Fire History Reflects Human History in the Pine Creek Gorge of North-Central Pennsylvania

Authors: Brose, Patrick H., Guyette, Richard P., Marschall, Joseph M., and Stambaugh, Michael C.

Source: Natural Areas Journal, 35(2) : 214-223

Published By: Natural Areas Association

URL: https://doi.org/10.3375/043.035.0202

RESEARCH ARTICLE

Fire History Reflects Human History in the Pine Creek Gorge of North-central Pennsylvania

Patrick H. Brose[1,3]

[1]USDA Forest Service
Northern Research Station
335 National Forge Road
Irvine, PA 16329

Richard P. Guyette[2]
Joseph M. Marschall[2]
Michael C. Stambaugh[2]

[2]University of Missouri
School of Natural Resources
1105 Rollins Road
Columbia, MO 65201

[3] Corresponding author:
pbrose@fs.fed.us; 814-563-1040

Natural Areas Journal 35:214–223

ABSTRACT: Fire history studies are important tools for understanding past fire regimes and the roles humans played in those regimes. Beginning in 2010, we conducted a fire history study in the Pine Creek Gorge area of north-central Pennsylvania to ascertain the number of fires and fire-free intervals, their variability through time, and the role of human influences. We collected 93 cross sections from fire-scarred red pine (*Pinus resinosa*) snags, stumps, and living trees at three separate sites along the western rim of Pine Creek Gorge. From these, we found 79 fire years and 11 multidecadal fire-free intervals between 1600 and 2010. The three fire histories were quite synchronous; their fire years and fire-free periods mirrored one another despite being 12 to 14 km apart. Before 1791, fires were rare, suggesting a low population of American Indians and (or) little woodland burning by the tribes. A prolonged fire-free interval from 1650 to 1735 coincided with the Beaver Wars and the introduction of European diseases. Another fire-free period coincided with the American Revolutionary War. After that, fires became quite common with nearly all of them occurring within the next 125 years while Pine Creek Gorge was intensively logged. Since logging ended and fire control started in the 1910s, fires have been virtually absent from the three sites. Based on the fire and human histories, we conclude that human activities and culture are the driving forces behind the fire regimes of Pine Creek Gorge.

Index terms: dendrochronology, European settlement, fire scars, Iroquois, *Pinus resinosa*

INTRODUCTION

Prior to European settlement, a conifer – northern hardwood forest covered a large portion of eastern North America. Sargent (1884) delineated it as extending west from the Gulf of St. Lawrence to beyond Lake Superior and south into the central Appalachian Mountains. Nichols (1935) named this forest the Hemlock – Pine – Northern Hardwood forest (hereafter the HPH forest) because of the principal species (eastern hemlock (*Tsuga canadensis* (L.) Carr.), eastern white pine (*Pinus strobus* L.), American beech (*Fagus grandifolia* Ehrh.), and sugar maple (*Acer saccharum* Marsh.)). Braun (1950) split the HPH forest type into two divisions, Appalachian Mountains and Great Lakes, based on the ratio of hemlock to pine, with the former dominating in the Appalachians and the latter dominating in the Great Lakes area. In Pennsylvania, the hemlock-dominant subtype of this forest covered much of the northern third of the state, but white pine and red pine (*Pinus resinosa* Ait.) were substantial associate species in some areas. One such area was the Pine Creek Gorge (PCG) of north-central Pennsylvania.

As its name implies, PCG was blanketed by the HPH forest before European settlement. Abrams and Ruffner (1995) reported that the pre-1800 witness-tree data for PCG and adjacent areas indicated that 70% of the trees were hemlock, beech, or maple. White pine, red pine, and pitch pine (*Pinus rigida* L.) only accounted for 3 to 5% of the witness trees, or about 15 to 35 trees per hectare. These pines are early- to mid-seral species and are generally associated with periodic fire (Hough and Forbes 1943), so their presence as scattered individuals or in small stands suggests that fire had a historical role in the PCG watershed.

Fire history is the study of past forest fires via the analysis of fire-scarred trees, stumps, and snags (Speer 2010). From those scars, researchers can reasonably reconstruct past fire regimes from fires that burned decades or centuries earlier. Climate and humans are the driving forces behind any fire regime because they ignite the fires and influence their intensity and spread. Also important in fire regimes are abnormally long fire-free periods, as they can indicate substantial changes to the climatic or human drivers. Fire history studies have been conducted throughout the world to better understand the roles of climate (especially droughts) and human cultures on fire regimes (Johnson et al. 1990; Veblen et al. 1999; Niklasson and Granstrom 2000).

Fire histories in Appalachian HPH forests are rare because extensive forest clearing during the 1800s removed fire-scarred trees and the humid environment makes the long-term preservation of fire-scarred wood unlikely. The first fire history reported for an Appalachian HPH forest was part of an ecological description study of Hearts Content National Scenic Area in northwestern Pennsylvania (Lutz 1930).

In the area surrounding Hearts Content (a virgin forest), a number of white pines were harvested. In their stumps, Lutz found evidence for five widespread fires and several smaller fires between 1727 and 1927. He theorized there were also fires before 1727, but decay had destroyed the evidence of their occurrence. Also in northwestern Pennsylvania, Hough (1936) dated a fire near the Tionesta Research Natural Area to the early 1870s; a date that coincides with one of the fires found at Hearts Content. Hough and Forbes (1943) used age relationships of the oldest hemlocks and pines at Hearts Content and Cooks Forest State Park to tentatively identify a stand-initiating fire in 1644. In Vermont, Engstrom and Mann (1991) and Mann et al. (1994) used fire-scarred dead and living red pines to reconstruct fire histories from the 1500s to 1900s. Forest fires were found to be rare before European settlement, but temporarily increased in frequency with colonization and ceased in the early 1900s. All of these studies focused on the ecological relationships of fire to the forest and none of them delved deeply into the associations between their respective fire histories and local human histories.

In 2010, the opportunity arose for us to augment this short list of fire history studies in Appalachian HPH forests with the discovery of numerous fire-scarred red pine snags and stumps at three sites along the western side of PCG. Initial analysis of the data generated from these snags and stumps indicated that PCG experienced three profoundly different fire regimes in the past 400 years, and climate/drought were minor or nonexistent factors in all of them (Brose et al. 2013). This latter finding implied that human culture was the driving force behind PCG's fire history. The objective of this paper is to elucidate the associations of that fire history with the American Indian and European settlement histories of the PCG region.

