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Brief Report

Dwarf Blackgum (*Nyssa sylvatica*) Contains Datable Fire Scars that Complement an Existing Fire History

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Abstract: Blackgum (*Nyssa sylvatica*) is a "consummate subordinate" hardwood tree species consigned to the mid-canopy of many eastern North American forests. Despite its wide distribution and ecological amplitude, blackgum is an underutilized tree species in fire history reconstructions within its range. In this study, I analyzed cross-section samples collected from 19 fire-scarred blackgum trees at a dry, nutrient-poor ridgetop study area in northeastern Pennsylvania. All but two of these samples were successfully crossdated, each containing between one and six fire scars. Fires recorded by blackgum occurred frequently, with site-level mean fire intervals between approximately three and five years. There was an increase in blackgum growth within two years following fire events, but this increase was not statistically significant and it was dependent on local fire regime characteristics. In addition, the blackgum fire-scar data increased the temporal and spatial resolution of an existing local fire history. These results provide evidence for the potential use of blackgum in fire history reconstructions, but applications may be limited by tree age, complacent growth that prevents crossdating, and the degree of rot resistance after scarring.

Keywords: blackgum; *Nyssa sylvatica*; fire scars; dendrochronology; fire history; fire sensitivity

1. Introduction

Blackgum (*Nyssa sylvatica* Marsh.), known alternatively as black tupelo or sour gum, is a North American hardwood tree species with a geographic range extending from Maine to east Texas and from southern Ontario to central Florida [1,2]. Abrams [3] has referred to blackgum as a "consummate subordinate," given its wide geographic range and the fact that it rarely dominates the overstory. It grows on xeric, upland sites [4] as well as hydric sites, including swamps and floodplains along the Atlantic and Gulf Coasts [5,6]. Blackgum is shade-tolerant and can persist in the understory for decades, while it can also colonize old fields and disturbed sites [7]. Mature individuals with thick bark display high levels of fire resistance and, when top-killed by fire, blackgum is a prolific sprouter [8]. In addition to its extensive range and ecological amplitude, blackgum is one of the longest-lived hardwood species in eastern North America, capable of reaching ages >600 years [9]. Yet, despite these characteristics that make it one of the most ubiquitous tree species in eastern North America (only rivaled by red maple (*Acer rubrum* L.)), blackgum has not been effectively utilized in any published fire history study within its range.

Fire scars embedded in the annual growth rings of trees are commonly used to reconstruct and infer historical fire regime characteristics, including the frequency, spatial extent, severity, and season of fire occurrence [10]. These scars can develop when a portion of cambium is damaged by the heat of a fire and subsequent growth envelopes the wound (Figure 1). Fire scars are assigned to a calendar year when samples are accurately crossdated against a local master growth chronology [11]. In most cases, long-lived tree species that exhibit fire adaptations, such as thick bark and rot-resistance after scarring [12] are targeted for sampling. This means that, even in the species-rich deciduous forests of eastern North America, published fire history reconstructions are typically based on a limited sub-set of tree species, including pine (*Pinus*) species such as Table Mountain pine (*P. pungens* Lamb.), pitch pine (*P. rigida* Mill.), red pine (*P. resinosa* Aiton), shortleaf pine (*P. echinata* Mill.), and longleaf pine (*P. palustris* Mill.) as well as a few oak (*Quercus*) species, including white oak (*Q. alba* L.), post oak (*Q. stellata* Wangenh.), black oak (*Q. veluntina* Lam.), northern red oak (*Q. rubra* L.), and chestnut oak (*Q. montana* Willd.) [10,13,14]. In a rare instance of sampling hardwood species other than oak in a fire history study, Silver and others [15] dated fire-scarred sourwood (*Oxydendrum arboreum* (L.) DC.) trees, but were unable to crossdate blackgum samples due to complacent growth (i.e., low interannual ring-width variability) and short chronologies. Here, the authors concluded that the interpretation of blackgum annual rings may be particularly challenging and, therefore, its potential use in fire history studies limited.

