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Article

Historical Drivers and Contemporary Perceptions of Wildfire in a Post-Industrial Rural Landscape

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Abstract: Placed-based fire management planning that considers historical patterns and processes as well as contemporary local knowledge is recognized as an alternative to broad-scale, regional approaches. In this paper, we used dendrochronology and an online survey to assess historical trends and contemporary perceptions of wildfire, respectively, in the fire-prone anthracite coal region of northeastern Pennsylvania. We developed an annual index of fire occurrence and extent from 216 fire-scarred pitch pine (*Pinus rigida*) distributed across 9 ridgetop study sites for the period 1900–2016. In addition, we collected survey responses from area residents regarding contemporary perceptions of wildfire hazards and management. Our results show that 20th century wildfire activity was not associated with drought, but closely followed fluctuations in the anthracite coal industry, with increased fire occurrence and extent associated with times of severe job losses. Less extensive wildfire continues to occur frequently, with area residents recognizing the need for fuel management (i.e., prescribed fire) and an increase in resources allocated to wildfire prevention and management as well as trash disposal and recycling programs. Our research represents one example of an integrated approach to informing sustainable fire management that considers the link between historical patterns and contemporary perceptions.

Keywords: dendrochronology; fire history; wildfire perceptions; survey; pitch pine; Pennsylvania

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1. Introduction

In recent decades, human ignitions have increased the number of large wildfires [1] and expanded the seasonal window of fire occurrence across the United States (U.S.) [2]. These trends are particularly concerning for land managers tasked with reducing wildfire hazards and protecting life and property in fire-prone landscapes characterized by complex socioecological feedbacks beyond the wildland-urban interface (WUI) [3]. To mitigate these hazards, wildfire management objectives are often informed by the paleoecological record (i.e., soil and sediment charcoal, pollen, and tree-rings) and an associated "historical range of variability" with regard to wildfire frequency, severity, seasonality, or spatial extent [4,5]. This historical context is then applied to fuel management or forest restoration programs in a variety of ecosystems. In more limited application in the U.S., "place-based" strategies, that draw upon traditional ecological knowledge (TEK) (e.g., [6,7]) or targeted landowner surveys (e.g., [8,9]), are used to develop "adaptive capacity" in fire-prone communities. These strategies link either traditional practices and beliefs (i.e., TEK) or contemporary perceptions about wildfire to the historical record (if available), informing management plans that are dynamic and compatible with local knowledge as well as 21st century climate trends and land use patterns (i.e., Firewise USA [10]). Accordingly, identifying landscapes where there is potential to integrate historical ecology with the perceptions and knowledge of individuals and the community at large will be essential to the successful implementation of locally appropriate, and sustainable, fire use and management plans.

Historically, humans have actively suppressed or excluded fire through land use and land cover change, while also using fire to create and manage landscapes for hunting, foraging, and agricultural purposes [11]. These "cultural landscapes" (i.e., [12]) not only reflect regional and local biophysical characteristics (e.g., climate, vegetation, and soils), but also the needs, values, and belief systems of the dominant human population. Paleoecological studies indicate that Native American, and then European-American, fire use varied across the Eastern Temperate Forests Region (ETFR; Level I Ecoregion [13]). For example, in the southern Appalachian Mountains, evidence from pollen and sediment charcoal records suggest that the selective use of fire by Native American populations maintained a patchwork of fire-adapted vegetation for most of the last 4000 years [14]. Annually-resolved tree-ring records indicate that this pattern of fire use continued through the transition to European-American settlement (ca. 1800) and into the industrial logging era in the early 20th century [15]. Fire was subsequently largely excluded from this landscape due to the decline of the logging industry and nation-wide fire suppression policies. Fire history studies in the Ozark-Ouachita Highlands in Missouri and Arkansas indicate a slightly different temporal trend, with fire activity peaking during European-American settlement (ca. 1860), relative to the previous century and a half when Native American populations were declining and/or being replaced by native peoples relocated from the East [16,17]. Fragmentation of the forest landscape due to agricultural development and subsequent fire suppression reduced fire extent in this region in the 20th century. Pennsylvania experienced a similar "wave of fire" associated with European-American settlement and industrial activities [18]. Here, tree-ring records across the central portion of the state indicate that fire activity peaked when settlement expanded and industrial activities (e.g., logging and charcoal and iron furnaces) intensified (ca. 1800), before declining in the 20th century. In each of these landscapes, it was determined that human activities (i.e., cultural practices/policy and industry), rather than climate (i.e., drought), were most strongly associated with patterns of fire activity.

Wildfire has persisted in some areas within the ETFR despite a general pattern of fire cessation in the 20th century. These relict fire regimes are concentrated in fire-prone landscapes with rural to semi-urban populations such as the Great Lakes Region [19,20], the New Jersey Pine Barrens [21], the Central Appalachian Mountains [22–24], and in isolated locations across the Ozark-Ouachita Highlands [25] and U.S. Southeast [26–28]. Human ignitions, including arson, accidental fire-setting, and the use of fire for informal resource management, are the primary causes of wildfire in the ETFR, while lightning strikes associated with low pressure systems contribute relatively few ignitions, with some exceptions (e.g., [22,29]). This prevalence of human-caused wildfire in the ETFR, both historically and in the modern record, has not translated into a broad-scale application of social science research with regard to fire knowledge and risk perception relative to studies conducted in arid and semi-arid ecosystems (see [30,31]). A few studies in the U.S. South and Northeast, however, indicate that landowner perceptions of wildfire risk range broadly from those who predominately view wildfire as a threat to property [32] to landowners who are generally unconcerned, despite being aware that wildfires occur nearby [8,21]. Regardless of risk perception, these studies note that increasing landowner awareness alone will not ensure the implementation of wildfire hazard reduction measures (e.g., brush clearing around property, obeying burn bans). Rather, public participation in fire management plans via advisory committees or focus groups could foster participation in, and acceptance of, fire and fuel management programs [8,33]. Linking historical patterns and drivers of wildfire with these modern perspectives can provide the basis for dynamic fire management initiatives that emphasize "place," simultaneously reducing wildfire hazards and promoting resilient forest landscapes.

In this study, we focus on the so-called former, or post-industrial, anthracite coal region in northeastern Pennsylvania (see Figure 1a). This distinct cultural and socioeconomic region (see [34,35]), with its fire-adapted ridgetop forests and abundant human ignitions [36], provides an ideal opportunity for place-based wildfire research. Our principle objective was to integrate a landscape-scale fire history with contemporary perceptions of wildfire, including those related to causes, hazards, and management responsibilities. In doing so, we attempt to provide a foundation for 21st century fire use and management that is grounded in time, place, and personal experience. Specifically, our objectives were the following: (1) develop a continuous, 20th–21st century, landscape-scale fire history for the most fire-prone region in Pennsylvania, (2) evaluate the relative influence of historical drivers of wildfire (i.e., drought and industry), and (3) using data gathered in an online survey, assess contemporary perceptions and knowledge of wildfire with regard to traditional fire use (i.e., promoting huckleberry [*Gaylussacia* spp.] growth) and present-day wildfire hazards and management. Our use of a traditional ecological knowledge (TEK) perspective here, refers to the fire use practices of European-Americans during the last century and does not consider the pre-settlement practices of indigenous populations. In addressing the objectives above, we discuss a fire use and management strategy that bridges historical patterns with modern realities and consider implications for similar fire-prone landscapes in the ETFR.