METHODS

Study Site

PCG lies within the Deep Valleys physiographic region of north-central Pennsylvania (Schultz 1999). This region is a dissected plateau consisting of broad flat hills, steep slopes, and numerous streams. Hilltop elevations generally range from 600 to 700 m while valley bottoms are between 250 and 400 m. Climate is humid continental, consisting of warm, humid summers and cold, snowy winters (Kohler 1986). Average annual temperature is 8.0 °C, with an average minimum mean of -10.0 °C in January and an average maximum mean of 25.6 °C in July. Annual precipitation averages 1060 mm of rain and 1840 mm of snow distributed evenly throughout the year.

PCG, nicknamed "The Pennsylvania Grand Canyon," was formed at the end of the last ice age by outflow from the receding Laurentide Glacier (Owlett 1993; Dillon 2006). PCG and its surrounding watershed are large and impressive (Figure 1). The gorge extends approximately 75 km in a north to south orientation. Gorge depth ranges from 250 to 500 m and distance between the east and west rims averages 1200 m. PCG and its accompanying tributaries drain about 2500 km^2. The beauty, ecological value, and cultural significance of the PCG watershed are apparent in its protected status: two state forests, four state game lands, four state parks, seven natural/wild areas (totaling 11,400 ha), and 30 scenic vistas.

With the guidance of Pennsylvania Bureau of Forestry personnel, we found three 5- to 9-ha sites with numerous fire-scarred snags and stumps of red pine on the west side of PCG. One site, Long Branch Hill (LBH, 41° 33.734 N, 77° 26.711 W) was on Tioga State Forest, while Slate Run (SLR, 41° 30.229 N, 77° 33.709 W) and Upper Dry Run (UDR, 41° 23.452 N, 77° 29.710 W) were on Tiadaghton State Forest. All of the sites were 2 to 3 km from PCG and, relative to each other, SLR was near the center of PCG's west side and LBH and UDR were situated approximately 12 and 14 km to the north and south, respectively (Brose et al. 2013).

All of these sites were located along the upper shoulder of northwest-facing ridges at an approximate elevation of 525 m (Brose et al. 2013). They were steep (>20% slope), dry, and rocky. The sites were fully stocked with the overstory, consisting of red and white pines, eastern hemlock, northern red oak (*Quercus rubra* L.), red maple (*Acer rubrum* L.), sweet birch (*Betula lenta* L.), and paper birch (*Betula papyrifera* Marsh.). Mountain laurel (*Kalmia latifolia* L.) dominated the understory.

Sampling Procedures

We systematically scouted each site for fire-scarred pine snags and stumps as well as fire-scarred living trees (Figure 2). When we found a suitable snag or stump, we cut a 5-cm-thick cross section from its base. We sampled fire-scarred living pines by cutting a partial cross section (10 to 15 percent of the tree's circumference) of similar thickness from the interface of the fire scar with the undamaged wood (Arno and Sneck 1977). Cross-sections from stumps and snags were wrapped in duct tape before cutting to prevent handling and vibration from damaging the cross section. We also recorded aspect, slope, and slope position of each cross section at the time of sampling. All samples were transported to the Tree Ring Laboratory at the University of Missouri for examination of the fire scars. LBH and UDR were sampled in fall 2010 and SLR was sampled in winter 2012. Also at UDR, we cored living old-growth red pines. Cores were extracted from the opposite slope sides of each tree at approximately 1.4 m above the ground.

In the lab, the cores and cross sections were sanded using a hand-held belt sander with progressively finer sandpaper, up to 1200 grit, until the cellular detail of annual rings and fire scar injuries was revealed. The red pine cores were dated from the outermost ring (2010) to the innermost ring, or pith, and signature years were identified. A signature year is a narrow annual ring that occurs consistently in most or all of the cores. These narrow rings aid in cross-dating because they serve as a quality-assurance check, ensuring that the correct year is assigned to each annual ring.

Fire scars were identified by the presence of callus tissue, charcoal, traumatic resin canals, liquefaction of resin, and (or) cam-

Figure 1. The Pine Creek Gorge of north-central Pennsylvania as seen from the Bradley Wales Vista. Note the rugged physiography of the gorge, extensive forest cover, and relatively equal heights of the surrounding hills and ridges. Photo by Patrick Brose, Northern Research Station.

bial injury. We only designated a scar as a fire scar when we were absolutely sure it had been caused by a fire; otherwise, it was classified as a nonfire injury. A radius (pith-to-bark tree-ring series) of the cross section with the least amount of ring-width variability due to fire injuries was chosen for ring-width measurement and cross dating. Ring-width series from each cross section were plotted to match ring-width patterns and cross-date the samples with the red pine chronology developed from the living trees (Speer 2010). Our ring-width chronology from the cores covered the years 1760 to 2010 and was extended back to 1538 with the measurements from the cross-sections. Signature years common to all sites were 1631–1632, 1670–1672, 1755, 1780, 1825–1826, 1868, 1911, and 1975. The COFECHA computer program (Holmes 1983; Grissino-Mayer 2001) was used to verify the accuracy of cross-dated tree-ring series.

Analysis

We used the FHX2 fire history software (Grissino-Mayer 2004) to record the calendar year of each fire. We also calculated the upper exceedance interval (UEI). This metric is the number of years above which a fire-free period is considered longer than normal. For determining the UEI, we used an alpha of 0.125, the default setting of the FHX2 software (Grissino-Mayer 2004). Data summaries were developed for the period of 1600 to 2010 for all three sites because they all had these years in common.

RESULTS

The three sites produced 93 samples. They were rather evenly divided among the sites: LBH had the most (35), UDR had the least (28), and SLR was intermediate (30). Fire regime characteristics such as mean fire interval and fire seasonality were

Figure 2. A fire-scarred red pine snag at the Upper Dry Run (UDR) site. Even though this tree lived and died decades ago, its high resin content has preserved the wood. Consequently, this snag may contain numerous fire scars from fires that occurred in the 1800s or even earlier. Photo by Patrick Brose, Northern Research Station.

previously reported in Brose et al. (2013) and will not be repeated here.

We identified 21 fires that occurred between 1600 and 2010 at LBH based on fire scars (Figure 3). Additionally, we identified two other possible fires (~1600 and ~1650) based on the similar pith dates of 9 and 19 recorder trees because cohorts of red pines frequently form shortly after a severe fire opens the forest canopy (Rudolf 1990). These 23 fires were distributed among the centuries as follows: three in the 1600s, three in the 1700s, 12 in the 1800s, three in the 1900s, and one since 2000. UEI was 41.5 years and this value indicated that there were three long fire-free intervals: 1650 to 1735 ($P = 0.034$), 1747 to 1793 ($P = 0.108$), and 1909 to 2008 ($P = 0.016$).