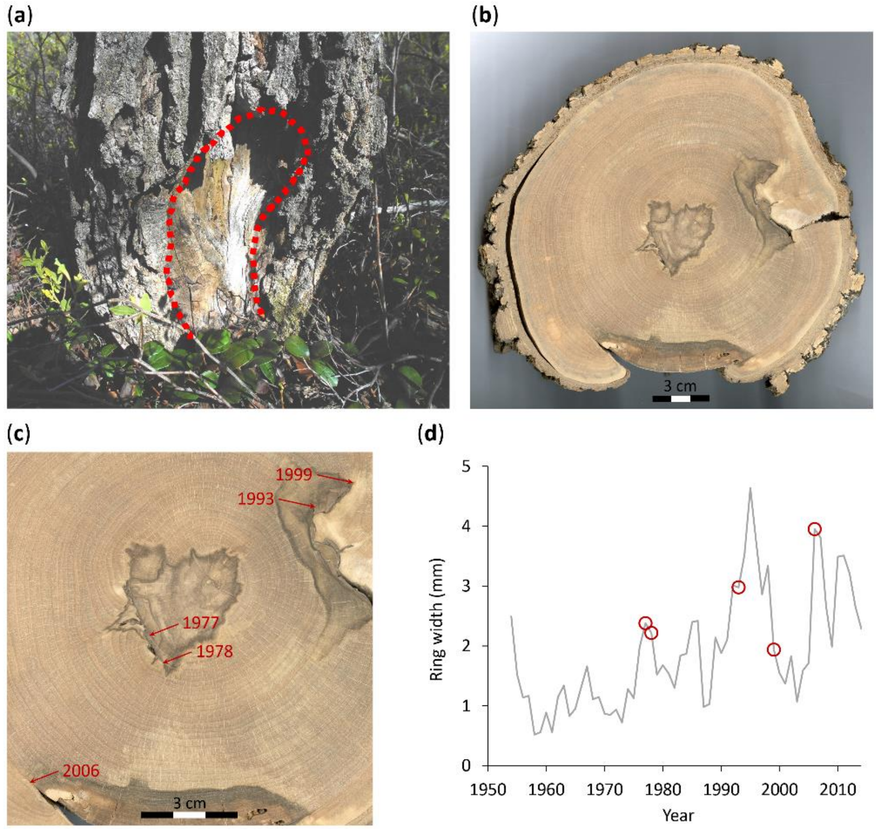

Figure 1. (**a**) Blackgum (SPMT19) with basal scar outlined; (**b**) full cross-section sample (SPMT19); (**c**) close-up of SPMT19 with fire-scar years noted; (**d**) annual ring-width measurements for SPMT19 with fire-scar years indicated by open circles.

This brief report addresses four questions regarding the use of blackgum in fire history studies: (1) Can samples collected from fire-scarred trees at a dry, nutrient-poor ridgetop study area in northeastern Pennsylvania be crossdated? (2) Is blackgum a recorder of frequent, low-intensity fires? (3) If so, how does fire impact the annual growth of blackgum? (4) Do these blackgum fire-scar data enhance the interpretation of an existing local fire history? The answers to these questions will fill a gap in the fire history literature and help inform future fire history reconstructions in eastern North America that incorporate tree species other than pine or oak.

