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A tree-ring record of historical fire activity in a piedmont longleaf pine (*Pinus palustris* Mill.) woodland in North Carolina, USA

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Abstract

Background: Longleaf pine (*Pinus palustris* Mill.) ecosystems were historically widespread in the North American Coastal Plain and in some southeastern piedmont and montane settings. The naval stores industry, deforestation, and other human activities resulted in an extensive loss (c. 97% loss) of the original woodlands and savannas. Longleaf pine ecosystems are maintained by frequent surface fire which promotes successful regeneration and maintains open canopy conditions and a largely herbaceous understory. Fire regimes (including the frequency and seasonality of fire) likely varied across the entire range of longleaf pine and through time; further research is needed to elucidate this variability.

Results: We used fire scars in stumps and snags to reconstruct fire history in a piedmont longleaf pine ecosystem in North Carolina. For each tree sampled, we examined multiple cross sections to avoid omission of fire events recorded by smaller fire scars. Our samples revealed evidence of frequent fire (c. 3–4-year fire interval) beginning in the early eighteenth century and extending to the mid-nineteenth century. Fires occurred in the dormant and early earlywood positions of annual rings and were likely human ignited.

Conclusions: To our knowledge, this is the first tree-ring-based fire history in longleaf pine of the piedmont. As such, it offers a rare glimpse into historical fire activity in a now scarce but important ecological setting. More research is needed to develop additional fire chronologies in the piedmont region, including for longer periods of time and for larger spatial areas.

Keywords: Longleaf pine, Dendrochronology, Fire scars, Piedmont, North Carolina, Wildland fire

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Resumen

Antecedentes: Los ecosistemas del pino de hoja larga (*Pinus palustris* Mill.) estuvieron históricamente distribuidos en la Planicie de la Costa Norteamericana, en algunos entornos montañosas y al pie de las montañas en el sudeste. La deforestación, la industria de los suministros navales y otras actividades humanas resultaron en una pérdida extensiva (c. 97% de pérdida) de los bosques y sabanas originales. Los ecosistemas del pino de hoja larga están mantenidos por fuegos superficiales frecuentes, los cuales promueven una regeneración exitosa y mantienen condiciones de apertura del dosel y una gran cantidad de vegetación herbácea en sotobosque. Los regímenes de fuego (incluyendo la frecuencia y la estacionalidad del fuego) probablemente variaron en todo el rango de distribución del pino de hoja larga y a través del tiempo; se necesitan más investigaciones para dilucidar esta variabilidad.

Resultados: Utilizamos cicatrices de fuego de tocones y árboles muertos en pie para reconstruir la historia del fuego en un ecosistema pedemontano del pino de hoja larga en Carolina del Norte. Para cada árbol muestreado, examinamos múltiples secciones transversales para evitar omisiones en eventos de fuego registrados por las cicatrices más pequeñas. Nuestras muestras indicaron evidencias de fuegos frecuentes (c. 3-4 años de intervalo entre fuegos) desde los comienzos de los 1800, extendiéndose hasta mediados de 1900. Los fuegos ocurrieron en la dormición y en áreas del leño temprano de los anillos de crecimiento anuales y su origen fue probablemente antrópico.

Conclusiones: Para nuestro conocimiento, esta es la primera historia del fuego del pino pedemontano de hoja larga basado en los anillos de crecimiento de los árboles. Como tal, ofrece una mirada rara en la actividad histórica del fuego, actualmente escasa pero en un marco ecológicamente importante. Se necesitan más investigaciones para desarrollar cronologías adicionales de fuego en la región pedemontana, incluyendo períodos de tiempo más largos y mayores superficies.

Introduction

Longleaf pine (*Pinus palustris* Mill.) ecosystems are characterized by a frequent, low-severity fire regime (Chapman 1932; Wahlenberg 1946; Frost 2007; Stambaugh et al. 2017; Noss 2018). Stands of longleaf pine maintained with regular prescribed burning provide critical habitat for a suite of wildlife and game species and support a largely herbaceous understory with high species richness (Platt 1999; Van Lear et al. 2005). Although most of the distribution of longleaf pine lies within the North American Coastal Plain (Peet 2006), the species also occurs in certain piedmont and montane environments (Peet and Allard 1993; Jose et al. 2007) that are > 200 km inland from the Gulf of Mexico and Atlantic Ocean coastlines (Fig. 1). Anthropogenic activities including the naval stores industry, logging, and land-use development have reduced the extent of mature longleaf pine markedly. Currently, approximately 3–5% of the original distribution remains (Ware et al. 1993), and longleaf pine and longleaf pine-oak forest types represent < 3% of forested land in the southeastern US from eastern Texas to Virginia (Oswalt and Guldin 2021). Furthermore, piedmont and montane longleaf pine ecosystems are now virtually absent (especially compared to the coastal plains ecosystems), with only a few examples remaining (Varner and Kush 2004; Patterson and Knapp 2016; Spooner et al. 2021). The historical role of fire in longleaf pine ecosystems has been extensively examined and discussed, but more research is needed to understand how historical fire regimes varied through time and across the range of longleaf pine, including in understudied piedmont and montane settings.