At SLR, we identified 23 fires from the fire scars between the years 1600 and 2010 (Figure 4). Additionally, there appears to have been another fire about 1600 based on the similar pith dates of 13 recorder trees. Like LBH, fires at SLR were not evenly distributed through the centuries. Four occurred in the 1600s, four in the 1700s, 14 in the 1800s, and two in the 1900s. The UEI was 29.2 years and indicated one significantly long fire-free interval, from 1649 to 1755 ($P = 0.001$), but the fire-free intervals from 1768 to 1793 and between 1806 and 1828 were almost significant ($P = 0.159$ and $P = 0.183$, respectively). We found no evidence of fire at SLR since 1911—a fire-free interval that is already more than 100 years long.

At UDR, 31 fires occurred between 1600 and 2010 (Figure 5). The pith dates of the oldest recorder trees suggest an additional fire may have occurred about 1575. The 32 fires primarily burned during the 1800s and early 1900s; only seven fires burned before 1800 and none after 1915. We detected two significantly long fire-free intervals: from 1635 to 1735 ($P = 0.001$) and from 1763 to 1791 ($P = 0.057$). Like SLR, UDR is in an ongoing fire-free interval that is already 99 years long.

The three sites all displayed the same temporal pattern of fires despite being 12 to 14 km apart and separated by numerous waterways. Therefore, we combined them to form a composite fire chronology of PCG (Figure 6). This overall chronology spanned from 1575 to 2010 and included 79 fires. The three earliest fires burned in the late 1500s and established the oldest recorder trees at each site. After that, 14 fires occurred in two distinct periods: six between 1623 and 1649 and eight between 1735 and 1768. Beginning in 1791, fires became quite common—61 over the next 123 years. Since 1914, only one fire has burned at any of the three sites. Of the 79 fires, 12 of them may have impacted two sites, and two fires, 1802 and 1891, may have burned all the sites.

DISCUSSION

It is widely accepted that the forests of eastern North America have experienced three distinct fire regimes in the past 400 years and each of these has a strong human component (Pyne 1982; Brose et al. 2001). In the first regime (1600 to 1800), forest fires of varying intensities occurred periodically due to the cultural burning practices of the various tribes of American Indians. They used fire for a myriad of reasons such as clearing land for agriculture, maintaining open areas for hunting, and facilitating travel (Pyne 1982; Williams 2003). European settlers adopted many of these aboriginal cultural burning practices as well as introducing some new ones like creating charcoal. The second regime corresponds to the 1800s. In that century, the eastern forests were cleared to create living space for a rapidly growing population and provide the raw materials

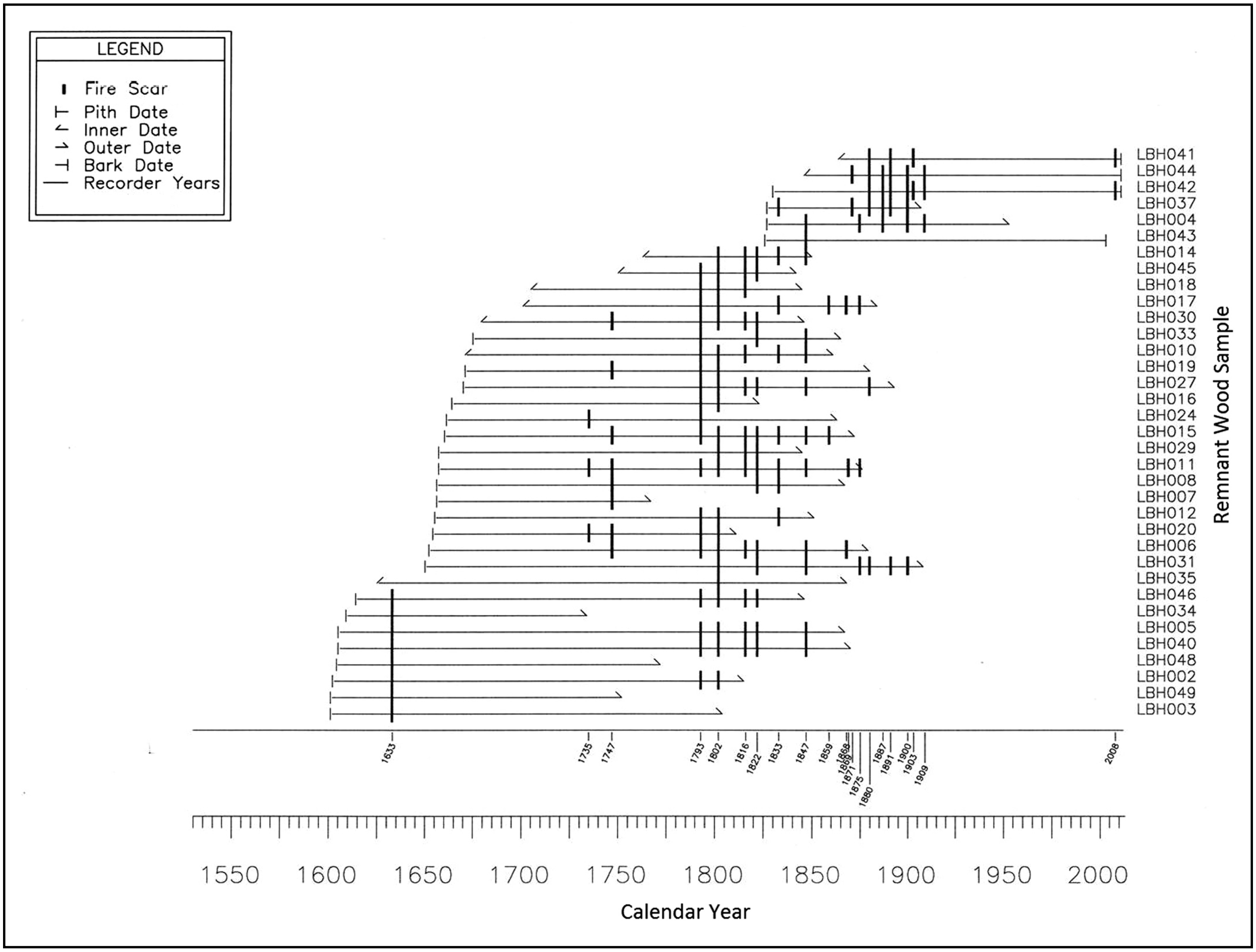

Figure 3. Fire chronology of Long Branch Hill (LBH) from 1600 to 2010. Each horizontal line represents one red pine sample tree and the dark black vertical bars represent the fires. Recorder years are the calendar years represented by the annual rings of that sample.

for the Industrial Revolution. Forest fires became quite common and intense. These wildfires alarmed the public and led to the third and current fire regime—a "no-fire" period in which fires are actively excluded by human behavior. The fire history we discovered at PCG illustrates these three fire regimes and the importance of humans to north-central Pennsylvania forests through the centuries.