2. Materials and Methods

Fieldwork was conducted in May 2015 on Spring Mountain in Schuylkill County, Pennsylvania (40°53′ N, 76°02′ W). The study area is a “ridgetop acidic barrens complex” (or “ridgetop dwarf tree forest") with stunted trees shaped by high winds and adapted to frequent fire growing on well-drained, nutrient poor soils of the Buchanan, Dakalb, and Hazleton-Clymer series [16]. Two oil pipeline rights-of-way (i.e., potential fire breaks) that pre-date 1950 [17] divide the study area into three sites, which were previously identified as Spring Mountain East (SME), Spring Mountain Central (SMC), and Spring Mountain West (SMW) [18]—there is no record of prescribed fire being used for management purposes on this privately owned land. Blackgum samples were cut with a chainsaw at 0.25–0.5 m above ground level from 19 individuals exhibiting fire-scar evidence, including a basal scar or "cat face" (Figure 1) and the presence of charred bark. Diameter at breast height (dbh) of these trees ranged from 14 cm to 30 cm, with an average of 20.1 cm. The full or partial cross-sections were collected while canvasing the approximately 180 ha study area for fire-scarred pitch pine and sassafras (*Sassafras albidum* (Nutt.) Nees), both of which were analyzed and described in previous publications [18,19].

Blackgum samples were stored in the Environmental Geography Lab at Concord University and not processed until the fall of 2019. At this time, all samples were surfaced first with an electric planar and then with an orbital sander using progressively finer sandpaper up to 1500 grit. This process revealed at least one and, in most cases, multiple fire scars in the blackgum samples (Figure 1). All samples were skeleton plotted and visually crossdated against a local pitch pine chronology and only further analyzed if there was a match between multiple uniquely narrow "pointer" (or "marker") years (e.g., 1964/65/66, 1988, 1999) [20]. A high-resolution (4800 dpi) image of each sample was then captured with a flatbed scanner (EPSON 1200XL). Annual rings were measured to the nearest 0.01 mm using the image analysis software CooRecorder 8.1 [21]. These measurements were taken along only one radii (i.e., series) due to the small size of most samples and in an effort to avoid the most distorted growth rings. Ring widths were statistically crossdated using the program CDendro 8.1 [21] and quality checked using the program COFECHA [22]. Correlations between each individual series and the master growth chronology are presented as well as two common chronology statistics, series intercorrelation and average mean sensitivity (i.e., interannual ring-width variability) [11]. A raw ring-width chronology was generated for the study area as a whole and for SME and SMC—only one blackgum sample collected at SMW was crossdated. Fire scars identified in each blackgum sample were assigned to a calendar year and, if possible, the season of occurrence based on the relative position to annual growth rings. Fire scars occurring between annual rings (i.e., dormant season) were assigned to the year of callus response [19]. Mean fire interval (MFI), or average number years between fire events, is presented for comparison to other regional fire histories.

I used Superposed Epoch Analysis (SEA) in the Fire History Analysis and Exploration System (FHAES) [23] to assess blackgum growth relative to site-specific fire years and non-fire years since 1970, when sample size was consistently greater than five trees at SME and SMC. I tested for significant departures in actual growth (i.e., site raw ring-width chronologies) from simulated growth within an 11-year window lagged five years before, during, and after fire years and non-fire years. In this analysis, 1000 randomly selected sets of 11-year intervals were used to estimate 95% confidence intervals for the growth departures. Site-specific fire years were identified when a minimum of two trees and at least 10% of the recorder (or live) trees of any species (blackgum, pitch pine, or sassafras) were scarred. I included fire years recorded by any of the three species in this analysis for two reasons: (1) The number of site-specific fire years recorded solely by blackgum were limited to seven years at SME and four years at SMC. (2) I hypothesized that blackgum growth would be impacted by a local fire event regardless of which species recorded it. Lastly, I compiled a multi-species fire history for the three Spring Mountain sites using the aforementioned fire-scar filter to identify fire years. I present the number of fire scars and percentage of recorder trees scarred for each year, site, and species. In addition, the locations of trees recording fires during the 1950s (when wildfires were most frequent and extensive in the last 120 years [18,19]) and subsequent decades were mapped to assess change in the fire regime on Spring Mountain.

