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RESEARCH ARTICLE

Fire History of a Rimrock Pine Forest at New River Gorge National River, West Virginia

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ABSTRACT: The fire history of a rimrock pine forest at the New River Gorge National River, West Virginia, was studied using 21 fire-scarred *Pinus virginiana* Mill. (Virginia pine) cross-sections. Fire frequency and the goodness-of-fit between the fire interval distribution and the normal and Weibull distributions were evaluated with the FHX2® program. A 107-year fire chronology (1898-2005) was constructed from 53 fire scars. Fire intervals ranged from 1 to 8 years. The Weibull median interval was approximately 3 years using liberal (one or more trees scarred during a single year) or conservative (two or more trees scarred during a single year) criteria. Similar to other mixed forest stands in the Central Hardwood Region, fires in the 20th century were likely ignited from coal mining activities and steam-driven locomotives near the study site. Anthropogenic fires may have caused an artificial increase in rimrock pine forests or allowed pines to persist in greater numbers than would be possible in the absence of disturbance. Restoration (e.g., prescribed burning) is probably not needed to retain *P. virginiana* as a component of the rimrock forest, but the species' dominance will continue to be restricted on the rim of the gorge.

Index terms: fire history, New River Gorge National River, *Pinus virginiana*, West Virginia

INTRODUCTION

The historic role of fire in forests of the eastern United States has seen a recent upsurge in interest. Investigators propose that a regime of frequent, low-intensity fires has occurred over the majority of the region (Pyne 1982; Abrams 1992; Brose et al. 2001), but the range of sites and vegetation types from moist mesophytic to xeric pine-dominated ridges would suggest that a variety of fire regimes existed in the past. Specific knowledge of fire regimes (e.g., frequency, intensity, seasonality, and extent) is necessary for the management of different vegetation types to achieve forest regeneration and ecosystem restoration objectives. The application of tree-ring analysis to date fire scars formed within the annual rings of trees has been useful in determining historical fire frequency, seasonality, and extent of surface fire regimes in western (e.g., Grissino-Mayer and Swetnam 2000; Veblen et al. 2000; Swetnam and Baisan 2003), and in some eastern, forests of the United States (e.g., Shumway et al. 2001; Guyette et al. 2002;). However, management requires a better understanding of how fire has behaved over time and space on the natural lands in the eastern United States; tree-ring analysis may be one of the best tools to accomplish this goal.

While most eastern forests, particularly those of the Central Hardwood Region (CHR), are dominated by broadleaf deciduous species, the genus *Pinus* L. is locally significant on ridges, rock outcrops, and south-facing aspects. Fire history data from contemporary records (e.g., Lafon et al. 2005; Lafon and Grissino-Mayer 2007) and tree rings support an association between vegetation and fire (natural or anthropogenic) in stands throughout the CHR. For example, Brose and Waldrop (2006) utilized tree-ring techniques to study fire and the origin of *Pinus pungens* Lamb.– *Pinus rigida* Mill. communities in the southern Appalachian Mountains. The authors found that regeneration of pine appeared dependent on a combination of low-severity surface fires and canopy disturbances. Other tree-ring investigations of fire frequency in pine and oak (*Quercus* L.) communities of the CHR have indicated fire-return intervals 2 to 20 years (Harmon 1982; Shumway et al. 2001; McEwan et al. 2007). Though studies located in the oak-pine interface do not represent the CHR as a whole, this research has provided valuable data for managing stands on upper slopes and south-facing aspects.

We conducted a tree-ring analysis of *Pinus virginiana* Mill. (Virginia pine) to determine the frequency and seasonality of the fire regime (i.e., fire history) of a rimrock forest located within the New River Gorge National River, West Virginia (NERI). According to the Natural Resource Assessment for NERI (Mahan 2004), rimrock pine forests are considered historically significant and in danger of decline due to the lack of disturbance (i.e., fire) and increased visitor usage. With quantitative evidence of the fire regime, the National Park Service will be better prepared to manage, and possibly restore, rimrock pine forests at New River Gorge.