In our study, the years 1791 and 1914 mark the boundaries between the three regimes. Prior to 1791, each site only had five or six fires in the previous two centuries. These fires primarily burned in the dormant season (Brose et al. 2013), and some appear to have initiated formation of red pine cohorts. Who or what lit these fires? It is impossible to know for certain, but the fact that the fires occurred during the dormant season strongly suggests that they were ignited by American Indians, specifically the Iroquois and Susquehannock tribes. In Pennsylvania, lightning-caused fires are rare, about 1% of all forest fires (Haines et al. 1978; Ruffner and Abrams 1998; PA DCNR 2013). Dormant-season lightning fires are virtually nonexistent because thunderstorms are infrequent during this time of the year and when they do occur, they almost always produce rain. However, Ruffner and Abrams (1998) point out that hemlock and white pine are the two most common tree species to ignite after a lightning strike. Therefore, we cannot entirely dismiss lightning as the cause of one or more of the pre-1791 fires, although American Indians are the more logical choice as the ignition source.

Why would the Iroquois or Susquehannock tribes start forest fires? Writings of early European settlers show that the Seneca tribe of the Iroquois burned the forests to promote fruiting ericaceous shrubs such as blueberries and huckleberries (*Vaccinium* spp. and *Gaylussacia* spp., respectively) and to kill rattlesnakes (*Crotalus horridus* L.) (Tome 1854; Pringle 1880; Hulbert 1910). The PCG watershed has widespread heath shrubs and a large rattlesnake population, so the fires of the 1600s and 1700s may have resulted from those practices.

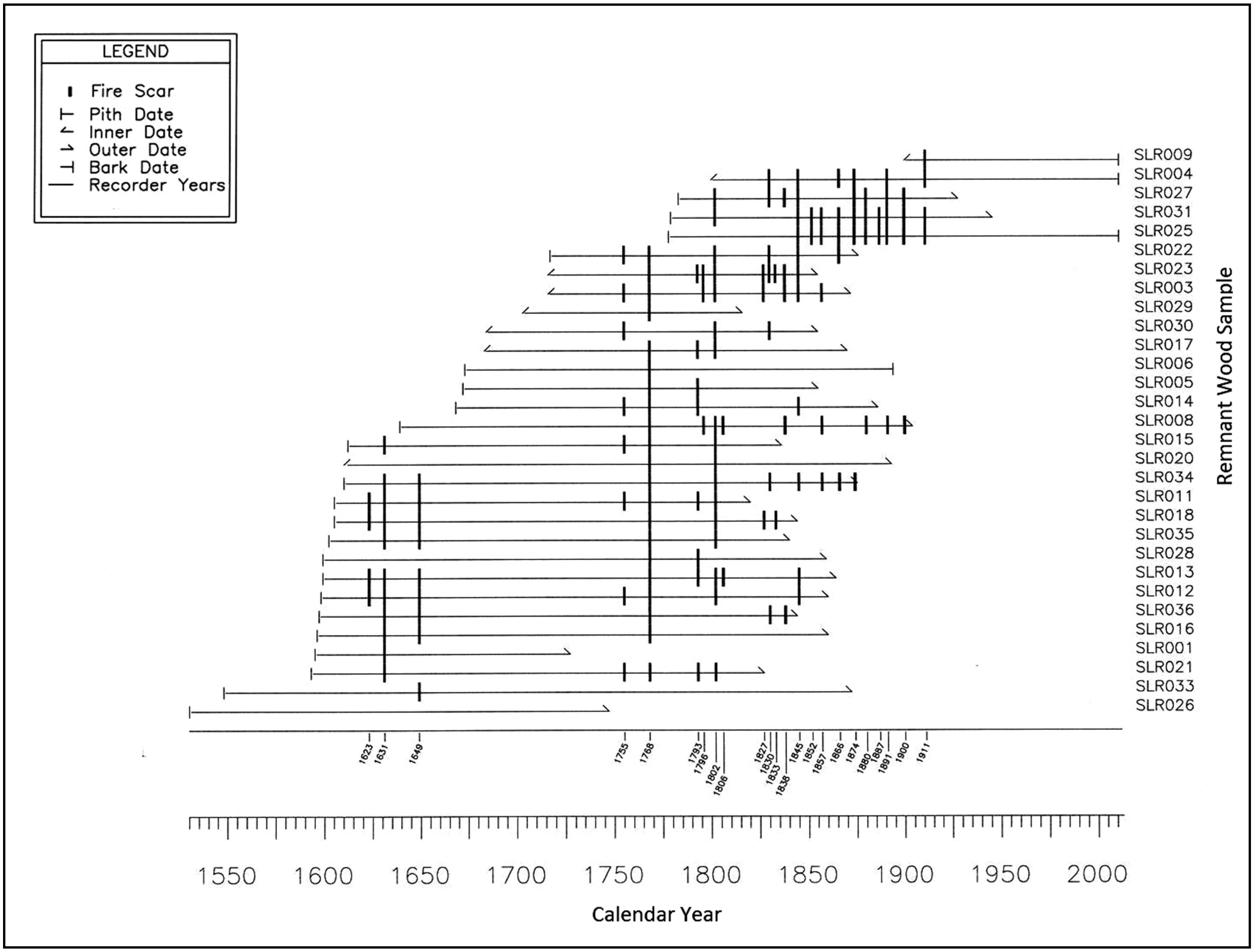

Figure 4. Fire chronology of Slate Run (SLR) from 1600 to 2010. Each horizontal line represents one red pine sample tree and the dark black vertical bars represent the fires. Recorder years are the calendar years represented by the annual rings of that sample.