2. Materials and Methods

2.1. Study Area

Anthracite coal production has had a profound impact on the social and cultural fabric of northeastern Pennsylvania for more than 150 years. Labor organization and strikes were a major component of the cultural environment in the region by the late 19th and early 20th centuries, but this movement faced significant, and often effective, repression from strike breakers and mine owners [37] (pp. 33–41). During this era, striking miners and their families used foraging and hunting on the local ridgetops as means of survival [37] (pp. 31–35). This survival strategy became central to regional culture during the Great Depression, during which the region faced massive layoffs and a climbing unemployment rate [37] (pp. 67–68). The anthracite coal industry declined, in fits and starts, for over 80 years, as one after another mining or manufacturing operation fell to the forces of deindustrialization [35] (pp. 114–116). Today, this region of Pennsylvania struggles economically and continues to see a steady decline in population. For the existing population, the history of the region is inextricably linked with the landscape and the use and misuse of natural resources by both powerful actors and everyday people.

We identified and were granted access to nine ridgetop fire history sites located on unmanaged land owned by private individuals (i.e., Spring Mountain) and local municipal water authorities (i.e., Locust and Broad Mountains) in north-central Schuylkill County (Figure 1b,c). Schuylkill County is situated in the ridge and valley province of the Appalachian Mountains and is included in Pennsylvania Forest District 18 (a.k.a. Weiser Forest District), which is the most fire-prone District in Pennsylvania based on statistics for 1979–2017 [38]. During this time period, trends in the number of fires and area burned within the District display no discernable pattern with the exception of a slight decrease in the 21st century (Figure 2). For the same time period, statewide statistics indicate that nearly two-thirds of all wildfires were caused by “debris burning” (32.6%) and “incendiary” activities (30.9%) annually, while very few wildfires were attributed to lightning (1.2%) [38]. Wildfires caused by debris burning and incendiary activities accounted for a combined 66.1% of area burned annually, while lightning was associated with just 1.1% of burned area [38]. In Pennsylvania, wildfire management is primarily the responsibility of the state Bureau of Forestry, with local fire companies often providing first response services.

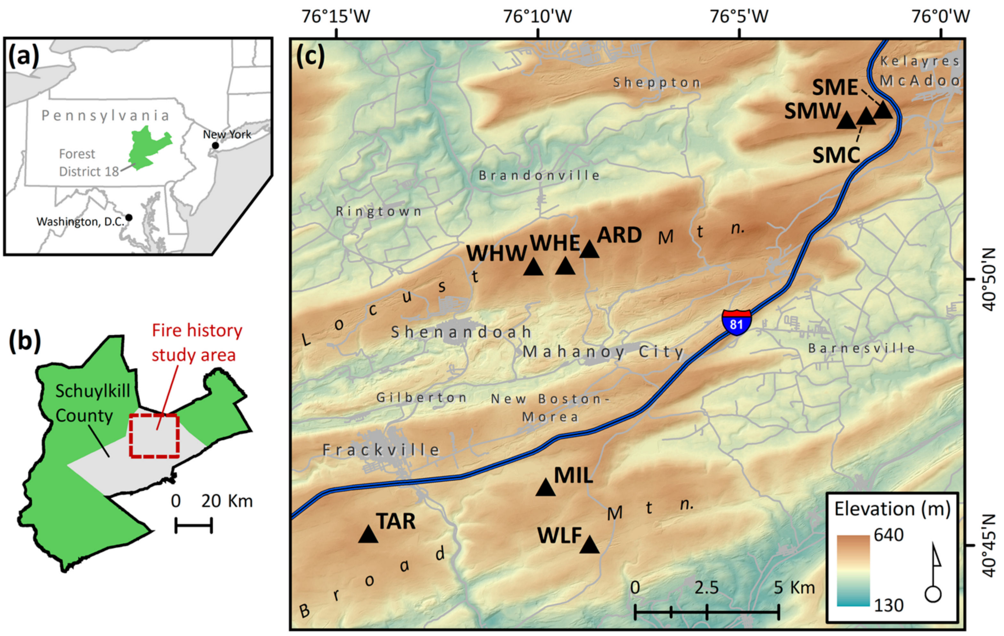

Figure 1. (**a**) Regional location of Forest District 18 (a.k.a. Weiser Forest District) in northeastern Pennsylvania, USA. (**b**) Location of Schuylkill County within Forest District 18. The dashed box highlights the mapped area in (**c**), which shows the location of nine ridgetop fire history sites (black triangles): Abandoned Road (ARD), Mill Creek (MIL), Spring Mountain East (SME), Spring Mountain Central (SMC), Spring Mountain West (SMW), Tar Run (TAR), Waste House Run East (WHE), Waste House Run West (WHW), and Wolf Creek (WLF).

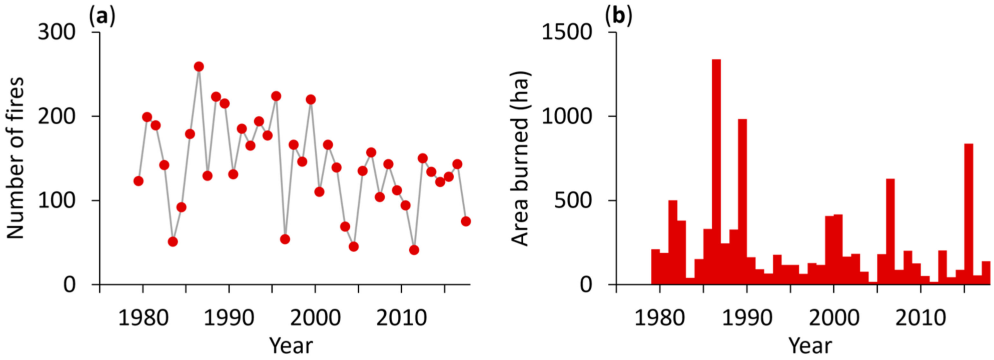

Figure 2. Trends in the observational fire record for Forest District 18 (1979–2017; [38]): (**a**) Number of fires and (**b**) area burned.

All fire history sites are accessible by permission (or illegally) on foot and to high-clearance or all-terrain vehicles (ATVs) and dirt bikes. Previously reported fire-scarred samples collected on Spring Mountain [36] have been separated into three sites based on the presence of two oil pipeline rights-of-way that divide the area into thirds. All sites have poorly developed soils of the Buchanan, Dakalb, and Hazleton-Clymer map units [39] at elevations that range from 465 m to 600 m (Table A1). Vegetation at each site includes components of the ridgetop acidic barrens complex, which is comprised of pitch pine (*Pinus rigida* P. Mill)-scrub oak (*Quercus ilicifolia* Wangenh.) woodland, pitch pine-mixed hardwood woodland, pitch pine-heath woodland, scrub oak shrubland, and low heath shrubland [39]. The disturbance dependent pitch pine woodlands and early successional shrubland communities, dominated by scrub oak or blueberry (*Vaccinium* spp.) and huckleberry species, succeed to mixed hardwood forest in the absence of fire [40]. Average annual temperature for the 30-year period 1981–2010 is 9.6 °C, with monthly temperatures ranging from a low of −3.2 °C in January to 21.9 °C in July [41]. Total annual precipitation is 122.4 cm on average for the same time period, with slightly more precipitation during the spring and summer (April–September; 67.0 cm) compared to fall and winter (October–March; 55.4 cm) [41].