Dendrochronology (tree-ring science) can provide important insights regarding past environmental conditions in longleaf pine ecosystems. Prior studies examined climate-growth relationships (e.g., Bhuta et al. 2009; Mitchell et al. 2019; Patterson et al. 2016; Soulé et al. 2021), habitat suitability for wildlife (e.g., Kaiser et al. 2020), and stand-age structure and tree regeneration dynamics (Brockway and Outcalt 1998; Varner et al. 2003; Pederson et al. 2008), among other topics. More recently, researchers have used tree-ring science to reconstruct historical fire regimes in longleaf pine ecosystems. There are a few refereed articles based on this work (Stambaugh et al. 2011; White and Harley 2016; Klaus 2019; Rother et al. 2020), along with some reports and dissertations (Henderson 2006; Huffman 2006; Bale 2009; Huffman and Platt 2014). The majority of tree-ring-based fire histories are derived from coastal plain stands; thus, fire management plans adopted from these studies are most applicable to this region. Conversely, the lack of piedmont and montane fire histories (*but see* Bale 2009; Klaus 2019) has provided limited evidence to base current fire management plans and underscores the need for research at the interior range limit of longleaf pine.

Tree-ring-based fire-history studies typically rely on fire scars in tree rings to reconstruct fire activity (Arno and Sneck 1977; Falk et al. 2011). These scars form due to localized cambial mortality from the heat of surface fires. The scars occur within annual rings, providing annual resolution for past fire occurrence. Additionally, the season of fire (i.e., dormant, spring, summer, etc.) can be estimated based on the intra-annual position of the fire scar within a tree ring. Researchers can also use fire scars to make estimations regarding fire severity and fire extent, although these estimations are coarse due to limitations of the data. Temporal trends in fire activity can be examined to see whether fire regime characteristics varied through time at a given site (Falk et al. 2011). In the case of longleaf pine, a modified approach that targets internal scars that are not visible in the field in addition to external scarring can provide a more complete record of fire activity (Huffman and Rother 2017).

Fire-scar records are not the only source of information regarding historical fire regimes. Sediment and soil charcoal records and historical written accounts also can provide evidence of past fire activity. Additionally, researchers use field experiments, insights from the evolutionary history of species, and environmental characteristics of a landscape such as topography and climate to make inferences regarding historical fire regimes. These types of studies suggest that a frequent, low-severity fire regime is characteristic of longleaf pine ecosystems. Historical fire frequency was greatest in the coastal plain (c. 1–3 years) and slightly lower in piedmont and montane ecosystems (c. 4–6 years), although each of these regions includes high spatial variability in fire regime based on soils, topoclimatic factors, and other characteristics (Frost 1998; Guyette et al. 2012; Spooner et al. 2021). Lower fire frequency in piedmont and montane ecosystems is related to a more dissected landscape that limits fire spread, less frequent lightning activity, and a relatively cooler and wetter climate (Spooner et al. 2021).

Here, we document historical evidence of fire activity at the Margaret J. Nichols Longleaf Pine Preserve (hereafter, “Nichols Preserve”) in the piedmont of North Carolina (hereafter, “the Piedmont”). Although this natural area is small (i.e., < 50 ha) for fire-data collection, it provided a rare opportunity to examine the history of fire in a piedmont site with remnant old-growth (> 200 years) longleaf pine. To our knowledge, the Nichols Preserve is the largest, publicly accessible tract of old-growth longleaf pine in the Piedmont and is one of only a few locations with old-growth longleaf throughout the piedmont ecoregion of North America. Given widespread efforts to restore and maintain longleaf pine ecosystems, insights from fire-scar studies provide an important context that can support and inform activities such as prescribed-fire programs and tree plantings.

