RESEARCH ARTICLE

Forest Disturbance History from 'Legacy' Pitch Pine (*Pinus rigida*) at the New River Gorge, West Virginia

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ABSTRACT: The mesosphytic forests of eastern North America represent a forest region characterized by dramatic 20th century changes in disturbance regimes, notably the exclusion of fire. Tree-ring reconstructions of forest disturbance can inform restoration and management plans by placing these changes into a historical context. This study examined forest disturbance with regard to land use change and drought in the New River Gorge region of West Virginia. I developed a 182-year pitch pine (*Pinus rigida*) growth chronology (1833–2014) using samples collected from 33 trees along 2 km of south- and southwest-facing slopes at Babcock State Park. Samples cut from fire-scarred pitch and Virginia pine (*Pinus virginiana*) were used to generate a fire chronology for the site. Temporal trends in pitch pine growth variability were assessed using regime shift and growth release detection methods. There was no change in pitch pine growth during the transition from the early settlement to industrial era (ca. 1885), while a significant decrease in annual growth variability characterized the post-industrial era (1963–2014). Seventeen fire events were recorded between 1887 and 1968. Growth releases displayed a temporal relationship with fire and there was a strong, but not significant, association between drought and fire years. These results suggest a coupled system in which anthropogenic fires driven by periodic drought maintained pitch pine before and during industrialization. Reintroducing fire to the post-industrial forest may not meet management objectives as decades of fire exclusion have altered forest fuels and species composition such that its effects would be difficult to predict.

Index terms: Central Appalachians, dendrochronology, fire history, fire management, *Pinus rigida*

INTRODUCTION

The mixed-mesophytic forest region defined by Braun (1950) is the most biologically diverse forest region in eastern North America. It principally includes the southern unglaciated Appalachian and Cumberland Plateaus, extending from southwestern Pennsylvania to northern Alabama west of the Appalachian highlands and east of the Mississippi lowlands. Dyer (2006) developed an updated map of Braun's forest regions, which expands the mesophytic forest region (renamed) to include Braun's western mesophytic and oak-chestnut forest regions. Red maple (*Acer rubrum* L.) has the highest average importance value in this new region, reflecting contemporary climate trends, land use patterns, and disturbance regimes. In addition to the exclusion of fire, a 20th-century wetting trend and increased herbivory from white-tailed deer (*Odocoileus virginianus* Zimm.) and wild turkey (*Meleagris gallopavo* L.) have favored shade-tolerant, mesophytic species, such as red maple, at the expense of oak (*Quercus* spp.) (McEwan et al. 2011). This phenomenon, referred to as the "mesophication" of eastern oak forests (Nowacki and Abrams 2008), has generated many dendroecological investigations into the historical role of disturbance, particularly fire, within the mesophytic forest region (e.g., McEwan et al. 2007; Hutchinson et al. 2008; Aldrich et al. 2014).

Within the mesophytic forest region there exist locally unique xeric and sub-xeric patch communities embedded within the greater landscape. These communities, including ridgetops and south- and southwest-facing slopes and rock outcrops, often include pyrogenic species dependent on periodic fire for regeneration (Lafon et al. 2014). Tree ring-based fire history studies within the mesophytic forest region often target these communities because they have a known history of fire occurrence and they are composed of pine species (*Pinus* spp.), notably pitch (*P. rigida* Mill.), Table Mountain (*P. pungens* Lamb.), or Virginia (*P. virginiana* Mill.), that preserve the fire record in resin-rich cambial wounds. This targeted approach to understanding the historical role of fire in the mesophytic forest region has its limitations as noted by Matlack (2013), who cautions against using these studies to guide landscape-scale prescribed burning programs. Fire is known to occur across ecological gradients, however, and the information gained from targeted studies should inform management decisions in the absence of fine-scale fire and plant community data (Stambaugh et al. 2015).

In this study, I used pitch pine to reconstruct the disturbance history of a pine-oak forest situated on south- and southwest-facing slopes at Babcock State Park, West Virginia, within the mesophytic forest region (Figure 1). The relative isolation of the study site and known dates of land use change and industrialization provide an excellent opportunity to examine forest disturbance patterns in the New River Gorge region. Pitch pine was selected as the prime recorder of forest history, given its site age and the fact that much of dendroecological record in this region has either been logged or consumed by fire. Additionally, pitch pine is generally shade-intolerant and establishment is best on bare mineral soil (Greenwood et al. 2002), such that its presence within the contemporary mesophytic forest is an indicator, or legacy, of past disturbance. Specifically, my objectives were to (1) develop the first large sample tree-ring record that pre-dates industrialization in the New River Gorge region; (2) reconstruct the fire and canopy disturbance history of a mixed pine-oak community embedded within the mesophytic forest region; and (3) test the relationship between climate and disturbance in the context of land use change and industrialization.