3. Results and Discussion

3.1. Blackgum Growth and Fire-Scar Data

A total of 17 samples (89%) collected from fire-scarred blackgum trees were crossdated and analyzed (SME = 8, SMC = 8, SMW = 1) (Table 1). The blackgum growth chronology developed from these fire-scarred trees spans 96 years (1919–2014), but only one sample pre-dates 1954. Fire(s) burning across the entire study area in 1954 likely caused high rates of above-ground mortality and abundant resprouting of blackgum [19]. Correlations between each individual blackgum series and the blackgum master growth chronology ranged from 0.18 to 0.64 (interseries correlation = 0.42). Although 0.18 is a relatively low correlation, confidence in the dating of this sample (SPMT59) was confirmed first by crossdating against the local pitch pine chronology and then by comparing annual growth to corresponding pointer years in the blackgum master growth chronology (see Figure A1). Average mean sensitivity for all dated series was 0.25, indicating a year-to-year tree growth variability sufficient for crossdating [11]. This differs from the complacent growth described by Silver and others [15], although the authors did not report a mean sensitivity value. Ring width was 1.84 mm per year on average (SME = 1.97mm; SMC = 1.68 mm), which is more than two times the radial growth rate of blackgum in Virginia [24] and more than three times the rate observed at an old-growth site in Pennsylvania [25]. In these cases, blackgum was growing in the understory for upwards of 170 years before being released into the overstory. The rapid growth rate observed in the Spring Mountain samples is possibly due to the comparatively young age of the trees, but is more likely the result of frequent fire disturbance and maintenance of an open canopy, particularly since the 1970s (Figure 2). Conclusions drawn from these comparisons are limited, however, since only fire-scarred samples were included in this analysis.

Table 1. Blackgum annual growth data and fire-scar years.

Sample ID	Site	Inner-Ring Year	Outer-Ring Year	Ring Width (mm) [1]	Correlation with Master Chronology (*r*)	Fire Year(s) [2]
SPMT14	SMC	1955	2014	2.08 ± 1.10	0.45	2004, 2005
SPMT16	SMC	1919	2013	1.10 ± 0.55	0.32	1986
SPMT19	SMC	**1954**	2014	1.90 ± 0.98	0.52	1977, 1978, 1993, 1999, 2006
SPMT20	SMC	**1957**	2013	1.56 ± 0.86	0.51	1992, 1997
SPMT21	SMC	**1954**	2013	1.46 ± 0.79	0.40	1985, 1992, 2007
SPMT22	SMC	1971	2014	2.32 ± 1.26	0.57	1983, 1985, 1992, 1998, 1999, 2000
SPMT24	SMC	**1955**	2014	1.17 ± 0.50	0.36	2003
SPMT27	SMC	1956	2014	1.84 ± 0.72	0.55	1993
SPMT45	SMW	1958	2014	2.10 ± 0.84	0.64	1986
SPMT57	SME	**1964**	2014	2.05 ± 0.67	0.54	1990, 2003
SPMT58	SME	1970	1997	3.19 ± 1.11	0.38	1986, 1993, 1995
SPMT59	SME	1962	2012	1.67 ± 1.44	0.18	1999, 2004, 2007, 2009, 2012
SPMT60	SME	**1972**	2014	2.96 ± 1.36	0.27	1993, 1999, 2005, 2009
SPMT61	SME	**1969**	2013	1.54 ± 0.77	0.24	1998, 2002, 2008
SPMT62	SME	**1954**	2014	1.53 ± 0.69	0.47	1993, 2000
SPMT63	SME	**1955**	2014	1.31 ± 0.72	0.43	2006, 2008
SPMT64	SME	**1961**	2014	1.53 ± 0.58	0.25	1979, 1997, 2004, 2005, 2006

Notes: [1] Mean ± 1 standard deviation. [2] All fire scars were located between annual growth rings and were assigned to the year of callus tissue response (i.e., spring fires). **Bold** inner-ring year indicates pith.