According to the 2010 U.S. Census, the population of Schuylkill County is 148,289, but has declined steadily in the last 7 years. The population is overwhelming homogeneous, with 94.84% identifying as "white," while just 15.3% of Schuylkill County residents hold a college degree. The median household income is $46,573 and the poverty rate is 12.8% [42]. The contemporary economy in the region is primarily based on manufacturing, retail, healthcare and social assistance, and transportation and warehousing [43]. Cultural and historical factors associated with anthracite coal production continue to shape communities in Schuylkill County and are significant aspects in our attempt to better understand contemporary perceptions and knowledge of wildfire in the region.

2.2. Fire Scar Data

Fire-scarred samples were collected on Spring Mountain in May 2015 [36] and at sites on Locust and Broad Mountains in May 2017. We traversed each site, targeting trees for sampling based on visual evidence of fire-scarring (Figure 3a), with the exception of WHE, where a 4-hectare 50-m resolution grid was used to census fire-scarred trees for a separate research objective. We used a chainsaw to cut a partial cross section approximately 3–4 cm thick from living trees, while a full section was removed from standing dead or live "hazard" trees after felling (e.g., [44]). In addition, we removed a partial cross section 0.5 m above ground level from trees that did not have a basal scar, but exhibited cambium damage in the upper portion of the trunk (Figure 3b).

Each sample was air-dried and surfaced with a belt sander and orbital sander (40–600 grit sandpaper) until cells were clearly visible under magnification [45]. We visually crossdated the samples against a local (Spring Mountain) master chronology and the common marker years of three regional chronologies [46–48] using skeleton plots [49] and the list method [50]. Each fire scar was assigned a calendar year and, when possible, the season of occurrence based on its position relative to annual growth rings (Figure 3c). Seasonal categories include: earlywood (E), latewood (L), dormant (D), and undetermined (U). Fire scars occurring between annual rings (i.e., dormant season) were assigned to the year of callus tissue response based the preponderance of early spring wildfire in the region [36]. Injuries that lacked a characteristic woundwood curl, but corresponded to a fire scar recorded by a nearby tree, were treated as a scar (Figure 3c). Injuries not meeting this requirement were left out of subsequent analyses.

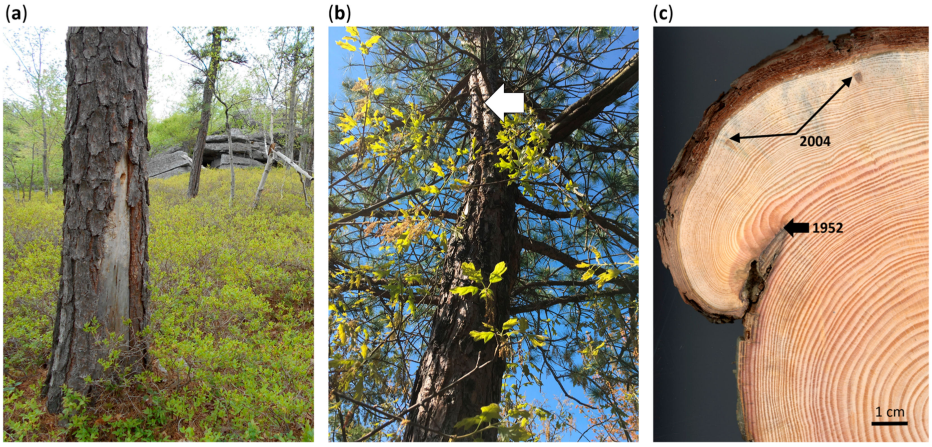

Figure 3. (**a**) An individual pitch pine on Spring Mountain with a fire scar (or "cat face") at its base. (**b**) A fire-scarred pitch pine at the Waste House Run West (WHW) site on Locust Mountain. The arrow highlights a section of cambium damage approximately 4 m from ground level. (**c**) Partial cross section of a fire-scarred pitch pine collected at the Tar Run (TAR) site on Broad Mountain. A dormant season fire scar (1952) and an injury that corresponds to a dormant season fire scar recorded by a nearby tree (2004) are noted.

We entered fire scar data in FHX2 format [51] and calculated site composite fire intervals using Fire History Analysis and Exploration System (FHAES) software [52]. Although we do not focus on individual site fire histories in this paper, we report composite fire interval statistics for each site in the Appendix. In addition, we calculated an annual index of fire occurrence and extent for each site using methods similar to those described by Taylor et al. [53]. Site indices were calculated by dividing the number of fire-scarred trees per year by the number of recorder (or live) trees in that year. An annual area-wide ridgetop fire index (hereafter "RFI") was then calculated by dividing the sum of site indices per year by the number of sites recording fire in that year [53]. Therefore, the theoretical maximum RFI value in a given year would occur if all recorder trees at all sites were scarred. In calculating the RFI, we only included site index values equal to or greater than the median of all site index values when there was a site sample depth of at least three trees. This objective "filtering" of fire years was also applied to fire interval calculations, which reduced bias associated with differences in sample size (over time and across sites) and sample area [54]. The start and end year of the RFI was determined by a minimum of three sites (33%) each having a sample depth of at least three trees.

2.3. Socioeconomic Eras and Fire Activity

We used regime-shift analysis [55] to identify rapid and sustained changes in regional anthracite employment (AE_Δ) [56], which has been previously used as a proxy for regional industrial and socioeconomic conditions [36]. Positive and negative values of AE_Δ indicate industrial/economic growth and decline, respectively, while values close to zero suggest a stable or stagnant regional economy. Regime-shift analysis uses a sequential *t*-test, which identifies a new regime when an observation in the time series is a statistically significant deviation from the mean value of the current regime [55]. The user defines an analysis window (or "cutoff length") that determines the minimum regime length. For our purposes, we used a 20-year cutoff length and a change point of $p < 0.1$ to identify regime shifts. This cutoff length was used in order to identify socioeconomic eras that include a sufficient number of years for further analysis of fire trends. We subsequently confirmed no regime shifts in RFI or the climate variables (see below) using the same parameters.

Chi-square goodness-of-fit tests were used to assess distributions of fire activity (i.e., occurrence and extent) during socioeconomic eras identified by regime-shift analysis. We first compared the ratio of observed fire occurrence (i.e., years when RFI > 0) to expected fire occurrence for each socioeconomic era. For expected values, we assumed an even distribution of fire years across socioeconomic eras in proportion to the number of years in each era. We then summed RFI values, representing the cumulative fire extent, for each socioeconomic era and applied a similar chi-square test. Expected summed RFI values were assumed to be equal across socioeconomic eras in proportion to the number of fire years.