METHODS

Land Use History of NERI

One challenge for current forest management at NERI is to document the long history of land use in the area. The earliest and largest recorded land survey in Fayette County of the Commonwealth of Virginia occurred in 1785, granting 16,463 ha along the New River to Henry Banks. In subsequent years, land was granted to hundreds of individuals along prominent branches of the New River with the more fertile land being claimed first (Peters and Carden 1926). By the time West Virginia became an official state in 1863, settlers occupying land in Fayette County were clearing forests for agriculture, raising of livestock, and probing the surface of New River Gorge for salt and coal.

The completion of the Chesapeake and Ohio Railroad in 1873 allowed coal extraction to become a profitable business in the New River Gorge, which greatly increased the rate of forest disturbance (e.g., timbering and wildfire). The Nuttallburg Coal Company operated two mines near the study site. The Nuttallburg mine, located on the slope of the gorge, was well-equipped with steam-driven machinery that served as a potential ignition source for wildfires. Additionally, the steam-driven locomotives that frequently passed through the gorge may have ignited fires that burned rapidly up the slope toward the rimrock pine forests.

To support the coal industry, companies purchased additional acreage to meet the timber requirements of the mines and mining towns. Brooks (1910) reported that the land surrounding the approximately 150 mines in the New River Gorge was harvested (and often burned) by the early 1900s, leaving about 21,450 ha (of ~173,100 ha) of virgin forests in the county. Though timber cutting and coal mining are no longer allowed within park boundaries, the lingering impact of decades of coal extraction and timbering has resulted in changes in species composition, forest structure, and disturbance regimes. Mining activities in the New River Gorge ceased in the 1950s and 1960s resulting in the abandonment of towns along the bottom of the gorge and, presumably, a decrease in the amount and rate of forest disturbance. In 1978, the New River Gorge was designated a national river by the National Park Service. Approximately 27% of the land zoned within the national river boundary belongs to private landowners. The New River Gorge National River has > 1 million visitors each year.

Study Area

The study area consisted of a linear stand (~100 ha) located 4 km east of Fayetteville, West Virginia, along the Endless Wall in NERI (38°03′15″N, 81°03′32″W; Fayetteville 7.5-min. quadrangle; Figure 1). The Endless Wall is a 15 to 35 m high sandstone cliff that extends approximately 6 km along the northern section of the gorge. The study site was located along a south-facing aspect of the gorge at an elevation of 580 m asl with slope ranging from 0 to 40%. Mean annual temperatures are 9.5 °C with high and low mean monthly temperatures of 20.1 °C and -1.9 °C recorded in July and January, respectively (Beckley, WV; National Oceanic and Atmospheric Administration 2005). Mean

