for hardwood species. However, these results should be interpreted with caution given our small sample size.

It is also important to acknowledge the uncertainty and bias in fire history analysis, particularly regarding the mean fire return interval (Baker and Ehle 2001), and we acknowledge that our precise estimate of a mean fire return interval should be interpreted with caution. Through this study, we were able to establish that sourwood is a viable species for documenting site-specific fire histories. While black gum trees record fire scars, interpretation of their annual rings is particularly challenging. This may limit the potential of using this species to document fire history. There were record-breaking fires in southwestern Virginia in April of 2012 suggesting that fire, as a disturbance mechanism in these forest types, cannot be ignored. The results of this historical fire analysis can help put these modern fires in perspective and allow us to respond and manage forests more effectively.

ACKNOWLEDGMENTS

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Emily Silver is currently a Ph.D. student at the University of Maine, holding her M.S. in Silviculture from the University of Minnesota. She has taught courses in Field Biology and GIS at Brandeis University and her research ranges from dendrochronology and old growth structure to quantitative approaches to understand the

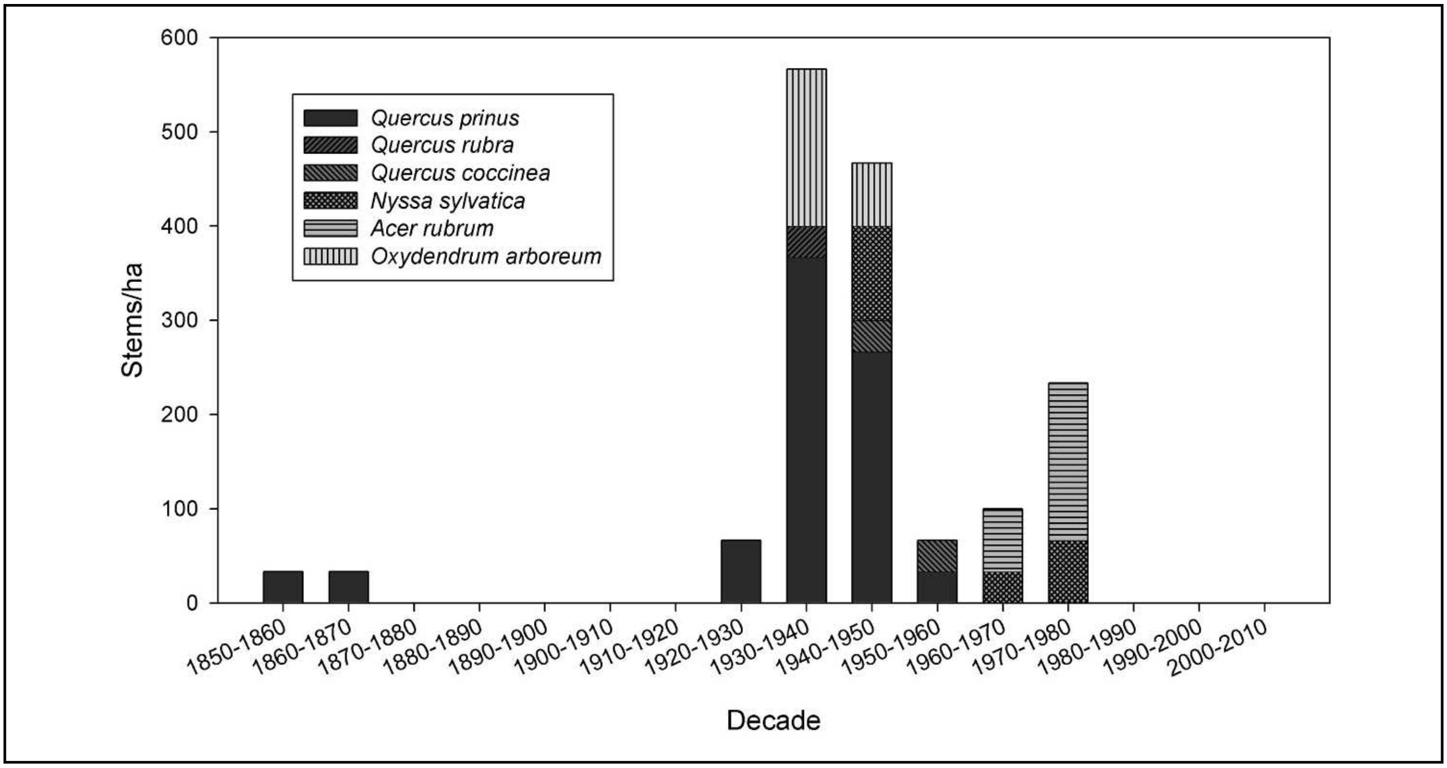

Figure 4. Establishment frequency of six hardwood species by decade on Price Mountain, VA. Data derived from increment cores in one 10-m radius circular plot.

dynamics of coupled human and natural systems.

Dr. Speer is a dendrochronologist at Indiana State University with experience in reconstructing environmental variables that affect tree growth, such as insect outbreaks, fire, masting, and climate. He is presently developing tree-ring chronologies in the tropics where previously researchers had thought that annual rings did not form. He has developed the first insect outbreak reconstructions on pandora moth, a frequent defoliator of western pine forests and he has developed new methods that enable dendrochronologists to use tree rings to reconstruct past fruiting in oak trees. He has received five NSF grants and many other federal grants to fund his work.

Dr. Kaye is an Assistant Professor of Forest Ecology at Penn State whose research themes include Northeastern forest regeneration and global change, impacts of woody shrub invasion on eastern forest dynamics, late-successional forest in the eastern United States, and climate, fire, and ecology of semi-arid pine forests in the western U.S. and Iberian peninsula. Dr. Kaye teaches field dendrology, forest fire management and ecology, ecological research in Spain, and introduction to tree-ring methods.

Dr. Nicholas J. Reo works with American Indian Tribes in the U.S. and other Native peoples on applied research concerning the management and use of natural resources. Nick explores the application, preservation, and outcomes of traditional resource management systems that are embodiments of tribal traditional ecological knowledge. He also studies the political interactions that occur between tribes and their neighbors surrounding natural resource issues, including cross-boundary cooperation and co-management of ecosystems and subsistence resources.

Dr. Wood is a post doctoral fellow at the University of Tasmania interested in combining historical data with spatial data to untangle the complex interactions between fire, vegetation, and soils that shape Australian vegetation communities. He is particularly interested in establishing long-term monitoring systems and developing dendro-ecological techniques to better understand past fire regimes.

Lauren Howard is an Assistant Professor of Plant Biology at Arcadia University in Glenside, PA. His scholarly interests include forest succession and disturbance, and his research explores the historic role of fire in shaping today's forest communities and the effects of contemporary controlled burning in the central Appalachian Mountains.

Alex Anning is a Ph.D. candidate at Ohio University holding a M. Phil. in Biological Sciences from Kwame Nkrumah University of Science and Technology (KNUST) in Kumasi, Ghana. Alex has several research interests in plant ecology including tropical forest/biodiversity conservation, forest structure and human disturbances, exotic plant invasions, phytoremediation, and dendrochronology. His current research, however, focuses on the effects of prescribed fire and thinning treatments on forest productivity and carbon sequestration in the mixed oak forest of the Central Appalachians.

Dr. Wilbur is a professor emeritus from the University of Virginia. His research focuses on population and community ecology from an evolutionary perspective. He spends his summers at the Mountain Lake Biological Station, a facility of the University of Virginia, supervising REU students and conducting his own research.

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