Forty-eight dormant season fire scars were identified and dated in the blackgum samples (Table 1; Figure 2). The earliest fire scar was recorded in 1977 and the most recent in 2012, with the majority (79%) occurring between 1990 and 2009. In samples with pith (n = 10), the first fire scar was recorded within the first 31 years of growth on average. At the site level, 26 fire scars were dated in SME samples (3.2 scars/sample), 21 fire scars were dated in SMC samples (2.6 scars/sample), and one fire scar was dated in a single SMW sample (Table 1). Mean fire interval (MFI) was 2.7 years at SME (n = 6 intervals) and 4.7 years at SMC (n = 3 intervals) when a minimum of two trees and at least 10% of the recorder trees were scarred. These MFIs are only slightly shorter than those observed in central Pennsylvania where remnant pitch pine was used to reconstruct the pre-suppression era fire history at two ridgetop sites [26] and are at the lower range of MFIs observed at nearby sites in Schuylkill County [18].

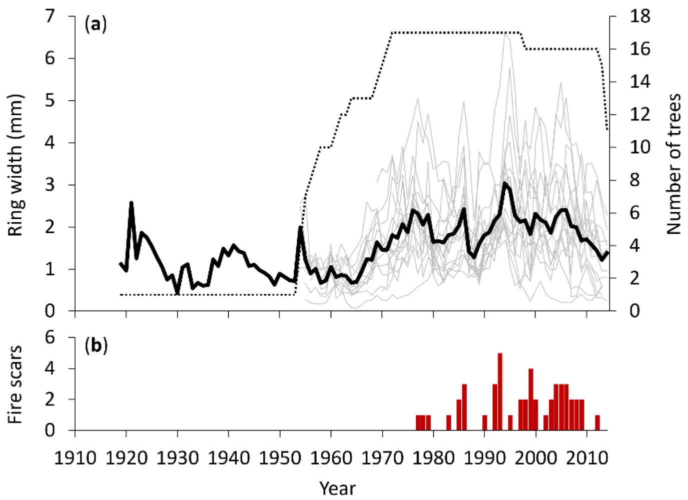

Figure 2. (**a**) Blackgum raw ring-width chronology (thick black line) with ring-width measurements for individual trees (gray lines) and sample size over time (dashed line); (**b**) number of fire scars recorded by blackgum trees per year.

Analysis of blackgum growth relative to fire and non-fire years indicates a marked, but not statistically significant, increase in growth within two years following a fire, particularly at SMC (Figure 3). Blackgum growth was comparatively unchanged at both sites in the five years preceding and following non-fire years. Dinh and others [27] found that increased growth after a fire event occurred during the immature phase of 60% of fire-scarred black oak (*Q. velutina* Lam.) samples collected in a remnant oak savanna. The authors attributed this finding to a greater sensitivity of immature trees to light availability associated with fire disturbance. The blackgum samples analyzed in this study were all relatively young and site-specific differences in growth response to fire are likely related to the local fire regime (i.e., fire frequency and intensity) and resulting forest structure. In 2015, I observed predominately scrub (or bear) oak (*Q. ilicifolia* Wangenh.) interspersed with isolated blackgum and pitch pine at SME, while SMC was characterized by a mosaic of closed and open pine-hardwood forest [19]. Consistent light availability at SME would make tree growth at this site less sensitive to fire disturbance compared to SMC, where less frequent fire occasionally opened the canopy and temporarily increased resources available for tree growth.