Methods

Study area

Our study area is in Montgomery County, North Carolina, along the interior distributional edge of longleaf pine. Early literature on longleaf pine at its interior range limit in North Carolina states, “The best and most extensive body of long-leafed pine, within my knowledge, is in Montgomery County, too far yet from transportation to be of much commercial value (Hale 1883).” Later, Ashe (1894) wrote, “Montgomery County, lying west of Moore, has in the eastern part, on a loam soil, a heavy growth of long-leaf pine which has never been lumbered.” Furthermore, in reference to the eventual arrival of the naval stores industry to the region, Ashe wrote, “Montgomery County is credited with no resinous products in the census of 1880, but in 1893 there were 12 distilleries operating there which produced 22,000 barrels of rosin.” Just 3 years following, Pinchot and Ashe (1897) noted: “The most active lumber operations in the interior are at Aberdeen, Troy Junction, and Carthage”—towns within and adjacent to Montgomery County. By 1930, Jurney and Davis wrote the following about longleaf in Montgomery County: “The county was formerly covered with longleaf pine and between 1890 and 1898 the turpentine industry was important. As soon as the turpentine was exhausted, the pine timber was cut for lumber (Jurney and Davis 1930).” These historical writings indicate several important lines of evidence for our study. First, Montgomery County contained old-growth stands of longleaf pine as late as the 1890s, and second, it was one of the last locations in North Carolina to experience the effects of the naval stores and destructive logging industries. Some small patches of old-growth longleaf remain in the area today.

The Nichols Preserve lies along the eastern edge of the piedmont, a physiographic region of rolling topography that forms the foothills of the Appalachian Mountains. The piedmont is characterized by soils with a higher clay content than the sandy soils of the coastal plain. Piedmont soils formed from the weathering of ancient igneous and metamorphic rocks (Peet and Allard 1993). The Nichols Preserve is a 47-ha mature longleaf pine and mixed-hardwood site located in northern Montgomery County in central North Carolina (35.46, -79.87; Fig. 1). The Nichols Preserve supports mature and old-growth (> 200 years) longleaf pine (Patterson et al. 2016; Mitchell et al. 2019) along with oaks (*Quercus* spp.) and other pines (*Pinus* spp.) common to this dry piedmont longleaf pine forest type including white oak (*Q. alba* L.) and shortleaf pine (*P. echinata* Mill.) (Schafale and Weakley 2012). The mean annual temperature is 15.5° C and the mean annual rainfall is 110 cm (PRISM Climate Group). Georgeville and Herndon Silt loams at 2–15% slopes dominate the site (USGS Soil Survey). Native Americans were present in the piedmont region of the eastern US for many millennia. Archeological sites in the Piedmont near the Nichols Preserve (e.g., the Hardaway Site and the Town Creek Site) indicate relatively large Native American populations in the region prior to the arrival of