2.4. Interannual and Interdecadal Drivers of Wildfire

We assessed the influence of climate (i.e., drought) and industry (i.e., regional anthracite employment) on the fire-scar record using Superposed Epoch Analysis (SEA) and correlation/regression analysis. In our analyses, we used the Palmer Drought Severity Index (PDSI; [57] as our primary measure of "drought" since reconstructed PDSI (i.e., [58]) is commonly used to assess relationships between annually-resolved fire-scar data and moisture conditions (e.g., [18,53]). In this study, however, we were able to use the instrumental PDSI record (1895–2016) for Pennsylvania Climate Division 2 [41], because it overlaps the full length of the RFI. In addition to PDSI, we calculated annual precipitation anomalies (i.e., deviations from the 20th century average) in the instrumental record [41] as a secondary drought indicator. We used SEA to test for statistically significant departures in PDSI, precipitation anomalies, and AE_Δ within a five-year window lagged three years before and one year after fire and non-fire years. This analysis of interannual fire-climate relationships is common in regional fire history studies (e.g., [15,36,59–61]) and it proved useful for analyzing socioeconomic data (i.e., AE_Δ) as well. To examine longer-term, or interdecadal, influences of climate and industry on fire, we calculated 10-year non-overlapping averages of z-scores for RFI, PDSI, precipitation anomalies, and AE_{Δ} for 1900 to 2009 ($n = 11$) and calculated correlation coefficients [53]. We then developed a simple linear regression model based on the relationship between the 10-year averages of z-scores for RFI and AE_{Δ} and used this model to predict RFI for 1900–2016.

2.5. Wildfire Survey

We collected information about contemporary perceptions and knowledge of wildfire via an online survey that was open between February and June of 2017. Information about the survey and a call for participants was made available to local news outlets, including two newspaper articles that included a link to the online survey: (1) "Survey seeks information on forest fires" (Hazleton Standard Speaker, 27 February 2017) and (2) "Professor conducts brush fire survey in Schuylkill" (Pottsville Republican-Herald, 8 June 2017). An explanation and link to the online survey was also distributed through email to the superintendents of 13 Schuylkill County school districts and posted on relevant Facebook group pages (e.g., Anthracite Region Accuvision Weather, Schuylkill County Trout Unlimited, Firewire Schuylkill County) for further dissemination. School district superintendents, serving as community leaders, circulated the survey among teachers and family members in the County. Participants in the study were selected from current and former Schuylkill County residents who agreed to participate in the survey. This study includes data from 64 respondents, including 29 males, 21 females, and 14 individuals who elected not to provide sex or gender data. Survey respondents were between the ages of 18 and 68, with a median age of 30 (see Figure 4c).

We collected information from survey participants via both closed-ended and open-ended questions. Closed-ended questions covered topics related to trends in local wildfire (i.e., forest fire) occurrence as well as wildfire hazards and management. Participants were also given an opportunity to openly respond to questions regarding the causes of wildfire in the region and potential measures of risk reduction and management. Summative and qualitative analyses were used to explore and interpret the survey data. We first present summary frequency charts in order to provide an overview of the perception and knowledge data. Additionally, open-ended qualitative responses were coded and thematically organized.

There are several limitations associated with the survey, including (1) a small sample size, (2) selection bias based on the voluntary nature of the study, and (3) the non-random nature of volunteer research. Survey research, including both closed- and open-ended questions, is regularly a feature of social science and human subject scholarship and small sample size is a common issue faced by researchers in these fields. Recent research suggests that while high non-response rates do not necessarily alter survey estimates, very small sample sizes are resistant to statistical correction when developing multi-variate models [62,63]. In order to address this limitation, our study provides only descriptive statistics of our sample, which demonstrate patterns among respondents. With regard to selection bias, like all ethical and legal human research projects, our survey project allowed participants to decline participation. However, as many researchers have noted, selection bias can occur when specific characteristics separate respondents from non-respondents. The risk of selection bias based on the voluntary status of subjects is inherent in social science research and must be addressed statistically or theoretically by all researchers [64,65]. In order to address this limitation, we elected to focus on the qualitative analysis of open-ended answers to develop theoretically-based policy recommendations. Qualitative analysis allows for the identification of trends among participants that form the basis of theoretical recommendations. However, as with any qualitative data, this work reflects only the specific context of the participants and, as such, it is not highly generalizable [66–69].

Our survey was approved by the federally recognized Concord University Institutional Review Board (S17-02; 15 February 2017) and maintained the highest standard of protection for human subjects research. All participants in the study were provided written consent statements and all aggregate data maintains strict confidentiality.

3. Results

3.1. Fire History

We crossdated 216 samples (92%) collected from 234 fire-scarred pitch pine trees distributed across the 9 ridgetop sites (Table A1). Samples not crossdated were either too decayed to distinguish annual rings or suppressed growth prevented accurate dating. Crossdated samples recorded a total of 321 fire scars representing 87 unique fire years from 1848 to 2016 (Figure A1). The majority (75%) of scars were recorded during the dormant season, while the remaining scars were identified as earlywood (10%), latewood (3%), and undetermined (12%). Site fire index values ranged from 0.010 to 0.964 with a median value of 0.071 when there was sample depth of at least three trees ($n = 153$). This median value represents the minimum site fire index value, and corresponding years, used in fire interval and RFI calculations. Across all sites, mean fire interval ranged from 2 years at WHE to approximately 14 years at WHW (Table A1). On Spring Mountain, fire occurred on average twice as frequent at SME than at SMC or SMW (Table A1), while numerous fires below the filter threshold differentiate SMC from SME and SMW (Figure A1). These differences in local fire histories justified the division of Spring Mountain samples into three sites for the landscape-scale analysis.