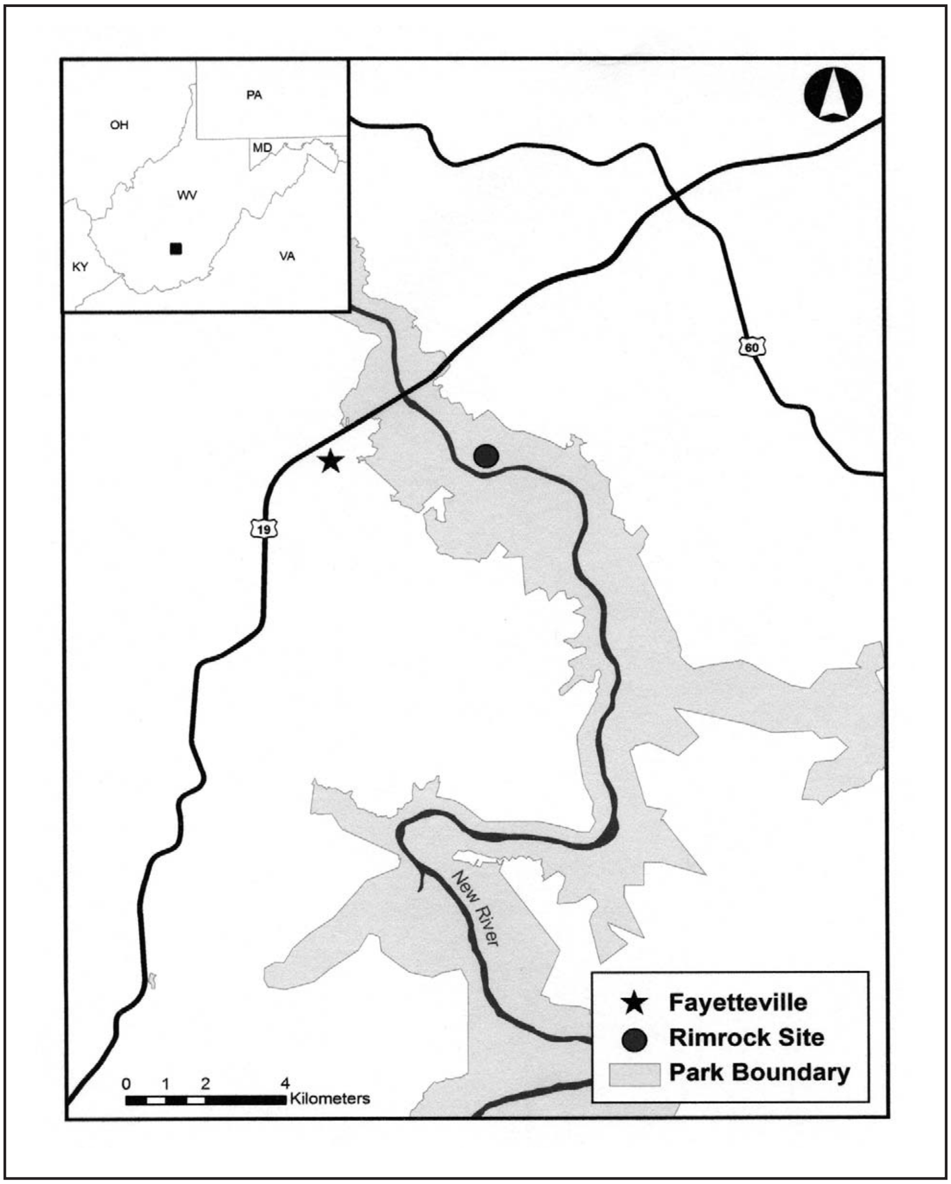

Figure 1. Study site location east of Fayetteville, WV.

annual precipitation is 100 cm and the mean annual snowfall is 91 cm (National Oceanic and Atmospheric Administration 2005). Precipitation is greatest during July but the area has no pronounced dry periods during the year.

The New River Gorge is a prominent physical feature on the landscape of the southern Allegheny Plateau, reaching over 300 m in depth and 1.6 km in width. Braun (1950) classified this area of the Allegheny Plateau as a mixed-mesophytic hardwood forest. *Quercus* spp. (oak), *Liriodendron tulipifera* L. (yellow-poplar), *Acer rubrum* L. (red maple), *Tsuga canadensis* (L.) Carr. (eastern hemlock), and other mesic species currently predominate within the park. However, unique forest communities, such as the rimrock pine forest, also exist within NERI. Several factors are responsible for the establishment and maintenance of the diversity at the park, including past and present land use, disturbance regimes, differences in aspect, slope, and elevation, and a mosaic of soil types.

The rimrock pine forest type is characterized by a canopy of *P. virginiana*, *Nyssa sylvatica* Marsh. (black gum), *Oxydendrum arboretum* (L.) DC. (sourwood), *A. rubrum*, and *Quercus* spp. Maxwell and Hicks (2007) found that the importance and frequency of *P. virginiana* decreased with distance from the cliff edge. Also, regeneration of shade-intolerant *P. virginiana* was sparse except near the cliff edge where more direct light was available.

Field and Laboratory Methods

To assess the fire history of the rimrock forest, stem cross-sections were collected from fire-scared live and dead *P. virginiana* (n = 21) at two sites (Fern Creek and Short Creek) within the study area. Cross-sections were dried, surfaced, and sanded according to standard dendrochronological techniques (Stokes and Smiley 1968). Then, cross-sections were skeleton plotted and crossdated by matching narrow tree-ring widths to assign a year to each ring. Skeleton plots from each cross section were crossdated against a *P. virginiana* master chronology developed from increment cores taken from live trees (16 trees/31 cores) at the study area (Maxwell and Hicks 2007) and a *Pinus rigida* Mill. chronology from the Ridge and Valley province (Sutherland et al. 1996).