METHODS

Study Site

Sewell, situated at the mouth of Manns Creek on the New River (Figure 1) and originally known as Bowyer's Ferry, was the first Euro-American settlement in the New River Gorge (ca. 1798). Sewell remained undeveloped until the Chesapeake and Ohio Railroad was completed in 1873 and the Longdale Iron Company opened its mines and the Gorge's first major coking operation at Sewell in the same year (Peters and Carden 1926). In 1883, when the coal was exhausted in the mines above Sewell, the Longdale Iron Company opened mines along Manns Creek near Clifftop (see Figure 1). The substantial difference in elevation between Sewell and Clifftop (>350 m) required that a narrow gauge railroad be built to move coal from the mines near Clifftop to the coke ovens at Sewell. Surveying for the construction of

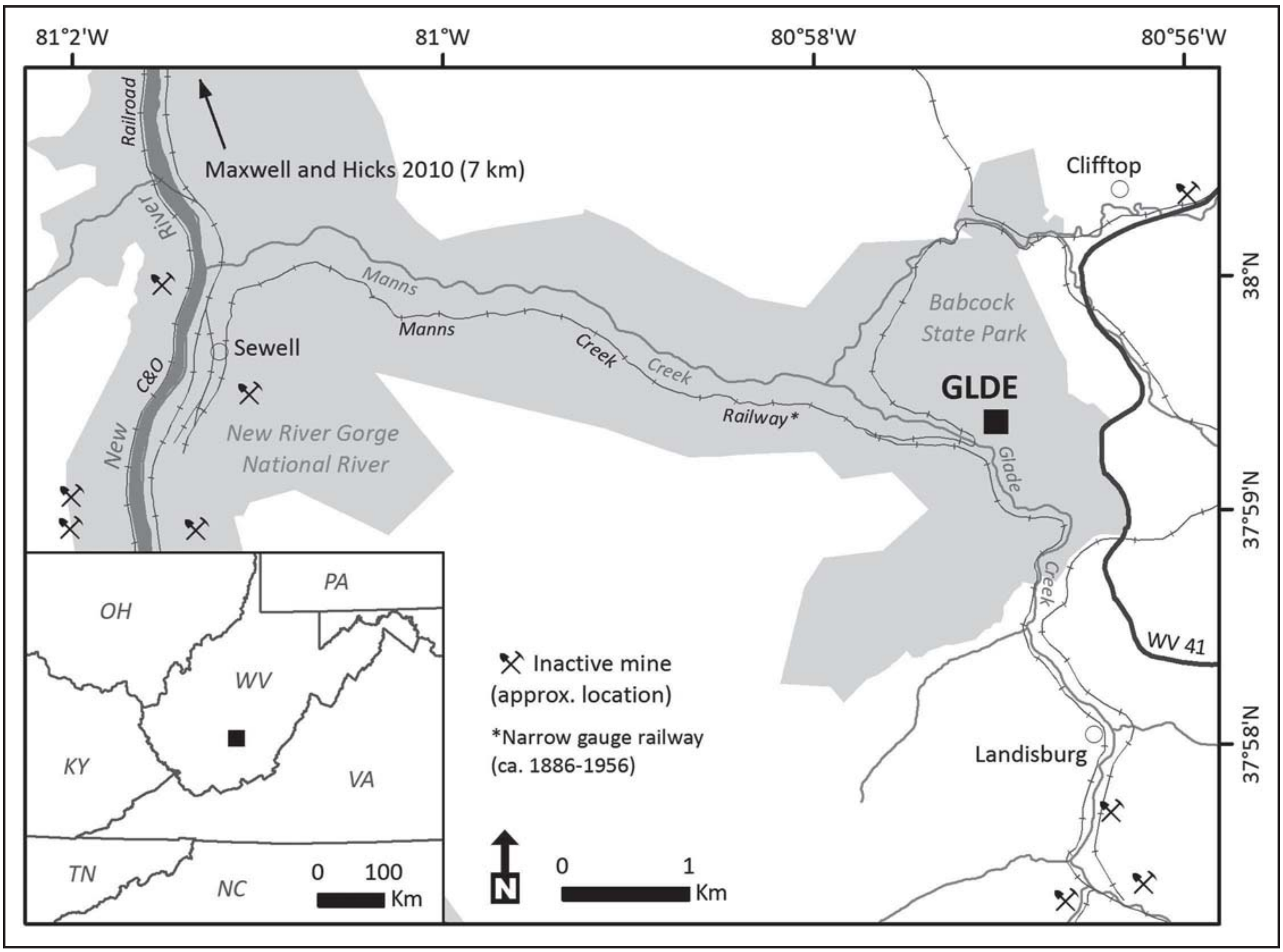

Figure 1. Regional location of the Glade Creek (GLDE) study site (inset) located within Babcock State Park, Fayette County, West Virginia. Select mining/railroad towns and approximate locations of inactive mines are also shown. The main line of the Chesapeake and Ohio Railroad along the New River was completed in 1873.

Manns Creek Railway began in 1884 and the railway started transporting coal from Clifftop in 1886 and was subsequently extended to Landisburg (ca. 1908), a lumber town located along Glade Creek (Peters and Carden 1926). The railway operated until 1956 when the coke ovens at Sewell and the mines near Clifftop shut down.

Pitch pine communities occur primarily on the sandstone cliffs above Manns Creek and Glade Creek within Babcock State Park (est. 1937). Soils are of the stony, well-drained Dekalb and Gilpin map unit. Isolated pitch pine can also be observed growing downslope of cliff bands and in concave cliff breaks (Figure 2). Other tree species characteristic of the clifftop communities include scarlet oak (*Quercus coccinea* Muenchh.), red maple (*Acer rubrum* L.), sourwood (*Oxydendrum arboretum* L.), black gum (*Nyssa sylvatica* Marsh.), and eastern hemlock (*Tsuga canadensis* (L.) Carr.). The shrub layer is dominated by mountain laurel (*Kalmia latifolia* L.), great laurel *(Rhododendron maximum* L.), and black huckleberry (*Gaylussacia baccata* (Wangenh.) K. Koch) (USDI-NPS).

Average annual temperature is 9.5 °C with monthly temperatures ranging from a high of 20.4 °C in July to −2.0 °C in January (West Virginia Climate Division 4; NOAA 2015). Annual precipitation is 123.5 cm, which peaks in July with an average total rainfall of 13.2 cm, while the driest months are October and November with average total rainfall amounts of 8.3 cm and 8.4 cm, respectively (West Virginia Climate Division 4; NOAA 2015).