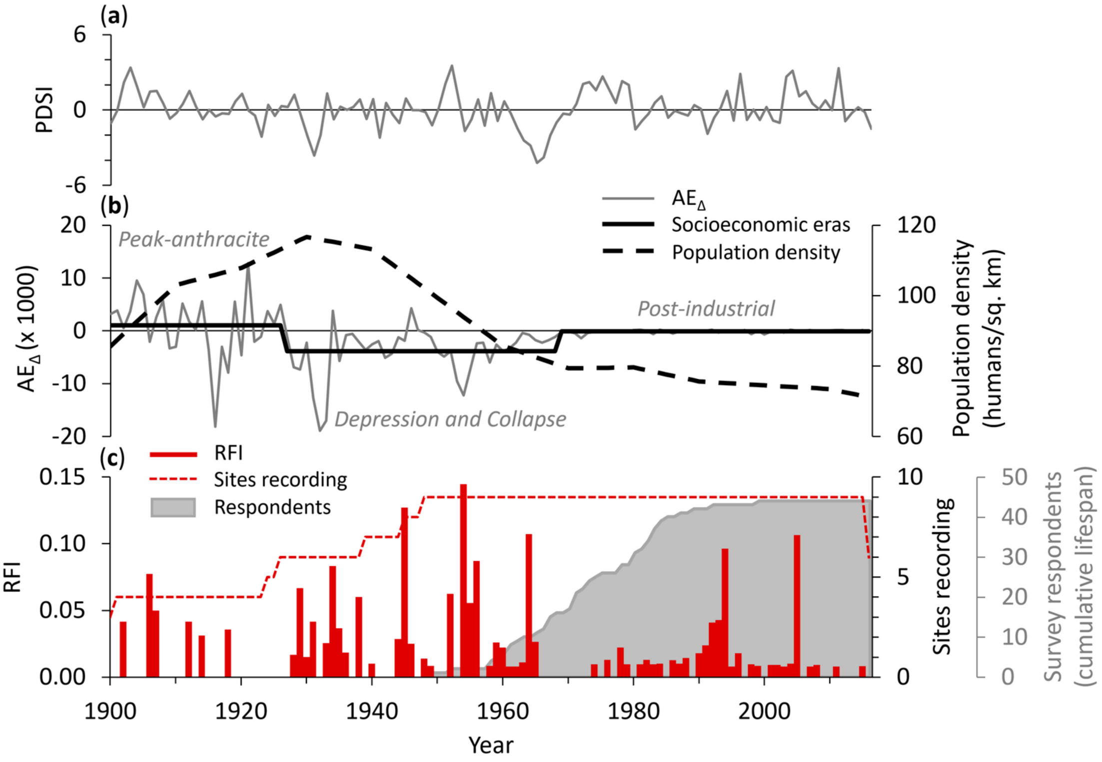

Figure 4. (**a**) Palmer Drought Severity Index (PDSI; [41]) and (**b**) regional anthracite employment (AE$_\Delta$; [56]) with Schuylkill County population density (dashed line) [39]. Regime shifts in AE$_\Delta$ (thick line) are defined by a 20-year cutoff length and a change point of $p < 0.1$ [55]. (**c**) The ridgetop fire index (RFI; bars), number of fire history sites recording through time (dashed line), and the cumulative lifespan of survey respondents who provided age data (gray area). Notes: Socioeconomic eras based on regime shift analysis of AE$_\Delta$ are noted for reference. No regime shifts were detected for RFI or PDSI.

The RFI (1900–2016) includes a total of 62 fire years from 1902 to 2015 (Figure 4c). RFI values were right skewed (skewness: 1.74) ranging from 0.008 to 0.145, with a median of 0.018. Seven of the 10 highest RFI values occurred between 1928 and 1964 and there were two "fire free" periods of at least 8 years, including 1919–1927 and 1966–1973 (Figure 4c). Chi-square goodness-of-fit tests indicate that fire activity (i.e., occurrence and extent) did not fit expected distributions across socioeconomic eras

[Peak-anthracite (1900–1926), Depression and Collapse (1927–1968), and Post-industrial (1969–2016)]. Fire occurrence was dependent on socioeconomic era ($\chi^2 = 6.32$, $p < 0.05$), with fires occurring more frequently than expected during Depression and Collapse (observed/expected: 1.21) and in the Post-industrial era (observed/expected: 1.14). Depression and Collapse is characterized by significant and persistent job loss in the regional anthracite coal industry, while a greatly diminished coal industry and a consistently declining population is characteristic of the Post-industrial era (Figure 4b). Boom-and-bust economic conditions prevailed in the Peak-anthracite era (Figure 4b), during which fire occurred less often than expected (observed/expected: 0.42). Fire extent (i.e., cumulative RFI) was also related to socioeconomic era ($\chi^2 = 13.00$, $p < 0.01$). Fire was more extensive than expected in the Peak-anthracite era (observed/expected: 1.44) and during Depression and Collapse (observed/expected: 1.32), while extent was less than expected during the Post-industrial era (observed/expected: 0.62).

3.2. Historical Drivers of Wildfire

Superposed Epoch Analysis (SEA) indicates an absence of interannual fire-climate relationships for the full period of analysis (1900–2016) and during Depression and Collapse (1927–1968) (Figure 5a–d). Conditions were not uniquely dry (or wet) in the three years preceding, during, or one year after fire years, despite the occurrence of multiyear droughts in the 1930s and 1960s (see Figure 4a). Similarly, there were no significant departures in mean PDSI or precipitation anomalies associated with non-fire years, although conditions were generally drier in the three years preceding non-fire years compared to fire years during Depression and Collapse. There was a significant negative departure (i.e., loss) in regional anthracite employment two years preceding fire years during both periods of analysis (Figure 5e,f). These interannual fire-employment relationships contrast with the three years preceding non-fire years in which losses in regional anthracite employment were relatively fewer. The number of fire years in the top 40% of RFI values during the "Peak-anthracite" ($n = 6$) and "Post-industrial" ($n = 4$) eras did not provide for statistically robust applications of SEA.

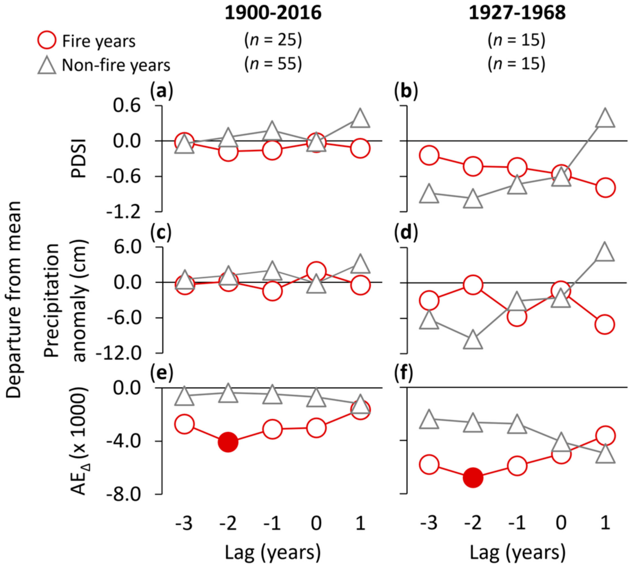

Figure 5. Superposed Epoch Analysis (SEA) results: (**a**,**b**) Palmer Drought Severity Index (PDSI; [41]), (**c**,**d**) precipitation relative to the 20th century average [41], and (**e**,**f**) regional anthracite employment (AE_{Δ}; [56]). Both variables are lagged three years before and one year after fire years (circles) and non-fire years (triangles) during the full period (1900–2016) and "Depression and Collapse" (1927–1968). Fire years are defined by ridgetop fire index (RFI) values in the 60th percentile. Shaded symbols indicate statistical significance ($p < 0.05$).

The decadal, or 10-year average, RFI was strongly related to AE_Δ ($r = -0.63$; $p < 0.05$), but displayed only a weak relationship to PDSI ($r = -0.22$; $p > 0.1$) and no relationship to precipitation anomalies ($r = -0.07$; $p > 0.5$). Given these results, we then used the 10-year average RFI and AE_Δ relationship ($r^2_{adj} = 0.34$; $p < 0.05$) to predict RFI for 1900–2016 (Figure 6). The model underestimated fire activity at the turn of the 20th century, but closely tracked the decrease in RFI during the 1920s. There was an abrupt decrease in regional anthracite employment beginning in the late 1920s (i.e., Great Depression), followed by a brief reprieve (i.e., World War II), and then the final collapse of the anthracite coal industry in the 1950s–1960s. During this nearly forty-year period, fire activity was the mirror image of trends in regional anthracite employment (i.e., industry fluctuations). Predicted RFI, however, exceeds observed RFI during the Great Depression, which also corresponds to the period of peak population density in Schuylkill County (see Figure 4b). In the Post-industrial era, fire activity generally declined to early 20th century levels with the exception of a slight increase in the 1990s.