Seasonality of each fire scar was determined by noting the position of the scar within the annual ring (Dieterich and Swetnam 1984). Fire scars located between the latewood of one growth ring and the earlywood of the next growth ring were identified as dormant season events and were assigned to the year of the previous full growth ring. Thus, a fire burning during the dormant season of 1953 may have occurred in the fall of 1953 or the spring of 1954.

Distributions of fire scar dates may not be adequately described by symmetrical measures of central tendency because there is no upper bound to fire-free periods and the lower bound can never be negative (Schuler and McClain 2003). Grissino-Mayer (2001) suggested that a two-parameter Weibull distribution would be more appropriate to characterize such distributions because fire scar dates tend to be positively skewed. With the Weibull distribution, a 0.50 exceedance probability is the 50th percentile, or the central tendency, of the distribution. Fire scar dates, seasonality, and inner and outer dates of each sample were entered into the FHX2® program to evaluate the goodness-of-fit between the fire intervals and the empirical and Weibull distributions using a one-sample Kolmogorov-Smirnov (K-S) test ($P \leq 0{,}05$) (Grissino-Mayer 2001). Following the methods of Schuler and McClain (2003), two criteria (conservative and liberal) were used to estimate composite fire intervals. A composite represents fire information from each tree-ring series at a site. The conservative criterion was a year when two or more trees recorded a fire event. The liberal criterion was a year when one or more trees had a fire scar. Additionally, box plots were created to display the median, quartile, and minimum and maximum fire interval values for each sample location and both sites combined.

RESULTS

A 107-year fire chronology (1898 to 2005) was constructed from 53 fire scars recorded by 21 trees along the Endless Wall in New River Gorge National River, West Virginia (Figure 2). All fires occurred in the dormant season. Pith dates from cross-sections ranged from 1898 to 1961. Fires were detected by at least one sample in 25 different years with the largest fires (≥ 5 fire-scarred trees) occurring in 1946, 1953, and 1970. The median fire-return interval (MedFI) for all sites was 4 years (using a minimum of one recorder tree) with minimum and maximum return intervals of 1 and 8 years, respectively (Figure 3; Table 1).

Fire-interval data were analyzed separately for each site. Fifteen trees were sampled from the Short Creek site and 13 fire intervals were recorded in the site chronology using the liberal criterion. A conservative criterion was not used to evaluate the intervals between fires at individual sites due to the small sample size. Schuler and McClain (2003) noted that the K-S test lacks robustness when the number of intervals being evaluated is small. Using the liberal criterion, the K-S test indicated that both the empirical ($P > 0.59$) and Weibull ($P > 0.99$) distributions adequately described the interval data. The MedFI and Weibull median fire interval (WFI) were both 4 years.

Six cross-sections were collected from the Fern Creek site and 13 fire-intervals were recorded in the site chronology. Using the liberal criterion, the K-S test indicated that the fire intervals only could be described by the Weibull ($P > 0.94$) distribution. The Weibull distribution yielded approximately a 5-year return interval for the Fern Creek site.

For the composite chronology (Fern and Short Creek sites), the empirical and Weibull distributions adequately modeled ($P > 0.52$ and $P > 0.55$, respectively) the intervals between fires when using the liberal criterion. Both the MedFI and WFI were 3 to 4 years (Table 1). Only the Weibull distribution was suitable ($P > 0.93$) to model the data under the conservative criterion; however, the distribution was skewed by a single 16-year interval. Measures of central tendency were again similar under the conservative analysis