Figure 2. Photograph of a lone pitch pine (center) with an inner ring date of 1843. This tree established on a concave, mid-slope site just downslope of the Skyline Trail at Babcock State Park, Fayette County, West Virginia. Note the mesic site-adapted Fraser magnolia (*Magnolia fraseri* Walt.) in the left foreground.

Field, Laboratory, and Analysis Methods

Tree cores and fire-scarred cross sections were collected in March 2015 along a 2-km section of south- and southwest-facing slopes above Glade Creek (GLDE) at an elevation of approximately 740 m (Figure 1). Live and standing dead pitch pine exhibiting old-growth characteristics (e.g., large, flat plates of bark, gnarled and twisted upper limbs) were targeted for sampling (see Figure 2). Two cores were extracted from each tree approximately 50 cm from ground level at a position perpendicular to slope aspect. Partial cross-sections were cut with a chainsaw from pitch or Virginia pine with visible fire scars (i.e., "cat faces") according to established fire history sampling procedures (Arno and Sneck 1977).

Tree core and cross-section samples were processed in the lab using standard dendrochronology methods (Stokes and Smiley 1968; Orvis and Grissino-Mayer 2002). Each ring series was visually crossdated against a nearby Virginia pine chronology (ITRDB WV004; Maxwell and Hicks 2014) and the North American Drought Atlas record (grid point 247; Cook and Krusic 2004) using the "list" method (Yamaguchi 1991). High resolution (3200 dpi) digital images of all samples were captured using a flatbed scanner. Annual rings were then measured to the nearest 0.01 mm using the image analysis software program CooRecorder 7.6 (Larsson 2003). Checks on crossdating were subsequently performed in the program COFECHA (Holmes 1983; Grissino-Mayer 2001a). Raw ring-width measurements from each dated pitch pine series were processed into a site growth chronology using the program ARSTAN (Cook 1985). The expressed population signal (EPS) was calculated to assess the influence of decreasing sample depth on the common variance of tree growth (Wigley et al. 1984). This study used an EPS minimum threshold value of 0.85 to indicate when increased variability in tree growth may be an artifact of low sample depth rather than forest disturbance.