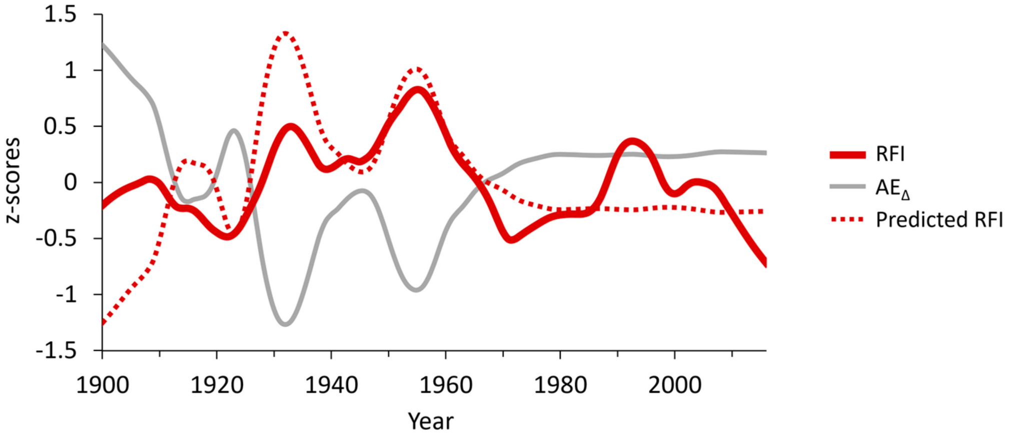

Figure 6. Interdecadal trends in the ridgetop fire index (RFI), regional anthracite employment (AE_Δ) [56], and predicted RFI from the 10-year average of AE_Δ. Each time series is smoothed using locally weighted regression ($s = 0.15$; [70]) for presentation.

3.3. Contemporary Perceptions of Wildfire

We divided closed-ended survey questions into three general categories: (1) "historical," (2) "hazards," and (3) "management" (Figure 7). A large majority (83%) of respondents agreed that wildfires are common occurrences in Schuylkill County. However, only about half (52%) of respondents indicated that most fires occur in the spring, while more than one-third (36%) of respondents disagreed with this factual statement. Over half (52%) of respondents indicated an awareness that fires are beneficial for huckleberry growth and production. Just less than half (45%), however, had no knowledge of the connection between fire and berries (Figure 7). This response dichotomy reflects one segment of the population that has some knowledge of the historical use of fire to maintain early-successional ridgetop plant communities, while the other segment is completely unaware of this history.

The response data is slightly more complex with regard to present-day wildfire hazards and management. Just over half of respondents (54%) consider smoke to have a negative impact on air quality, while a larger number (78%) consider wildfires to be a threat to human life and property (Figure 7). Almost all (89%) respondents identified human actions as the primary cause of wildfire in Schuylkill County, which is supported by the near absence of natural (i.e., lightning) ignitions in the region. In addition, a large portion of respondents (84%) indicate an understanding of the positive impact of prescribed fire on wildlife habitat and its role in reducing the severity of future fires. This data clearly shows that while fire is recognized as a hazard and there is overwhelming support for prescribed fire as a measure to reduce fire risk, there is disagreement amongst respondents as to whether county/state officials should increase activities related to fire management (Figure 7).

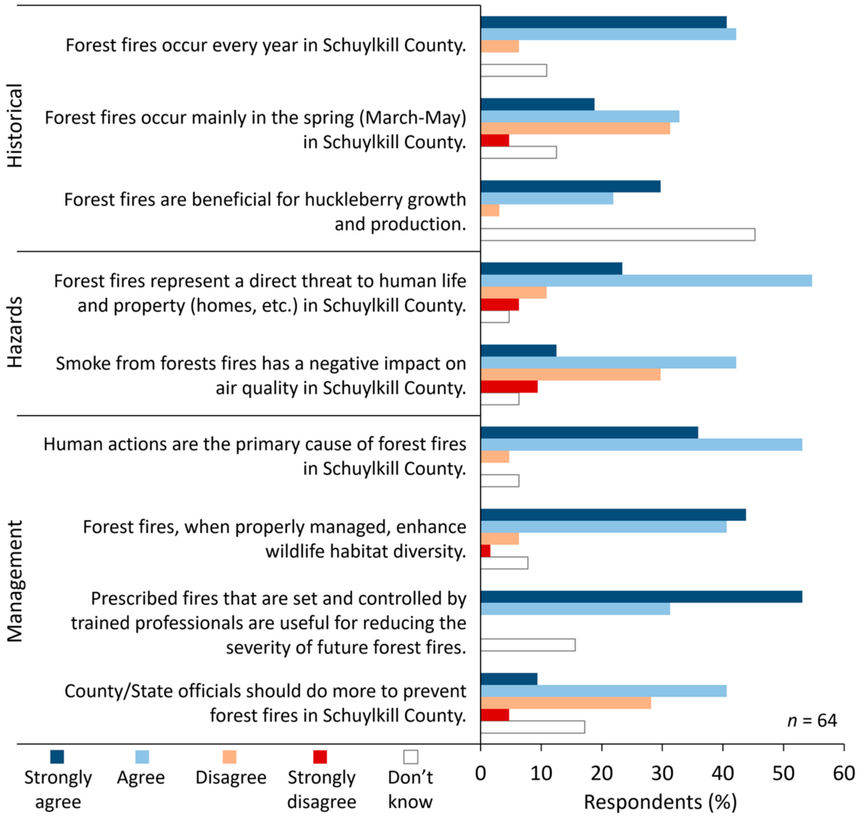

Figure 7. Survey results for closed-ended questions. The phrase "forest fires" was used to differentiate wildfires occurring in a forested landscape from structural fires or backyard brush fires.

Perhaps the most compelling data compiled in the survey was the qualitative information collected from open-ended questions (Table A2). As part of the survey, we provided open-ended questions to all participants that addressed two primary topics. First, we asked participants to describe what they consider to be the most common cause of wildfire ignition. With the exception of three respondents, human-caused or human-related indicators were most common, with "carelessness" or "negligence" being the most common responses (Table A2). Within the context of human carelessness, the issue of burning trash or debris was the most commonly identified element of human carelessness/negligence, followed by the inappropriate disposal of cigarettes. A second, less common theme to emerge from this data was deliberate fire setting or arson.

Our second open-ended question addressed what community members believe should be done about wildfires in Schuylkill County. The most common theme to emerge was a call for education in the local community, specifically education about wildfire risks and consequences (Table A2). A second common theme that emerged was the need for fuel reduction via prescribed fire or "controlled burns." Respondents also discussed a need for increased training and equipment with regard to fire suppression, including funding for local fire companies and updated infrastructure. One respondent specifically mentioned the need for a fire tower on Locust Mountain, where a wildfire burned 114 ha (282 acres) in May 2017 (Figure 8). The respondent, however, did not mention this particular fire event in his or her statement. Finally, the implementation and enforcement of formal behavior controls, including laws or policies, was also mentioned. This theme included elements related to punishment as well as statements related to policies that ban trash burning or provide alternatives to the practice, such as recycling (Table A2).

Figure 8. The "Greenie Fire" on Locust Mountain. This 114 hectare (282 acre) fire burned over the Waste House Run West (WHW) site on 18 May 2017, one day after samples were collected. Photo source: Llewellyn Wildland Crew (copyright unknown).