Why were there so few forest fires? Relative to most other fire histories in eastern North America (Shumway et al. 2001; Guyette et al. 2006; Aldrich et al. 2010), PCG burned rather infrequently. The human aspect to this lack of fire is that this entire region (north-central Pennsylvania) was a hinterland, a largely uninhabited area between the Iroquois to the north and Susquehannock to the south (Donehoo 1928; Wallace 1952). Part of the lack of habitation was due to the rugged physiography of the region, but also, these two tribes were enemies so the region served as a buffer between them. They did use it as a hunting ground in the autumn and traveled through it on footpaths, but this usage was sporadic. Simply put, the tribes probably were not in the PCG area when conditions for starting a forest fire existed.

Why would the fires cease occurring between the mid-1600s and mid-1700s? This extended fire-free interval occurred at each site and is not an artifact of a small sample size because 83 of the samples covered this period. This hiatus of fire corresponds to the "Beaver Wars," a period when the Iroquois attempted to monopolize the fur trade with Europeans by defeating their neighboring tribes (Meginness 1892; Hulbert 1910; Sipe 1931). Oral Indian histories recorded by David Zeisberger and John Heckewelder (Moravian missionaries of the mid 1700s) indicate a sporadic war lasting several decades among the Delaware, Iroquois, and Susquehannock tribes that ended in the early 18th century with the expulsion of the Susquehannock from the region and the subjugation of the Delaware to the Iroquois (Meginness 1892; Hulbert 1910). In addition, the time period between 1630 and 1730 coincides with the arrival of European diseases among the American Indians of this region. Mann (2005) documents an unidentified epidemic in 1616 in New England, followed by a smallpox epidemic in 1633. It is likely that either, or both, of these epidemics reached Pennsylvania given the trading and other interactions that existed among the various tribes. In Pennsylvania in the 1700s, Zeisberger and Heckewelder mention encountering Indians suffering from measles, smallpox,

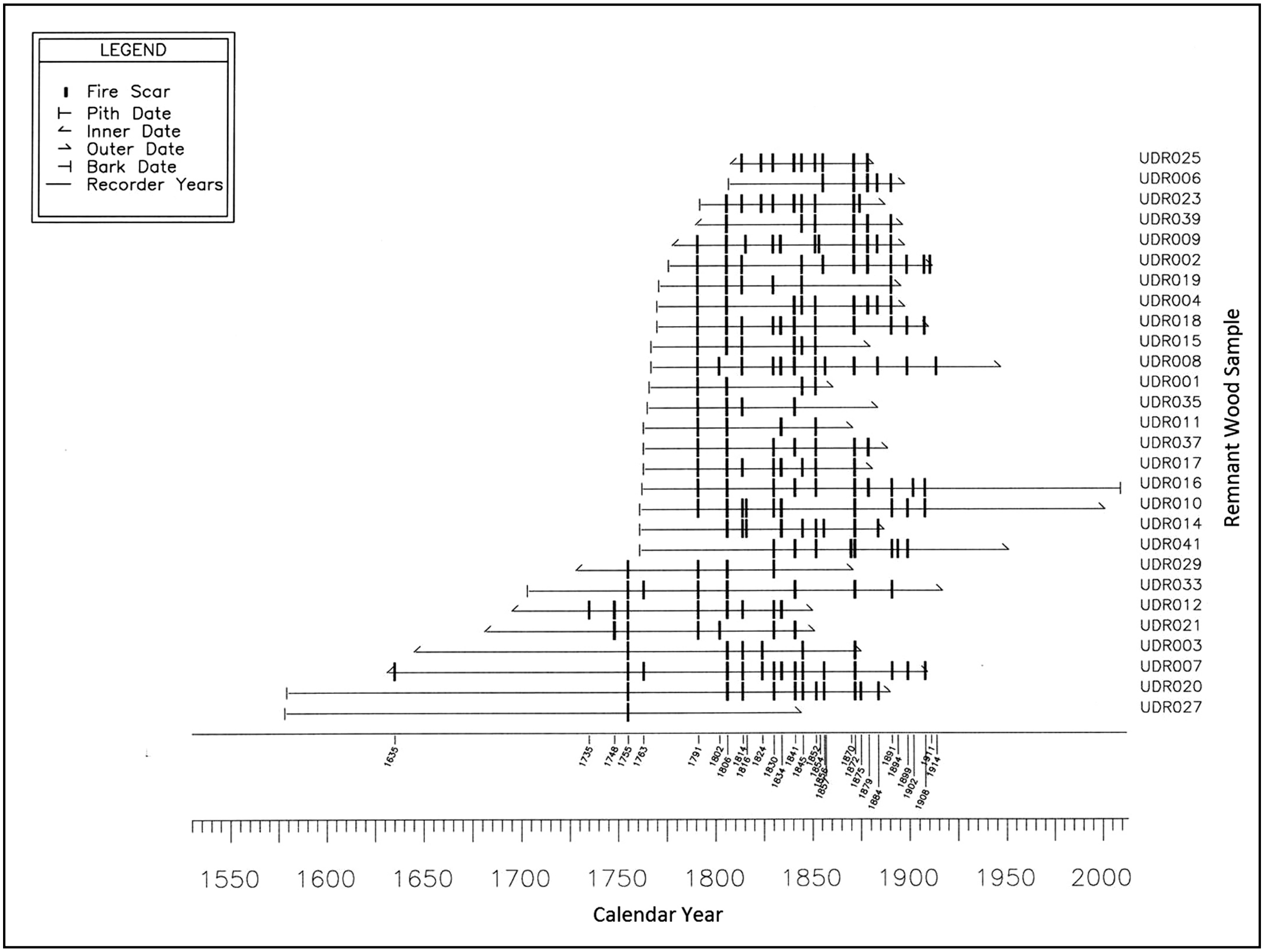

Figure 5. Fire chronology of Upper Dry Run (UDR) from 1600 to 2010. Each horizontal line represents one red pine sample tree and the dark black vertical bars represent the fires. Recorder years are the calendar years represented by the annual rings of that sample.

and other diseases (Hulbert 1910; Wallace 1958). A meteorological aspect to this 85-year fire-free interval is that it coincides with a period of minimal temperatures during the Little Ice Age (Mann 2002), so climate may have also contributed to the absence of fires.