Regime shift detection (Rodionov 2005) was used to test whether changes in annual growth variability correspond to rapid industrialization (1870–1880s) and industrial decline (1950s). I hypothesized that a significant increase in the annual growth variability (i.e., sensitivity) of pitch pine would mark a transition to the industrial era, during which frequent fire (Maxwell and Hicks 2010) and logging (Peters and Carden 1926) have been documented in the area. I expected that annual growth variability should then decrease during industrial decline, a period characterized by depopulation and fire exclusion (Stahlgren et al. 2007; Maxwell and Hicks 2010).

Canopy disturbance history was assessed using growth release detection methods (Lorimer and Frelich 1989; Nowaki and Abrams 1997; Aldrich et al. 2010). Unique growth increases can indicate the occurrence of fire or other disturbances (e.g., windthrow) that increase resource availability and promote tree establishment. For this study, a growth release event occurred when ring-width increased at least 50% over a 15-year period in relation to the previous 15-year period.

Fire scars were dated and seasonality was determined based on fire scar position in relation to growth rings. Dormant season scars were assigned to the previous calendar year in order to remain consistent with nearby fire history studies (Maxwell and Hicks 2010; Hessl et al. 2011). Fire scar data were entered in the Fire History Analysis and Exploration System (FHAES) (Grissino-Mayer 2001b; Sutherland et al. 2015) and summary statistics were generated.

Climate-disturbance relationships were assessed by comparing reconstructed Palmer Drought Severity Index (PDSI; grid point 247) (Cook and Krusic 2004) to fire and growth release years. Superposed Epoch Analysis (SEA) was used to test for departures in mean annual PDSI during event years and for the ten years preceding and two years following an event (e.g., Grissino-Mayer and Swetnam 2000; McEwan et al. 2014). Significant departures in PDSI were identified as those exceeding the 95% confidence interval.

RESULTS

Fire History

Partial cross sections were cut from four pitch pine and two Virginia pine exhibiting evidence of fire scarring (i.e., "cat face"). An exhaustive search revealed that fire evidence at the site was limited to these six trees and isolated oak species with hollowed out basal scars; sample depth diminishes to one tree in 1882. The 157-year fire chronology incudes a total of 21 fire scars, representing 17 fire years using a liberal 1-scar filter (Figure 3). All fires occurred during the dormant season and were recorded during an 82-year period between 1887 and 1968. Median fire interval for this period was four years, with a maximum fire-free interval of 13 years (1954–1966); no fires were recorded from 1969 to 2014. Three trees (75% scarred) recorded fire in 1929, while two trees (33% scarred) recorded fire in 1942 and 1953 (Figure 3).

Pitch Pine Growth Dynamics

The pitch pine growth chronology includes 33 trees (55 series) and spans 182 years from 1833 to 2014 (Figure 4a). Eleven core samples had either significant rot or numerous missing rings and were not used to develop the growth chronology. The chronology presented here begins with a sample depth of two trees, although