4. Discussion

In contrast to nearby pre-suppression era fire histories [18,59,60], our study provides a continuous record of fire from the late 19th century to present. Indeed, the unmanaged ridgetop forests in Schuylkill County, Pennsylvania represent an enduring legacy of the "wave of fire" described by Stambaugh et al. [18], which moved southeast-to-northwest across Pennsylvania between approximately 1700 and 1900. Unlike much of Pennsylvania, and the ETFR in general, this period of peak fire activity associated first with European-American settlement and then with industrial activities (i.e., mining and logging) continued well into the 20th century in the Pennsylvania Anthracite Region [36]. This continuous fire activity, however, likely consumed much of the tree-ring record, limiting our landscape-scale fire history to approximately 120 years. Nevertheless, our present study indicates that wildfire was driven primarily by human ignitions that corresponded to downturns in the regional anthracite coal industry. The absence of drought-driven wildfire is similar to other regional fire histories (e.g., [15,18,59–61]) where abundant human ignitions associated with industrial activities may have masked annual-scale fire-climate relationships. In the "Peak-anthracite" era, successfully setting fires to promote huckleberry production at these ridgetop sites would have required specific ecological knowledge and planning, especially during periods of extremely wet or dry conditions. This hypothesis is supported by our contrasting results for fire occurrence (less than expected) and extent (more than expected) during this era, which suggests that humans were relatively efficient fire-setters at this time. Alternatively, or possibly simultaneously, decreasing sample size could have resulted in an underestimation of fire occurrence. As the 20th century progressed and economic stresses increased (i.e., "Depression and Collapse"), this informal resource management strategy may have been compromised by an abundance of unemployed miners, leading to an increase in poorly timed ignitions and incendiary fires.

Fires continued to occur frequently across the ridgetop sites during the "Post-industrial" era, but were considerably less extensive compared to the mid-century fires (see Figure 4c). This reduced extent may be attributed to multiple interacting factors, including reduced ignition sources associated with a declining population in general (see Figure 4b) and, specifically, fewer hunters spending time in these forests [71]. Additional factors may include a late 20th century increase in moisture availability across the region [72] and increased efficiencies in fire suppression strategies [73]. Large fire events like the 2017 Greenie Fire (Figure 8), which occurred during a brief (<1 week) hot, dry period, might be unique at the local scale, but not necessarily across Forest District 18 (see Figure 2). A heat wave induced "flash drought" [74], with four days of unusually high temperatures and strong winds, created fuel moisture conditions necessary for this particular wildfire to threaten the energy infrastructure (i.e., wind turbines) on Locust Mountain. Flash droughts that occurred during times of relatively high moisture availability likely played a role in the historical fire regime, but this association is impossible to assess due to fire scar dates that are limited to season of occurrence and corresponding calendar year. Temporal and spatial patterns of flash droughts and the relationships to wildfire deserve further attention, particularly in fire-prone landscapes (i.e., abundant ignitions and fire-adapted vegetation) in humid climate regions. These unique historical, economic, and environmental conditions that characterize Schuylkill County, and the Pennsylvania Anthracite Region in general, have produced culturally and regionally specific fire perspectives among area residents.

Our understanding of culturally informed fire perspectives is primarily the result of qualitative analysis, which, while not generalizable, allows for an in-depth and socially situated understanding of the local social context. Additional conclusions drawn from our survey were limited by the number of responses. However, we identified two key instances for how contemporary fire prevention measures in Schuylkill County might be improved. First, when participants were asked to make recommendations for how to address the issue of wildfires in the area, each of the themes that emerged would require intervention from county or state officials. Education, prescribed fire (i.e., controlled burns), behavioral restrictions and controls, and increased training and equipment would all inevitably require governmental support. Yet, only half of the participants in this study answered positively when they were asked if officials should do more. There are several possible reasons for this discrepancy, including the possibility that respondents do not fully understand the role of county and state officials in this process, or there is some degree of anti-government bias and/or the belief that officials already do enough. Among politically conservative residents of rural communities, support for limited government may impede explicit support for local and state officials intervening in environmental issues [75]. Therefore, in order to most effectively capitalize on regional/cultural ties to the landscape, fire managers must identify and navigate such contradictions and provide solutions that meet the needs of local communities both ecologically and socially. In the case of Schuylkill County, the development of a fire management approach that incorporates elements of both local ecological knowledge and community forestry approaches [76,77] may effectively address the local opposition to the role of government officials. Focusing on local management of natural resources has emerged as a key technique in global development work, reflecting regional histories and contemporary culture, and has the potential to be effective in Schuylkill County as well.

Secondly, our survey results indicate that human action, specifically "carelessness" when engaging in tasks such as trash burning, plays a significant role in the contemporary fire patterns of this region. The practice of illegal dumping and burning of trash in rural communities is potentially linked to income, with low wage communities being unable to finance the necessary resources to enforce burn bans and provide resources for trash pickup and management [78]. Using this data, place-based fire management strategies for Schuylkill County might include working with local community groups to provide additional enforcement for burn bans as well as investing in increased municipal services to deal with trash, including various options for recycling [79]. While financial costs of such programs may be high for low income communities, a decrease in the financial investment involved in fighting active wildfire and the associated risks to physical health and property might be an effective offset. Furthermore, focusing on signage and educational programs in communities and schools, might be means that are both cost-effective and supported by community members.

The complex relationships that exist between environment, society, and wildfire in Schuylkill County continue to be driven by fluctuations in economic conditions and the residual effects of historical instabilities and shifts in economic and labor markets in the region. Communities made up of descendants of those who lived through the development and transformation of the region have an intrinsic connection to a regionally specific fire culture. Therefore, understanding and interpreting the socioeconomic and environmental history of the region will allow for the development of place-based fire management policies that focus on the specific needs and expectations of community members [7]. Applying place-based fire management techniques can encourage increased policy effectiveness and compliance (i.e., "community buy-in") when local practices and behaviors are considered [80]. Furthermore, providing individuals with fire prevention and management frameworks that align with their cultural values, behavioral practices, and social norms can increase community investment and overall effectiveness in managing wildfire.

5. Conclusions

In this study, we have coupled an approximately 120-year landscape-scale fire history with survey data that provide insights into contemporary perceptions of wildfire in northeastern Pennsylvania. Specifically, our results indicate a 20th century fire regime that was closely linked to fluctuations in the regional anthracite coal industry with increases in ridgetop fire activity associated with periods of severe job losses (see Figure 6). Following the collapse of this industry, fires continued to occur frequently across the landscape, but were generally less extensive compared to the first 60 years of the 20th century. Today, wildfire remains a hazard in Schuylkill County (see Figure 8), with area residents in general agreement about the need for active fuel management (i.e., prescribed fire) and an increase in resources allocated to wildfire prevention education, trash disposal and recycling programs, as well as fire management training and infrastructure. These findings can provide the basis for a 21st century fire use and management paradigm informed by historical patterns, but guided local knowledge and contemporary perceptions of wildfire.

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Appendix A

Table A1. Fire history site characteristics and composite fire interval statistics.