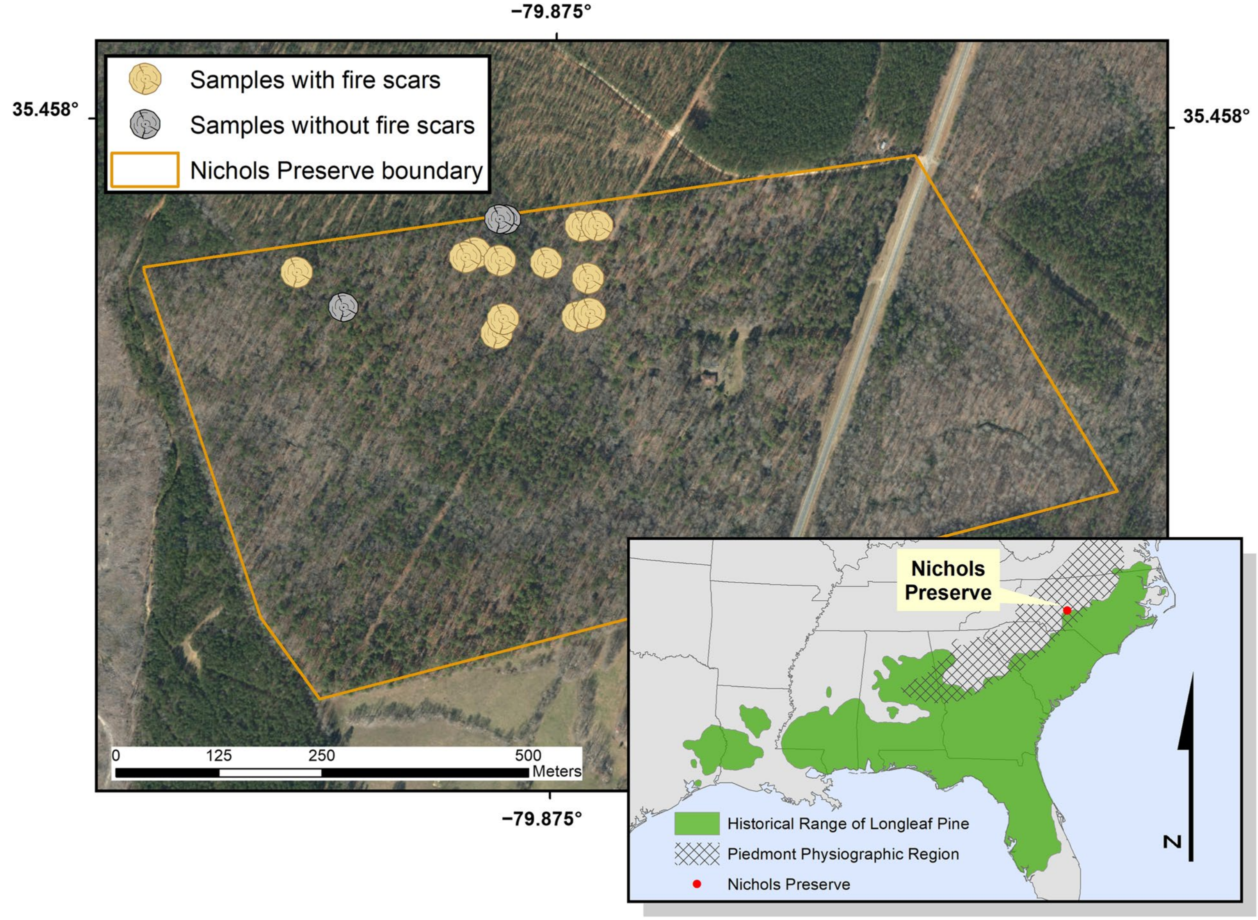

Fig. 1 Study area at the Nichols Preserve in the piedmont of North Carolina. The inset map shows the historical distribution of longleaf pine and the location of the Nichols Preserve along the interior edge of the distribution. The Piedmont Physiographic Region is also shown. We sampled 14 dead trees (stumps and snags) of which 11 included fire scars that provided evidence of past fire activity at the site. Data were collected in 2019–2021

European settlers (Coe 1964; Daniel Jr and Butler 1996; Boudreaux 2007; Spooner et al. 2021). No specific records for Native American use of the Nichols Preserve are available, although former landowner, Margaret Nichols, was known to have found Native American stone tools on the property (Ramona Bates, North Carolina Plant Conservation Program, Personal Communication).

The earliest census records for the Nichols Preserve provide evidence of habitation by European settlers (the Nichols family) beginning c. 1790. The Nichols were largely agrarian, and nothing is known about their use of fire to open areas for farming or for other purposes. The only evidence of twentieth-century fire activity was through communication with the North Carolina Forest Service that described a small (approximately 1 ha) fire in the 1930s (Scott Maynard, North Carolina Forest Service, Personal Communication). The North Carolina Zoo purchased the tract of land from the Nichols family in 2012, and since this acquisition, three dormant-season prescribed fires have been conducted on a biennial rotation.

Data collection, processing, and analysis

We collected fire-scarred material from longleaf pine snags (i.e., standing dead trees) and stumps (i.e., approximately 1-m flat-topped trees from crosscut felling) to characterize the fire history of the Nichols Preserve. Many of the snags and stumps we examined were either highly decayed or partially consumed by a recent prescribed fire, leaving a limited amount of material suitable for our research. We concentrated our sampling within the northwestern portion of the Nichols Preserve, where most of the intact material was located. Elevation in this area of the Nichols Preserve is approximately 190 m. Based on previous work in longleaf pine (Huffman 2006; Stambaugh et al. 2011; White and Harley 2016; Huffman and Rother 2017), we expected to find buried scars (i.e., internal scarring) in addition to external scars. We preferentially sampled material that appeared old but sufficiently intact to contain at least 50 rings, thus increasing the likelihood of crossdating success. To target these buried scars, we collected a large amount of wood from each stump or snag. We excavated around the bases of each dead tree and collected a portion of the tree bole starting from near or just below the ground surface (approximately 10 cm into mineral soil) and extending upward approximately 0.5 m (*see* Huffman and Rother 2017).