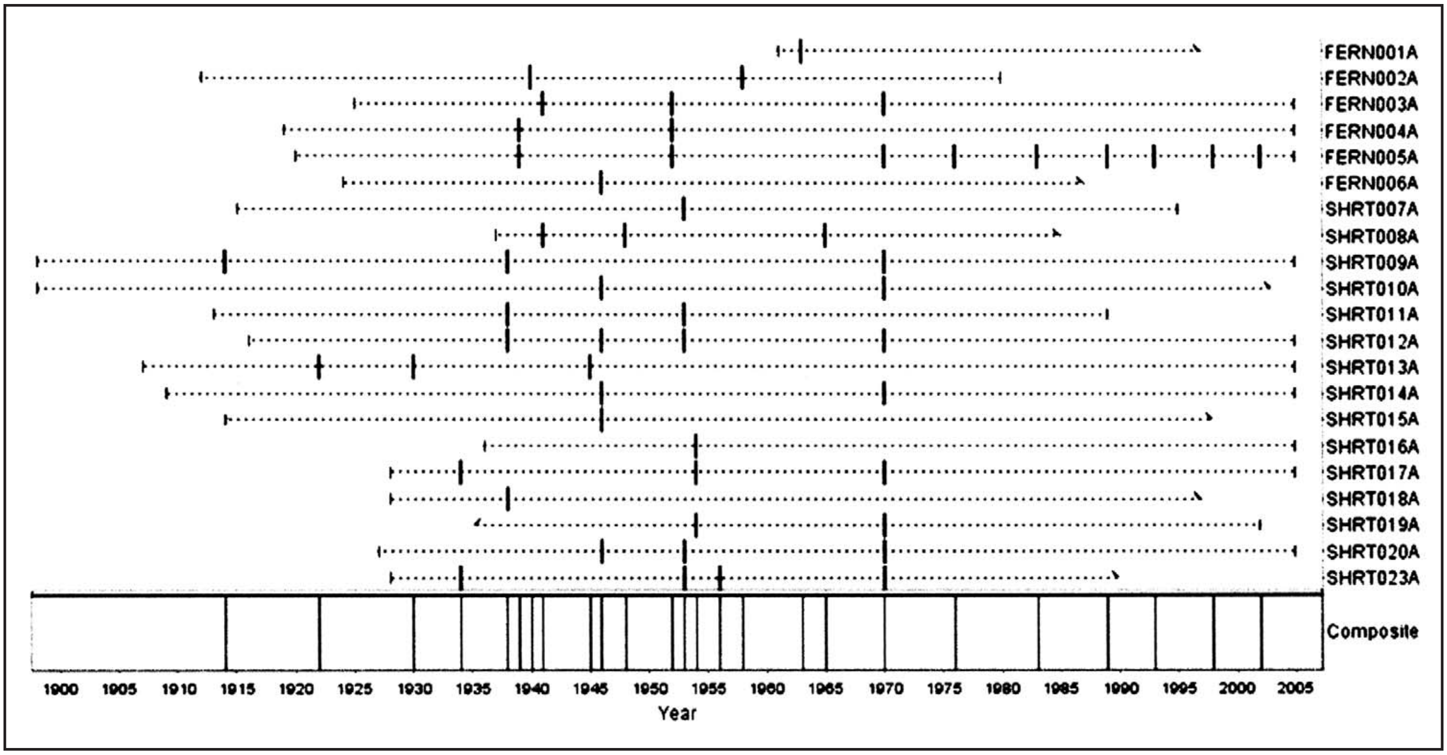

Figure 2. Fire-scar chronology from 21 Pinus virginiana stem samples collected from the Endless Wall in the northern section of New River Gorge National River, West Virginia. Each horizontal line (dashed) represents the annual rings of one sample cross-section. Vertical lines represent pith dates (left) or outer ring dates (right). Forward slashes represent earliest dated annual rings when pith was not present. Back slashes represent outermost ring of samples without bark. Bold vertical bars represent fire events. The composite includes fire information from all individual tree-ring series.

resulting in fires occurring approximately every 3 to 4 years (Table 1).