A shorter fire-free period at all three sites, this one from about 1770 to 1790, marks the transition from the American Indian cultures to that of the initial Scotch-Irish settlers and corresponds to events of the American Revolutionary War (Meginness 1892; Sipe 1931). The American Revolutionary War commenced in 1775 and pitted the Iroquois tribes against the settlers. In 1778, the Iroquois drove the settlers out of north-central Pennsylvania, an event called the "Great Runaway." The following year, General John Sullivan of the Continental Army led a retaliatory campaign against the Iroquois villages of western New York. This expedition destroyed the Iroquois, virtually ending Indian influence in Pennsylvania. The result of these two actions—the Great Runaway and Sullivan's campaign—was that north-central Pennsylvania and PCG were once again uninhabited, resulting in a fire-free period. Like the previous fire-free interval, this one also coincided with a period of especially cold temperatures during the Little Ice Age (Mann 2002), so climate may have also contributed to the absence of fires.

PCG finally became available for European settlement in the 1790s. The frequency of fires increased approximately 5-fold relative to the preceding two centuries. This marked increase in fire occurrence surprised us as we had anticipated that this change would not occur until the start of railroad logging in the late 1800s. However, this increase in fire may not be entirely attributable to logging. First, logging of the pine-hemlock forests began near the mouth of Pine Creek with initial European settlement and steadily advanced upstream along it and the principal tributaries, as well as upslope from the stream bottoms. The study sites are several kilometers from Pine Creek and the major tributaries. Thus, the sites were likely not logged until later in

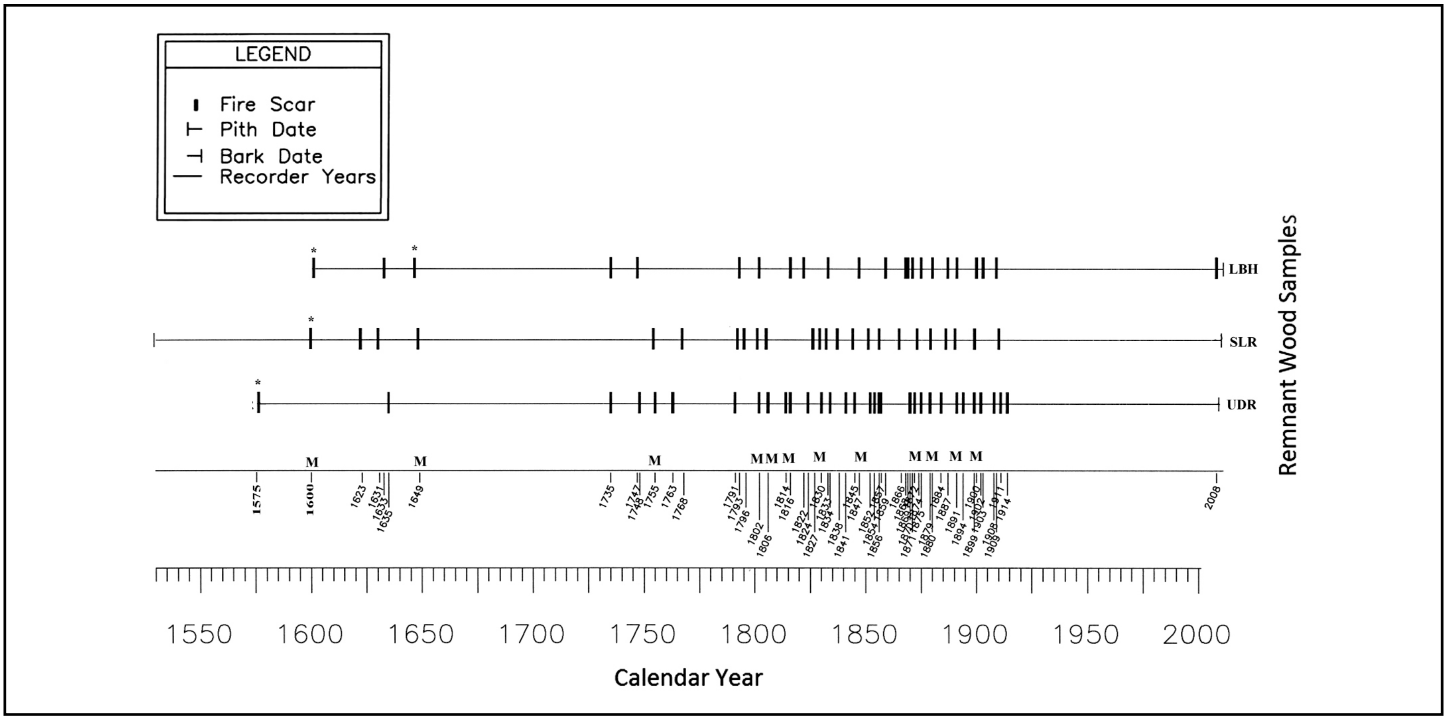

Figure 6. Composite fire chronologies of the Long Branch Hill (LBH), Slate Run (SLR), and Upper Dry Run (UDR) study sites in north-central Pennsylvania. Each horizontal line represents the chronology of one site and each dark black vertical bar represents a fire. Asterisks (*) denote fires identified from formation of red pine cohorts, not from fire scars. M indicates potential multisite fires. Note the synchrony of fires and fire-free periods among the three sites despite them being 12 to 14 km apart.

the 1800s. Second, logging was primarily done during the winter so draft horses could pull the logs to the waterways and then the spring floods would carry them to the sawmills. Winter logging is an unlikely ignition source. Rather, the increase in fire activity may be the result of the settlers adopting the Iroquois practice of broadcast forest burning to control rattlesnakes and promote fruiting shrubs (Tome 1854; Pringle 1880).

A period of no, or few, fires occurred from the late 1840s to the 1870s. This period is most clear at UDR (no fires from 1857 to 1870), but is also evident at LBH (one fire between 1847 and 1868) and SLR (three fires between 1845 and 1874). The years of this reduced fire activity are interesting because they were drier than normal and included a mild multiyear drought (average Palmer Drought Severity Index was -1.05 from 1854 to 1876, Cook et al. 2004) that should have exacerbated the frequency and severity of fire, but the fire scar history clearly does not support this association. This lull in fire occurrences can be accounted for by several historical factors. First, the discovery of gold in California in 1849 attracted hundreds of young men from northern Pennsylvania (Sexton 1883). Second, northern Pennsylvania provided thousands of soldiers to the Union Army during the American Civil War (1861 to 1865). For example, Tioga County at the northern end of PCG provided more than 4000 soldiers, approximately 50% of the young men in the county (Sexton 1883). This exodus and mass enlistment of young men removed the ignition source from PCG. Finally, the amount of pine-hemlock forest available for harvesting may have been exhausted given the technology and transportation limitations of the time (railroad logging had not yet begun), resulting in a decrease in fires.