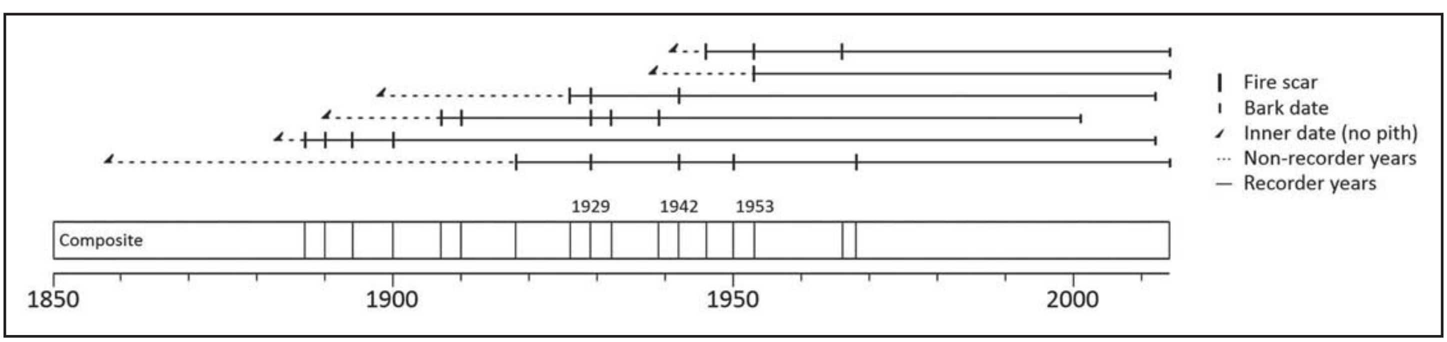

Figure 3. Fire history chart for the Glade Creek (GLDE) site at Babcock State Park, Fayette County, West Virginia. Each horizontal line represents a fire-scarred tree (n = 6). The composite fire chronology highlights all years in which one tree recorded a fire, while years in which at least two trees recorded a fire are labeled.