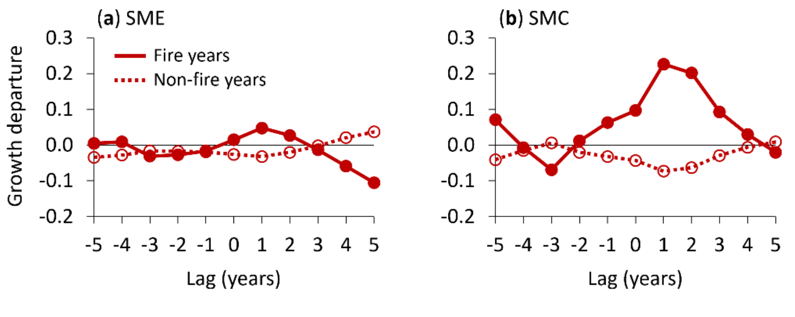

Figure 3. Normalized growth departures in fire-scarred blackgum five years before, during, and after "fire years" and "non-fire years" at (**a**) Spring Mountain East (SME) and (**b**) Spring Mountain Central (SMC). See Table 2 for site-specific fire years (n = 9). Site-specific non-fire years include all other years since 1970 (n = 31). No statistically significant ($p < 0.05$) departures in tree growth were detected.

3.2. Multi-Species Fire History (1954–2014)

Samples collected from fire-scarred blackgum were combined in a multi-species fire history with previously analyzed pitch pine and sassafras samples [18,19] (Table 2). This fire history begins in 1954 because only one blackgum and one sassafras sample pre-date this year, when more than 20% of pitch pine recorded fire at each of the three sites on Spring Mountain. Between 1954 and 2014, there were a total of 18 unique fire years occurring every 3.5 years on average, but with a ~20-year "fire free" period between 1956 and 1976 (Table 2). The persistence of young blackgum and sassafras trees provides evidence for a near complete absence of fire during this time period since these individuals would have been highly vulnerable to top-kill by fire [7]. After 1992, pitch pine recorded fire in only one year (2005), while the two hardwood species recorded 11 fire years combined (Table 2). The 1993 fire recorded by blackgum (SME/SMC) and sassafras (SMC/SMW) is important because it highlights a relatively large fire event that did not scar any pitch pine. The post-1992 fire years, therefore, suggest a shift to low-intensity fires that scarred 40 to 60-year old blackgum and sassafras, but were not hot enough to injure more fire resistant pitch pine. This differential scarring potential is the primary benefit of a multi-species fire history, in which the three species described here are situated along a continuum of fire resistance, with mature pitch pine being the most fire resistant, followed by blackgum and then sassafras [7,28]. In other words, a fire history inferred from only pitch pine would suggest that fire was infrequent and of minor importance on Spring Mountain after 1992.

Table 2. Spring Mountain fire years (1954–2014) with site- and species-specific fire-scar data. Pitch pine and sassafras samples were analyzed and described in previous publications [18,19].

Fire year [1]	Site	Species	Fire Scars	Trees Scarred (%)
1954	SME	Pitch pine	5	62.5
	SMC	Pitch pine	3	21.4
	SMW	Pitch pine	6	46.2
1956	SME	Pitch pine	2	25.0
1976	SMC	Pitch pine	2	11.8
1982	SMC	Pitch pine	2	11.8
1985	SMC	Blackgum	2	25.0
1991	SME	Pitch pine	3	21.4
1992	SME	Pitch pine	3	21.4
	SMC	Blackgum	3	37.5
1993	SME	Blackgum	3	37.5
	SMC	Blackgum	2	25.0
	SMC	Sassafras	5	71.4
	SMW	Sassafras	2	100.0
1996	SMC	Sassafras	2	28.6
1999	SME	Blackgum	2	28.6
	SMC	Blackgum	2	25.0
2000	SMC	Sassafras	2	28.6
2004	SME	Blackgum	2	28.6
2005	SME	Blackgum	2	28.6
	SME	Pitch pine	2	14.3
	SMC	Sassafras	2	28.6
2006	SME	Blackgum	2	28.6
2008	SME	Blackgum	2	28.6
2009	SME	Blackgum	2	28.6
2012	SMC	Sassafras	3	42.9
2014	SMC	Sassafras	5	71.4

Notes: [1] Minimum 2 trees and 10% scarred.