Fires ceased from the 1950s to present with few exceptions (Figure 2). Notably, sample FERN005A continued to document fire disturbance into the 21st century. FERN005A was located on a heavily-used area next to a private farm and may have been scarred by localized fire incidents related to farming and hunting activities. The cessation of fires (in most samples) coincided with the final closing of the Nuttallburg mine in 1952, the post office in 1955, and the train depot in 1962. Also, the transition from steam- to diesel-powered locomotives on the Chesapeake and Ohio Railroad in the late 1940s to early 1950s may have contributed to the cessation of fire activity throughout the New River Gorge. However, a stand-wide fire in 1970 resulted in the greatest percentage of fire-scarred trees (43%) with evidence of fire present at both sites along the Endless Wall (Figure 2). In the absence of mining and timbering, the current ignition source is unknown. The designation of the New

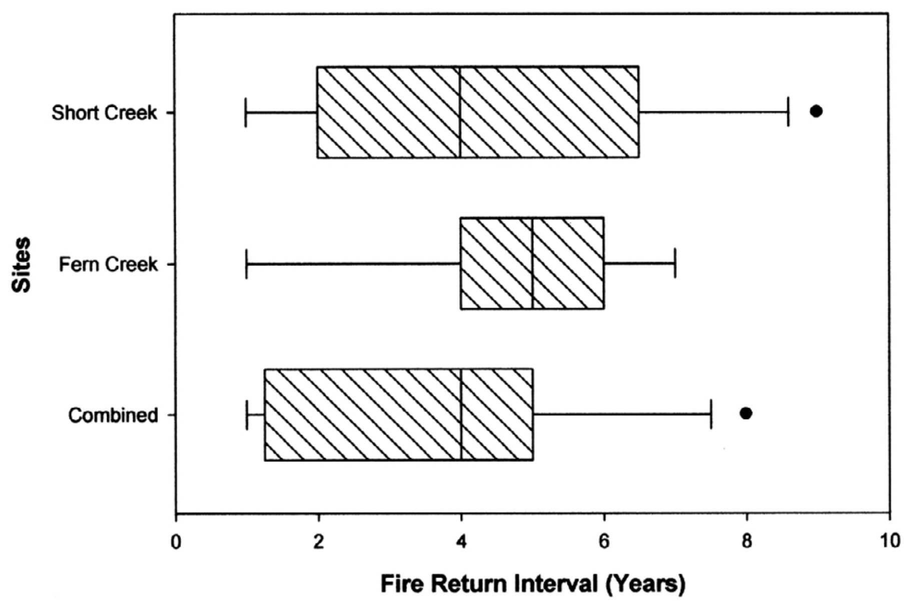

Figure 3. Fire-return interval box plots for Short Creek (n = 13), Fern Creek (n = 13), and Combined site composites (n = 24). Intervals were calculated using the liberal criterion. Note that fire interval data were not adequately modeled with the empirical distribution at the Fern Creek site; however, data are presented for comparison.

Table 1. Fire interval analysis for the combined composite chronology using liberal (at least 1 tree recording a fire event) and conservative (at least 2 trees recording a fire event) criteria.

	Liberal criteria	Conservative Criteria
Total intervals	24.0	8.0
Median fire interval (yrs)	4.0	3.0[a]
Mean fire interval (yrs)	3.7	4.5[a]
Standard deviation (yrs)	2.3	5.0
Weibull median fire interval (yrs)	3.3	3.2

[a] Fire interval data were not adequately modeled with the empirical distribution using the conservative criterion; however, data are provided for comparison.

River Gorge as a national river in 1978 introduced an active fire suppression policy explaining the near absence of fire scars in recent decades.

DISCUSSION

The purpose of our study was to reconstruct the fire history (including frequency and seasonality) of a rimrock pine forest at the New River Gorge National River, West Virginia, with tree-ring data. The primary species of interest, *P. virginiana*, requires disturbance, such as logging or fire, to regenerate on competitive sites (Fenton and Bond 1964; Carter and Snow 1990). These disturbances prepare the seedbed by exposing mineral soil and opening the canopy to provide direct sunlight for seedling establishment. In the present study, fires on sites dominated by *P. virginiana* were found to occur every 1 to 8 years during the 20th century. The WFI at each site was 3 to 5 years when using one tree as an indicator of a past fire. Larger fire events, injuring at least five trees, were recorded in 1946, 1953, and 1970. Despite the size of these large fires, the presence of fire-scarred survivors indicates low-intensity events. Compared to other mixed forest types in the CHR, fires occurred with similar frequency along the rimrock. For instance, McEwan et al. (2007) investigated temporal and spatial patterns of fire occurrence in mixed-oak forests on the Allegheny and Cumberland plateaus and found fires occurred every 6 to 7 years during a period of frequent burning from 1875 to 1936.