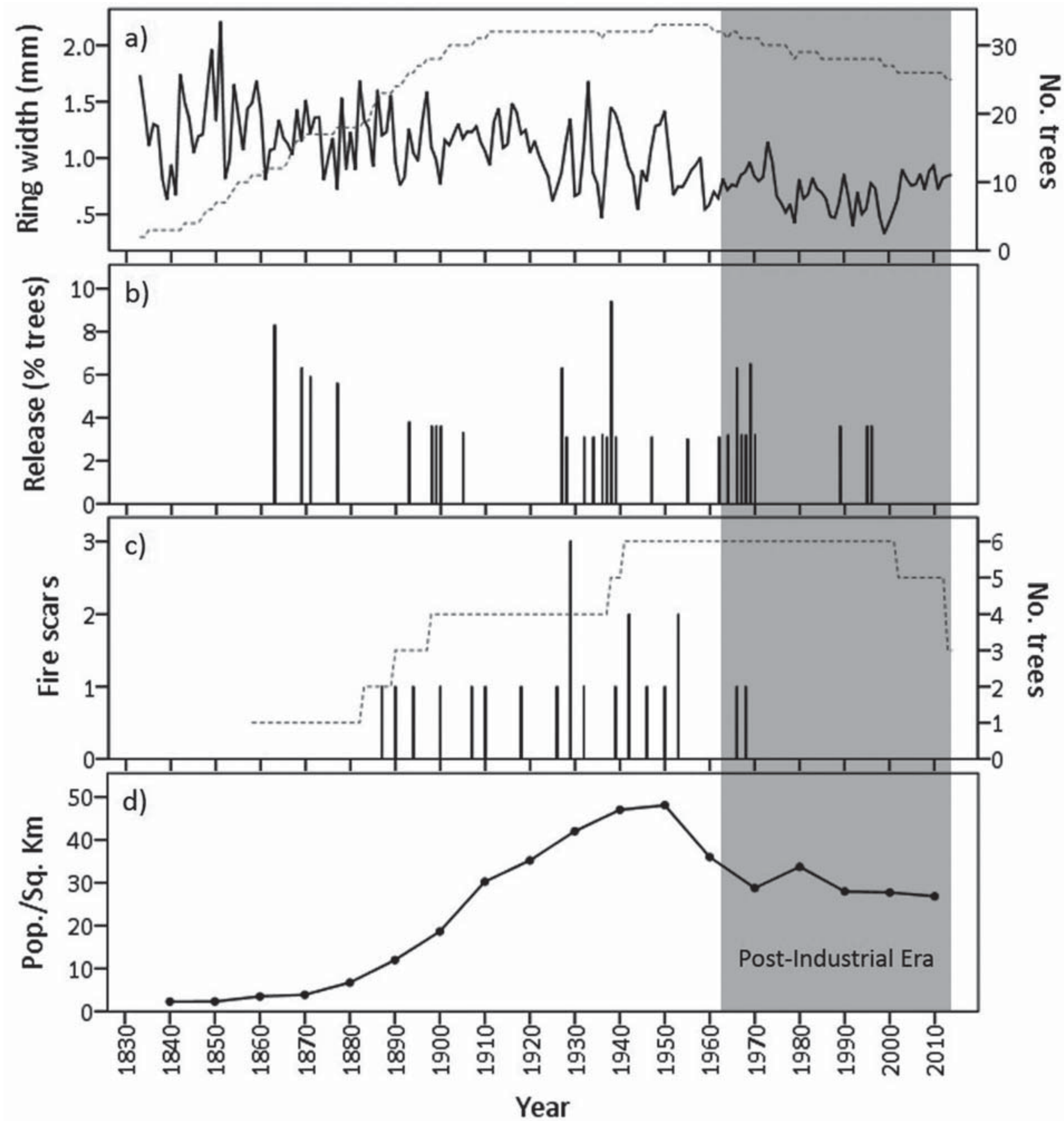

Figure 4. (a) Annual ring-width measurements for pitch pine at the Glade Creek (GLDE) site with sample depth indicated by the gray dotted line (trees = 33; series = 55). (b) Growth release events recorded by pitch pine at the Glade Creek site. Vertical bars represent the percentage of trees recording a growth release in a given year. (c) Fire events at the Glade Creek site. Sample depth (i.e., fire-scarred trees) is indicated by the gray dotted line. (d) Population density of Fayette County, West Virginia, over time. The post-industrial era (1963–2014) is defined by a significant decrease in annual tree-growth variability (*P* < 0.001).

the earliest inner-ring date was 1828. Sixteen (48%) of the trees sampled had an inner-ring that pre-dated 1870 and only one tree had an inner-ring date after 1911. The EPS value first falls below 0.85 in 1869, but fluctuates above and below this threshold through 1851. Subsequent regime shift analysis of annual growth variability begins in 1855 (n = 10 trees), so as to minimize the effect of decreasing sample depth.

Pitch pine growth follows a negative exponential trend with ring-width decreasing through time as tree diameter increases (Figure 4a). A 30-year cutoff length (α = 0.01), or minimum regime length, was used in the regime shift analysis of annual growth variability. Thirty years approximates the timing between 1855 and the onset of industrialization near the study site, which is marked by the construction of Manns Creek Railway (ca. 1884–1886). No significant shift in annual growth variability was detected during this transitional period. However, a statistically significant ($P < 0.001$) decrease in annual growth variability was identified beginning in 1963. This time period (1963–2014) is subsequently referred to as the post-industrial era, which corresponds to a period of near complete fire exclusion (Figure 4c) and rapid depopulation of Fayette County (Figure 4d). No change in either mean or variance was detected for reconstructed annual PDSI (1833–2003; grid point 247) (Cook and Krusic 2004) or instrumental annual precipitation or PDSI (1895–2014) (West Virginia Climate Division 4; NOAA 2015). No change in the variance of instrumental average annual temperature was detected, but there were significant shifts in the mean in 1960 (decrease) and 1990 (increase) (West Virginia Climate Division 4; NOAA 2015).

A total of 34 growth releases were identified in the pitch pine chronology, representing 28 release event years (Figure 4b), with 20 of 33 trees (61%) recording at least one growth release. The median interval between release events was two-years and the maximum interval between events was 22 years (1906–1927). Release events occurred in pulses throughout the chronology, most notably during the 1860s and 1870s, at the turn of the 20th century, during the late 1920s through the 1930s, and again during the 1960s (Figure 4b).

There is evidence of a temporal relationship between fire and release event years. Fire and release events occurred in the same year on five occasions (1900, 1932, 1939, 1966, and 1968), while eleven release events (39%) occurred within three years of a fire event. This link between fire and unique growth increases exists for the entire 82-year period of recorded fires.

Climate-Disturbance Relationships

Superposed epoch analysis revealed no statistically significant departures in mean reconstructed PDSI during fire years or in the ten years prior or two years following a fire event (n = 17) (Figure 5a). However, mean PDSI during fire years was lower than any other year in the 13-year analysis window. There is a strong association between extended dry periods and growth release events, with a statistically significant negative departure in mean reconstructed PDSI three years prior to a release event (Figure 5b).

DISCUSSION

Annually resolved tree-ring–based disturbance histories are sparse throughout the