After the Civil War, logging changed with the development of narrow gauge railroads and locomotives that could access the most remote parts of the PCG watershed (Taber 1972). The principal railroad through PCG was completed in 1883, but by then numerous secondary railroads had been built into adjoining drainages. All three sites had these spur railroads pass through their respective drainages. Relative to before the war, logging rates accelerated. More than 100 sawmills of various sizes were built throughout PCG to process the logs. The locomotives served as ignition sources because they lacked spark arrestors in their smoke stacks to prevent the emission of burning embers (Decoster 1995). The logging debris promoted severe fires capable of covering hundreds of hectares (Decoster 1995). For example, the 1891 fire impacted all three sites and was so large it was reported by several newspapers (Daily Gazette and Bulletin 1891).

By the early 1900s, the logging of PCG was ending (Taber 1972; Dillon 2006). Virtually the entire watershed had been stripped of its pine-hemlock forest. The secondary railroads were abandoned and the cut-over land sold to Pennsylvania for its fledgling state forestry system. The end of logging removed the primary ignition source, and the advent of forest protection further prevented wildfires. Since 1914, fire has been virtually nonexistent at the sites. A wildfire in 2008 impacted the LBH site, but the other two have been unburned for about a century. The prolonged absence of fire from these sites, as well as throughout PCG, will probably be the normal condition into the future due to the constraints of a modern 21st century society.

The fire history of PCG is consistent with the fire histories of other parts of the Appalachian HPH forest. In the three centuries prior to European settlement, we only found eight fires that scarred most of the available recorder trees and (or) initiated pine regeneration. This agrees with the findings of Hough and Forbes (1943) that presettlement fires in HPH forests in Pennsylvania were rare but could be damaging and influential. Additionally, we found fire to be absent for 85 to 100 years and this agrees with Lutz (1930) who found a similar fire-free period at Hearts Content in northwestern Pennsylvania. Engstrom and Mann (1991) and Mann et al. (1994) also reported this pattern of fires and fire-free intervals for Vermont. However, they found more growing-season fires, suggesting that lightning might be an important ignition source at the northern end of the Appalachian HPH forest.

Like any study, this one has limitations. The individual site and overall composite chronologies have small sample sizes at both ends, so we may have missed fires in the early 1600s or in the 1900s. Our assumption that the oldest red pine cohorts at each site were created by fires may be erroneous because severe canopy disturbance in red pine stands can initiate regeneration. The identification of 12 landscape-level fires affecting two or more sites may be an overestimation, as there is no means of distinguishing between one large fire and two or three smaller synchronous fires. Finally, caution must be exercised in extrapolating the lack of fire before 1790 to other parts of eastern North America. PCG was a hinterland with scant American Indian influence, so the lack of fires may not be representative of other locations that were closer to American Indian villages and major travel routes.

CONCLUSIONS

The fire history of the Pine Creek Gorge region reflects the local human history. Prior to European settlement, the population of American Indians was low and use of the watershed consisted of hunting and travel. Consequently, fires were rare. When disease and war disrupted tribal life, the forest fires ceased. European settlement started in the late 1700s and brought permanent villages, agriculture, and logging to the area. The increased population, coupled with more demand for materials from the forests, caused fires to become commonplace, occurring several times a decade throughout the 1800s. The advent of industrial-scale logging maintained this frequent fire regime until logging ended and forest protection began in the early 1900s. Since then, fires have been virtually nonexistent, and this current situation is unlikely to change due to the numerous constraints of forest burning in 21st century society.

ACKNOWLEDGMENTS

We thank the Pennsylvania Bureau of Forestry, especially the staffs of the Tiadaghton and Tioga State Forests, for their permission to conduct this research on their lands, help with locating potential sites, and access to the sites. We also thank Eric Baxter and Greg Sanford of the USDA Forest Service, Northern Research Station, for all their hard work in collecting the samples. We are indebted to the staffs of the Lycoming and Tioga County Historical Societies for access to numerous historical documents and rare books. Funding for this project was provided by the Joint Fire Science Program.

Patrick Brose is a Research Forester with the USDA Forest Service, Northern Research Station. His primary research interest is to understand the role of fire in eastern oak ecosystems.

Richard Guyette is a Research Professor with the University of Missouri, School of Natural Resources. His research interests include all aspects of fire history, especially in North America.

Joseph Marschall is a Senior Research Specialist with the University of Missouri, School of Natural Resources.

Michael Stambaugh is a Research Assistant Professor with the University of Missouri, School of Natural Resources. His primary research interest is documenting long-term changes in forest ecosystems to better understand management effects and likely future conditions.

LITERATURE CITED

Abrams, M.D., and C.M. Ruffner. 1995. Physiographic analysis of witness-tree distribution (1765–1798) and present forest cover through north central Pennsylvania. Canadian Journal of Forest Research 25:659-668.

Aldrich, S.R., C.W. Lafon, H.D. Grissino-Mayer, G.G. DeWeese, and J.A. Hoss. 2010. Three centuries of fire in montane pine-oak stands on a temperate forest landscape. Applied Vegetation Science 13:36-46.

Arno, S.F., and K.M. Sneck. 1977. A method for determining fire history in coniferous forests of the mountain West. General Technical Report INT-42, US Forest Service, Intermountain Forest and Range Experiment Station, Ogden, UT.

Braun, E.L. 1950. Deciduous Forests of Eastern North America. MacMillan Publishing, New York.

Brose, P.H., D.C. Dey, R.P. Guyette, J.M. Marschall, and M.C. Stambaugh. 2013. The influences of drought and humans on the fire regimes of northern Pennsylvania, USA. Canadian Journal of Forest Research 43:757-767.

Brose, P.H., T.M. Schuler, D.H. Van Lear, and J. Berst. 2001. Bringing fire back: the changing regimes of the Appalachian mixed-oak forests. Journal of Forestry 99:30-35.

Cook, E.R., D.M. Meko, D.W. Stahle, and M.K. Cleaveland. 2004. North American summer PDSI reconstructions: IGBP PAGES/World Data Center for Paleoclimatology, Data Contribution Series #2004-045. NOAA/NGDC Paleoclimatology Program, Boulder, CO.

Daily Gazette and Bulletin. 1891. The burning forests. Accessed January 2013 <www.newspaperarchive.com>.

Decoster, L.A. 1995. The legacy of Penn's Woods: a history of the Pennsylvania Bureau of Forestry. Pennsylvania Historical and Museum Commission, Harrisburg.