The relationship between fire return and the establishment and maintenance of some forest communities in the CHR appears to be dependent on human population, cultural development, and a shift from a subsistence culture to a technological society (Guyette et al. 2002). The similarity between the fire return intervals estimated in the present study to both pine and mixed forest communities in CHR is likely explained by common ignition sources and land-use history during the late 19th and early 20th centuries. While natural fires caused by lightning do occur in the eastern United States (e.g., Blue Ridge Province; Lafon and Grissino-Mayer 2007), the majority of historic fires have been caused by human ignition sources (Abrams 1992). In Appalachian mixed-oak forests, steam-driven locomotives and mining activities have been identified as potential ignition sources (Pyne 1982; Brose et al. 2001; Shumway et al. 2001); and the history of NERI suggests that these ignition sources were common during the 19th and early 20th centuries. The operation of more than 150 mines and continuous traffic on the Chesapeake and Ohio Railroad provided ample sources of ignition needed to drive an anthropogenic fire regime in the gorge.

Ignitions from steam-driven locomotives and mining activities would have produced fires that burned quickly up the slope of the gorge with increasing intensity and flame length. To reach the rimrock above the 15 to 35 m high sandstone cliffs, the fire had to travel up vegetated gaps or ignite from burning debris landing on the top of the cliff. Alternatively, fires may have been ignited on surrounding timberland, farmland, or open mines present on the plateau above the gorge. The presence of live fire-scarred *P. virginiana* suggest that the fires were of low to moderate intensity once burning began along the rimrock forest. The linear form of the rimrock pine forest may have allowed only small sections of the rimrock to burn during each event. This is evidenced by the greater number of short fire-return intervals calculated from the composite fire chronology for the entire study area. A frequent fire regime of this type would have allowed dominant pines to survive while creating small patches of even-aged regeneration. However, it must be noted that due to low sample size, fire-return intervals calculated using a single recorder tree must be interpreted with caution. Future work should concentrate on increasing sample size across the study area to detect replicable differences in the spatial and temporal behavior of fire.

Fire records from 1939 to present (West Virginia Division of Forestry, unpubl. data) confirm the presence of frequent fires in the vicinity of the study area during periods of mining. The West Virginia Division of Forestry reported a greater number of fires occurring in Fayette County during the spring fire season than the fall fire season with the average spring in the 1940s and 1950s having 50 fires. Though spring fires burned more often, fall fires have historically accounted for the most extensive fires in the county with an average of 2430 ha burned in each year during the 1950s. The largest fire year occurred in 1952 when 118 fall fires burned over 15,780 ha. The present study found 100% of fires occurred during the dormant season (including the period of the spring prior to budbreak). In a spatial analysis of fire occurrence (1970 to 2003) in the central Appalachians of Virginia, Lafon and Grissino-Mayer (2007) found a similar pattern of increased anthropogenic fires in the fall and spring during the period of tree dormancy.

The current fire history study (1898 to 2005) covers the period of intense land use in the New River Gorge. Mining activities and the resulting fires may have caused an artificial increase in rimrock pine forests or allowed pines to persist in greater numbers than would be possible in the absence of disturbance. A conflict arises between managing for, and restoring to, a period of known disturbance history and land use (i.e., 20th century) and restoring the rimrock to an unknown disturbance history prior to that reported in the present study. While *P. virginiana* has most likely been an important component to the rimrock pine community, the vegetation and disturbance history prior to the 20th century are based only on anecdotal accounts. Returning to a disturbance history established during the mining and timbering period of the 20th century may not be prudent as these activities are no longer permitted within the park. In the absence of disturbance, regeneration of *P. virginiana* forests along the New River Gorge will decline except where the species persists as an edaphic climax on the exposed sandstone lining the rim of the gorge (Maxwell and Hicks 2007). Finally, our circumscribed study of disturbance history along the rimrock does not account for the historic role of fire to surrounding forest communities. To provide a better understanding of fire history in rimrock pine forests at the New River Gorge National River, it may be necessary to investigate the disturbance history of vegetation growing on the slopes of the gorge and plateau.

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