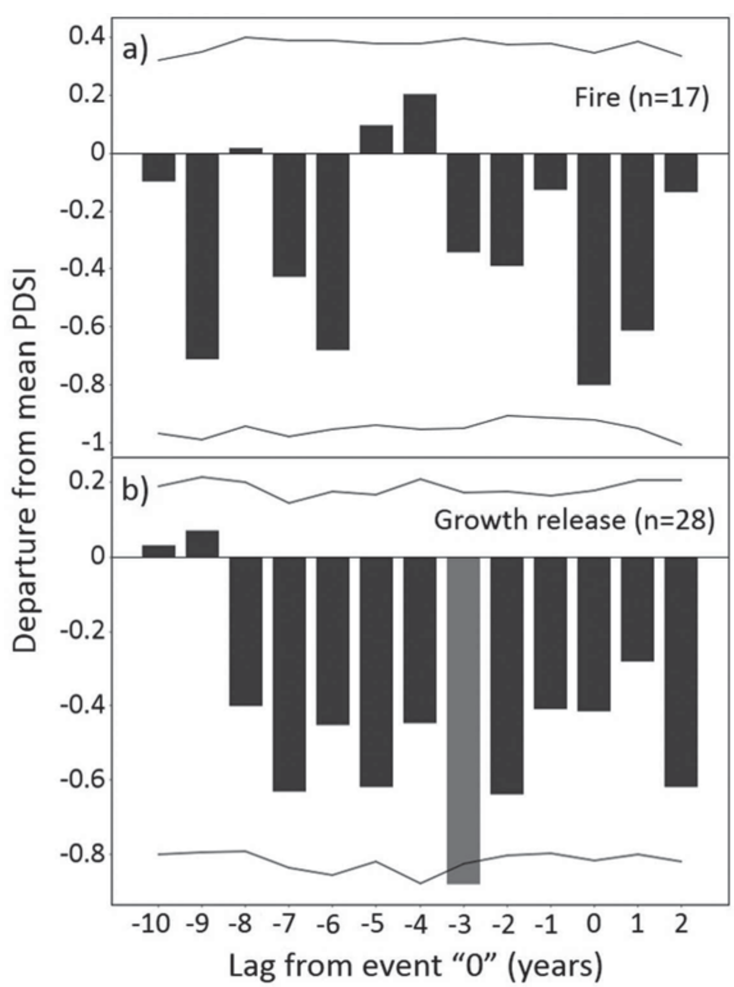

Figure 5. Results of Superposed Epoch Analysis (SEA) for (a) fire and (b) growth release events. The vertical bars represent departure from mean reconstructed Palmer Drought Severity Index (PDSI) (Cook and Krusic 2004) lagged ten years before and two years after an event. The horizontal lines indicate the 95% confidence interval. Sample sizes are the number of events analyzed.

diverse mesophytic forest region due to extensive forest clearing during Euro-American settlement and industrialization as well as the high rates of decomposition associated with a humid-continental climate (Hart and Buchanan 2012). This study provides the first tree growth chronology that predates the industrial era in the New River Gorge region of southern West Virginia. Maxwell and Hicks (2014) developed a Virginia pine chronology at a site approximately 7 km from the present study, with only two trees pre-dating 1903 and just one pre-dating 1875.

I was able to use a relatively long pitch pine chronology and a priori knowledge of the timing of land use change and industrialization to identify unique periods of forest disturbance. The results herein suggest that fire and canopy disturbance occurred regularly in the two to three decades prior to the industrialization of the New River Gorge region. This conclusion is supported by two lines of evidence: (1) The annual growth of pitch pine remained highly variable from 1855 through the industrial era, suggesting a common disturbance regime during this period. Only when industrial activities ceased did annual growth variability decline, characterizing a unique period of limited disturbance and fire exclusion (1963–2014). Additionally, climate seems unrelated to this shift in growth variability, but investigating more sites may be required to rule out any influence of synoptic-scale climate patterns. (2) The topographic position and inner-ring dates of at least sixteen pitch pine suggest that fires burned with enough regularity prior to industrialization to create conditions suitable for germination (i.e., abundant light and bare mineral soil). Some of these older pitch pine are growing on mid-slope concave sites currently favored by mesosphytic species (see Figure 2). Other studies in the mesosphytic forest region that have produced longer disturbance chronologies note a similar temporal trend in forest disturbance (e.g., Aldrich et al. 2010; McEwan et al. 2014; Flatly et al. 2013). Further conclusions about the pre-industrial disturbance regime at the GLDE site are limited by diminishing sample depth, which exists for both the annual growth and fire chronologies.