After the 1950s, not only were blackgum and sassafras the primary recorders of fire on Spring Mountain, but its occurrence was concentrated in three locations (Figure 4). The decreased spatial extent of fire, with the exception of the 1993 fire(s), is indicative of repeated fire caused by the same people in the same location [18], a decrease in response times by local fire departments [29], a wetter climate [19], or a combination of all three factors. These spatial patterns should be interpreted with caution, however, since the fire-scar data were filtered and the sampling strategy only included trees with visible fire-scar evidence.

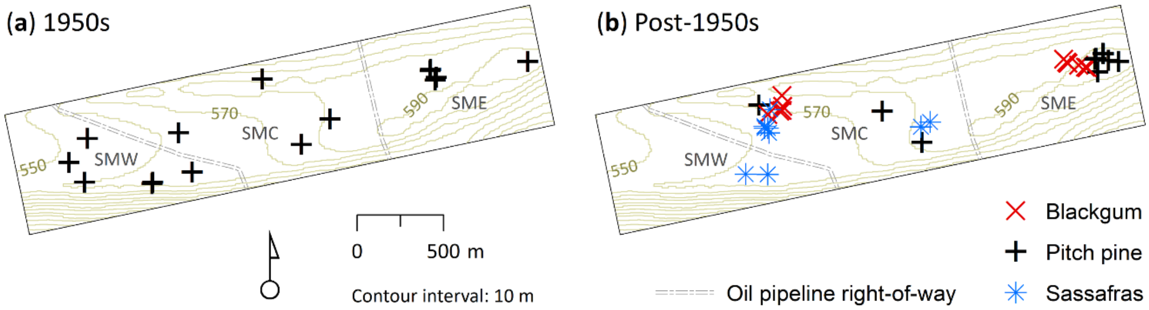

Figure 4. Spatial distribution of trees recording fire during the (**a**) 1950s and (**b**) post-1950s (see Table 2 for specific fire years). Oil pipeline rights-of-way divide the study area into three sites: Spring Mountain East (SME), Spring Mountain Central (SMC), and Spring Mountain West (SMW).

4. Conclusions

This brief report provides new insights into the use of blackgum in fire history studies. In revisiting my initial questions, I can conclude the following: (1) Samples collected from fire-scarred blackgum trees on Spring Mountain can be accurately crossdated, with the exception of two samples in this study. (2) These trees are recorders of frequent, low-intensity fires (MFI < 5 years). (3) Blackgum growth increased within two years following a fire event, but this increase is not statistically significant and is dependent on the local fire regime and forest structure. 4) Fire-scar data derived from blackgum samples added temporal and spatial resolution to an existing fire history and documented a change in the fire regime on Spring Mountain. Application of these findings to other regional fire histories is possible, but may be limited by the age of blackgum trees (~60 years in this study), complacent growth that prevents crossdating, and the degree of rot resistance after scarring in individual trees.

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Conflicts of Interest: The author declares no conflicts of interest.

Appendix A

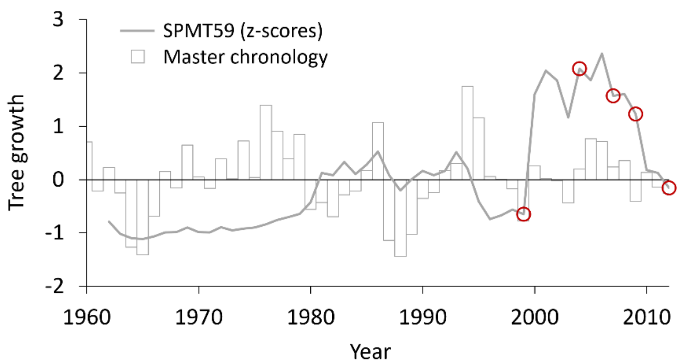

Figure A1. Comparison between annual ring-width measurements (z-scores) for SPMT59 and the blackgum master growth chronology. Fire-scar years are indicated by open circles.

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