Site variable	ARD	MIL	SME	SMC	SMW	TAR	WHE	WHW	WLF
Area (ha)	~20	~20	~50	~50	~50	~50	4	~20	~40
Elevation (m)	540–555	465–490	590–600	560–585	550–575	500–520	535–555	505–560	470–490
Trees (*n*)	23	29	14	17	14	22	58	27	12
Analysis period [1]	1926–2016	1939–2016	1901–2014	1892–2014	1856–2014	1900–2016	1945–2016	1924–2016	1948–2016
Earliest fire	1931	1945	1929	1898	1861	1907	1992	1934	1956
Latest fire	1988	1964	2011	1982	1999	2004	1998	2015	2008
No. intervals	11	1	14	7	12	10	3	6	11
MFI (years)	5.2	NA	5.9	12.0	11.5	9.7	2.0	13.5	4.7
s.d. (years)	3.7	NA	7.2	12.7	12.9	10.9	1.7	14.9	3.2
Range (years)	2–15	NA	1–28	4–37	2–45	1–38	1–4	3–43	1–13
WMFI (years)	4.7	NA	4.0	9.2	8.1	7.0	1.8	10.2	4.3

[1] Analysis was limited to time periods with a sample depth of at least three trees and fire years with site fire index values ≥0.071. MFI = Mean fire interval; s.d. = standard deviation; WMFI = Weibull median fire interval; NA = insufficient number of intervals to calculate fire interval statistics.

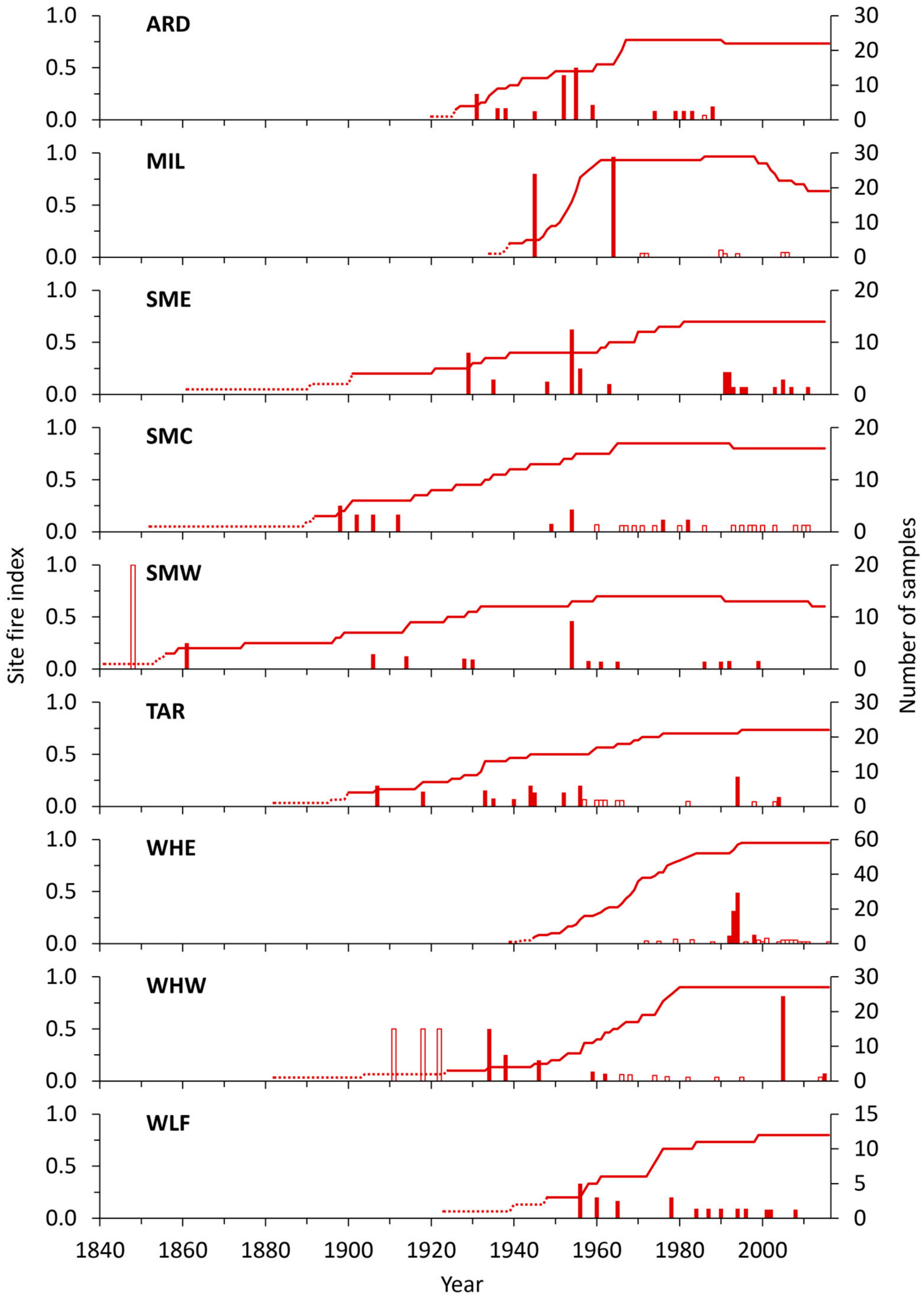

Figure A1. Fire indices (bars) and sample depth (lines) for 9 ridgetop fire history sites in Schuylkill County, Pennsylvania, USA. Solid bars represent site fire index values ≥0.071. These fire years were used in calculations of mean fire interval (see Table A1) and the ridgetop fire index (RFI; see Figure 4c). Solid lines indicate a sample depth of at least three trees.

Appendix B

Table A2. Representative responses to open-ended survey questions organized by qualitative themes and subthemes.

What is the most common cause of forest fires in Schuylkill County, in your opinion?
Theme 1: Carelessness/negligence Subtheme 1: Trash or debris burning *"Unattended burning of garbage"* *"Human carelessness, trash burning in some areas"*
Subtheme 2: Cigarettes *"Most [fires] are started by people throwing light[ed] cigarettes out the car."* *"Smoking and throwing cigarettes out on ground areas that are dry"*
Theme 2: Arson *"Intentionally lit by humans"*
What, if anything, should be done about forest fires in Schuylkill County?
Theme 1: Education *"I believe the forest areas should be posted explaining the legal ramifications of careless behavior regarding fires and the harm that they can cause."*
Theme 2: Fuel management (i.e., prescribed fire) *"As an avid four-wheeler enthusiast, I often comment that there is such a huge amount of brush that needs to be cleared in the northern end of the county. It's a tinder box in many areas."* *"Should be more controlled burns. Really don't see many of those around."*
Theme 3: Equipment and training *"I believe our volunteers should have a bit more training in handling forest fires and brush fires just in case, and there should be a fire tower placed somewhere in the forest atop Locust Mountain."* *"Better training and buy-in from fire departments as to extinguishment methods and 'best practices' would be beneficial."*
Theme 4: Behavioral controls Subtheme 1: Punishment *"Fines should be given and jail* [time] *depending on the damage."*
Subtheme 2: Reduce debris burning (via recycling programs). *"I feel that even though people are aware of the dangers they continue to burn due to often difficult (and expensive) trash removal services and many towns/municipalities not providing safe ways to eliminate trash that cannot be collected (such as tires, electronics, etc.). Providing resources, such as they do for recycling, I feel may cut down on people trying to burn items not meant for such."* *"Ban outside burning of household garbage. More recycling should be done to prevent people from burning their household wastes."*

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