Fire history at the GLDE study site follows the regional pattern of 20th century fire activity in which the exclusion of ignition sources, namely the cessation of industrial and agricultural activities and subsequent population decline, resulted in a near absence of fire since the 1950s. Maxwell and Hicks (2010) noted a general cessation of fires along the Endless Wall section of the New River Gorge following the closure of the Nuttalburg Mine (1952) and associated train depot (1966). The last major fire occurred in 1953 at a site on North Fork Mountain in Pendleton County, West Virginia, approximately 150 km to the northeast of the present study (Hessl et al. 2011). Land use change, including a reduction in grazing activities, and a decrease in population density coincided with fire cessation in this mountain landscape. Farther south at sites in the Blue Ridge Mountains of North Carolina and in the Ridge and Valley and Blue Ridge physiographic regions of eastern Tennessee, fire cessation dates were in the 1950s, 1960s, and 1930s, respectively (Flatley et al. 2013). In each case, it was shown that fires occurred regularly from the late 1700s through the end of the industrial logging era. The GLDE fire chronology likely underestimates pre-1950 fire occurrence with only six fire-scarred tree samples in total and three or fewer trees recording before 1900.

The incomplete fire record at GLDE is supplemented by the temporal relationship between fire and growth release events. The results presented here show that 39% of growth release events occurred within three years following a fire and 18% occurred in the same year as a fire. The likelihood exists that many of the remaining ~40% of growth releases are related to fire disturbance, although this is difficult to confirm given 19th century sample depth limitations. Additionally, the pulse-like growth release pattern reflects a fuel accumulation fire cycle, rather than gap-phase dynamics in which growth releases would be expected to occur randomly and continuously throughout the chronology (Foster 1988; McEwan et al. 2014).

The prevalence of anthropogenic fires throughout the fire record may have masked a stronger climate–fire association (McEwan et al. 2007; Flatley et al. 2013). Fire events generally occurred during dry years (see Figure 5a) and there was a significant association between drought and growth release events (Figure 5b), suggesting that fire was driven by periodic drought, in addition to early settlement and industrial activities. These results differ from a nearby study on Price Mountain near Blacksburg, Virginia (Silver et al. 2013). Forest composition and soils are similar to the GLDE site, however, no discernable relationship to climate was found. Proximity to a large settlement (Blacksburg; est. 1798) may have driven a fire regime independent of climate. In comparison, human activities near present-day Babcock State Park were limited prior to the 1870s (Stahlgren et al. 2007). The area was first traversed by Native Americans on the nearby Midland Trail, then by early Euro-American settlers on the Old State Road (commissioned by George Washington in 1785 and completed in 1790), which was rerouted and named the James River and Kanawha Turnpike (present-day US 60) (Peters and Carden 1926). Isolated homesteads dotted the landscape and infrequent anthropogenic fires along this travel corridor were likely associated with dry conditions prior to industrialization.

Management Implications

Fire is commonly used as a management tool to restore or maintain what are known to be fire-dependent plant communities throughout the mesophytic forest region and elsewhere (Ryan et al. 2013). This study has shown that deindustrialization in the New River Gorge region marked a significant step change in the forest disturbance regime that is not seen previously in the GLDE dendroecological record. Consequently, the pine-oak forest that characterizes the GLDE site may not be suitable for the reintroduction of fire given the near complete exclusion of fire since the mid-20th century, which has favored shade-tolerant species and the development of a closed canopy (see Figure 2). Additionally, the effects of reintroducing fire to mixed pine-oak forests that have undergone such extreme transitions are not well understood (Grissino-Mayer 2016) and may cause unintended effects such as negative impacts on oak regeneration (Fredericksen and Frank 2014) or the propagation of exotic species (Alba et al. 2015).

CONCLUSIONS

In summary, I have demonstrated that pitch pine establishment and maintenance prior to industrialization was likely dependent on periodic fire driven by anthropogenic activities, which continued through the industrial era. Increased pitch pine establishment has been associated with Euro-American settlement activities elsewhere (Copenheaver et al. 2000), which can explain the early 19th century inner-ring dates of isolated pitch pine at GLDE. Drought seems to be a secondary driver of fire, which implies a coupled human-environment disturbance regime. Regional fire managers, therefore, should consider this reconstructed disturbance history in the context of historical land use patterns and recent climate trends (i.e., warming and wetting of the mesosphytic forest region) when developing fire management plans for similar forest communities. Additional study sites within the mesosphytic forest region, and Central Appalachian Mountains in particular, are necessary in order to elucidate larger-scale patterns and climate linkages in pre-industrial disturbance regimes.

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Dr. Saladyga is an Assistant Professor of Geography at Concord University in Athens, West Virginia, where he teaches courses in physical and environmental geography. His research utilizes dendrochronology and Geographic Information Systems to examine forest ecosystem stability and resilience in the context of changing climate, land use, and/or management strategies.

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