Dillon, C.W. 2006. Pennsylvania's Grand Canyon: A Natural and Human History. Pine Creek Press, Wellsboro, PA.

Donehoo, G.P. 1928. Indian Villages and Place Names in Pennsylvania. Gateway Press, Baltimore, MD.

Engstrom, F.B., and D.H. Mann. 1991. Fire ecology of red pine (*Pinus resinosa*) in northern Vermont, U.S.A. Canadian Journal of Forest Research 21:882-889.

Grissino-Mayer, H.D. 2001. Evaluating cross-dating accuracy: A manual and tutorial for the computer program COFECHA. Tree-Ring Research 57:205-221.

Grissino-Mayer, H.D. 2004. FHX2 User's Manual. University of Tennessee Press. Knoxville, TN.

Guyette, R.P., D.C. Dey, M.C. Stambaugh, and R.M. Muzika. 2006. Fire scars reveal variability and dynamics of eastern fire regimes. Pp. 20-39 *in* M.C. Dickinson, ed., Fire in Eastern Oak Forests: Delivering Science to Land Managers. General Technical Report NRS-P-1, US Forest Service, Northern Research Station, Newtown Square, PA.

Haines, D.A., W.A. Main, and E.F. McNamara. 1978. Forest fires in Pennsylvania. Research Paper NC-158, US Department of Agriculture Forest Service, North Central Forest Experiment Station, Newtown Square, PA.

Holmes, R.L. 1983. Computer-assisted quality control in tree-ring dating and measurement. Tree-Ring Bulletin 43:69-78.

Hough, A.F. 1936. A climax forest community on East Tionesta Creek in northwestern Pennsylvania. Ecology 17:9-28.

Hough, A.F., and R.D. Forbes. 1943. The ecology and silvics of forests in the high plateaus of Pennsylvania. Ecological Monographs 13:299-320.

Hulbert, A.B. 1910. David Zeisberger's History of the Northern American Indians in 18th Century Ohio, New York, and Pennsylvania. Wennawoods Publishing, Lewisburg, PA.

Johnson, E.A., G.I. Fryer, and M.J. Heathcott. 1990. The influence of man and climate on the frequency of fire in the interior wet belt forest, British Columbia. Journal of Ecology 78:403-412.

Kohler, C.D. 1986. Soil survey of Lycoming County, Pennsylvania. US Soil Conservation Service, Washington, DC.

Lutz, H.J. 1930. The vegetation of Heart's Content, a virgin forest in northwestern Pennsylvania. Ecology 11:2-29.

Mann, C.C. 2005. 1491: New Revelations of the Americas Before Columbus. Knopf Publishing, New York.

Mann, D.H., F.B. Engstrom, and J.L. Bubier. 1994. Fire history and tree recruitment in an uncut New England forest. Quaternary Research 42:206-215.

Mann, M.E. 2002. The little ice age. Pp. 504-509 *in* M.C. MacCracken and J.S. Perry, eds., The Earth System: Physical and Chemical Dimensions of Global Environmental Change. Wiley and Sons Publishing, Chichester, UK.

Meginness, J. 1892. The Early History of Lycoming County, Pennsylvania. Wennawoods Publishing, Lewisburg, PA.

Nichols, G.E. 1935. The hemlock – white pine – northern hardwood region of eastern North America. Ecology 16:403-422.

Niklasson, M., and A. Granstrom. 2000. Numbers and sizes of fires: long-term spatially explicit fire history in a Swedish boreal landscape. Ecology 81:1484-1499.

Owlett, S.E. 1993. Seasons Along the Tiadaghton: An Environmental History of the Pine Creek Gorge. Pine Creek Gorge Press, Wellsboro, PA.

[PA DCNR] Pennsylvania Department of Conservation and Natural Resources. 2013. Wildfire statistics. Accessed January 2013. <www.dcnr.state.pa.us/forestry/fire/firestatistics/index.html>.

Pringle, C.G. 1880. The forests of Pennsylvania. Pp. 506-516 in C.S. Sargent, ed., Report on the Forests of North America. US Government Printing Office, Washington, DC.

Pyne, S.J. 1982. Fire in America: A Cultural History of Wildland and Rural Fire. University of Washington Press, Seattle.

Rudolf, P.O. 1990. Pinus resinosa Ait. (Red pine). Pp. 442-455 in R.M. Burns and B.H. Honkala, eds., Silvics of North America, Volume 1: Conifers. Agricultural Handbook 654, US Department of Agriculture, [Washington, DC].

Ruffner, C.M., and M.D. Abrams. 1998. Lightning strikes and resultant fires from archival (1912-1917) and current (1960-1997) information in Pennsylvania. Journal of the Torrey Botanical Society 125:249-252.

Sargent, C.S. 1884. Report on the Forests of North America. US Government Printing Office, Washington, DC.

Schultz, C.H. (ed.). 1999. The Geology of Pennsylvania. Geological Survey, Department of Conservation of Natural Resources, Harrisburg, PA.

Sexton, J.L. 1883. History of Tioga County, Pennsylvania. Munsell Publishing, New York.

Shumway, D.L., M.D. Abrams, and C.M. Ruffner. 2001. A 400-year history of fire and oak recruitment in an old-growth oak forest in western Maryland. Canadian Journal of Forest Research. 31:1437-1443.

Sipe, C.H. 1931. The Indian Wars of Pennsylvania. Historical Society of Pennsylvania, Philadelphia, PA.

Speer, J.H. 2010. Fundamentals of Tree Ring Research. University of Arizona Press, Tucson.

Taber, T.T. 1972. Logging Railroad Era of Lumbering in Pennsylvania, Volume 4: Sunset along the Susquehanna. Lycoming Printing Company, Williamsport, PA.

Tome, P. 1854. Pioneer Life or, Thirty Years a Hunter. Aurand Press, Harrisburg, PA.

Veblen, T.T., T. Kitzberger, R. Villalba, and J. Donnegan. 1999. Fire history in northern Patagonia: the roles of humans and climatic variation. Ecological Monographs 69:47-67.

Wallace, P.A. 1952. Historic Indian Paths of Pennsylvania. Pennsylvania Historical and Museum Commission, Harrisburg.

Wallace, P.A. 1958. Thirty Thousand Miles with John Heckewelder. Wennawoods Publishing, Lewisburg, PA.

Williams, G.W. 2003. References on the American Indian use of fire in ecosystems. US Department of Agriculture, Forest Service, Washington, DC.