In the laboratory, we prepared the samples for tree-ring analysis. We first sectioned each sample into several approximately 5-cm-thick cross sections using a bandsaw. We examined multiple sections from each tree to increase the likelihood of detecting small fire scars found only on portions of the tree and to aid with potential crossdating challenges related to abnormal ring patterns near the root-shoot boundary (Fig. 2). Cross sections that showed scarring or possible scarring were then selected for further analysis. These sections were sanded using progressively finer sandpaper to improve the visibility of the tree rings (Stokes and Smiley 1968; Speer 2010). Sanded sections were scanned at high resolution (1200 dpi) on a flatbed scanner. We then used the software program CooRecorder (Larsson 2016) to mark and measure the tree rings.

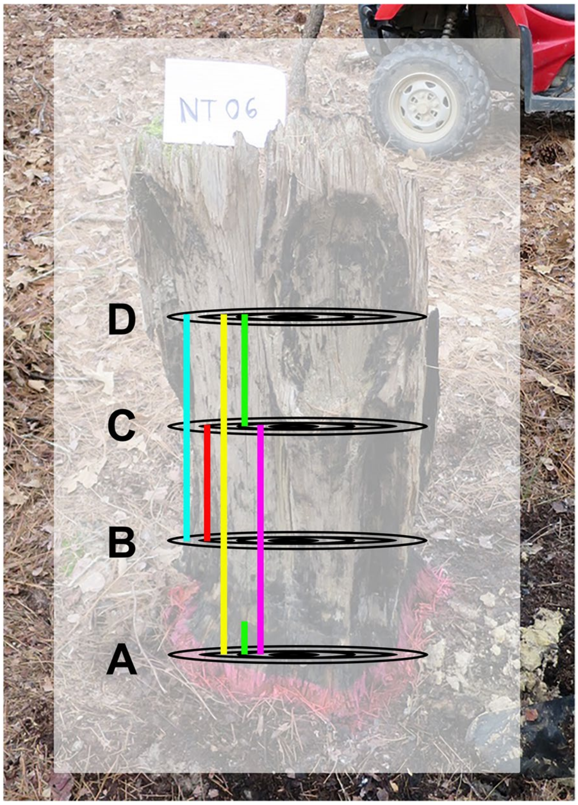

Fig. 2 Schematic diagram of fire scars (vertical lines) distributed in four cross sections (**A**–**D**). Note how fire scars can appear across all sections (yellow line) or in only some sections (all other lines)

We relied on the standard dendrochronological method of crossdating (Stokes and Smiley 1968; Speer 2010) to ensure that the tree rings were assigned to the correct year of formation. We conducted visual and statistical crossdating; visual crossdating was completed in CooRecorder while statistical crossdating was conducted in the software program Cofecha (Holmes 1983). Each sample was dated against a reference chronology of longleaf pine latewood width developed at the Nichols Preserve (Mitchell et al. 2019). Previous research in longleaf pine of North and South Carolina found that climate-growth relationships were stronger when examining latewood width rather than earlywood or total ring width (Soulé et al. 2021; Stambaugh et al. 2021), and this finding was supported by the relative ease of crossdating latewood for our samples.

After crossdating the tree rings, fire scars were dated based on their position within an annual ring. Whenever possible, we also assigned a season of fire-scar formation using a classification system developed in southeastern pine savannas (Rother et al. 2018). This system works well for tree species with higher ratios of latewood, including longleaf pine, and includes the following six positions: dormant (D), for the position between the previous year's latewood and current year's earlywood; (2) early earlywood (EE), for the first half of earlywood; (3) late earlywood (LE), for the second half of earlywood; (4) transition (T), for the area where trees change from producing earlywood to latewood; (5) early latewood (EL), for the first half of latewood; and (6) late latewood (LL), for the second half of latewood. In that same study, cambial phenology data were collected to estimate the time of year that corresponded with each position. Those data were collected in the southernmost portion of the North American Coastal Plain (in southwestern Georgia and northern and central Florida), and thus, it is unclear if those estimates are also applicable for our study area.

For most trees, multiple sections were crossdated (Fig. 2). In these cases, we recorded fire scars on each section and aggregated those data to determine fire history at the tree level. In some instances (<10%), the seasonality assignment differed among cross sections from the same tree. Those scars were revisited, and the clearest scar was used for a seasonality assignment. Once data were aggregated to the tree level, we used the Fire History Analysis and Exploration System (FHAES) to enter our data and produce an FHX2 file (Brewer et al. 2016). The R package *burnr* (Malevich et al. 2018) was then used to calculate the mean and median fire interval for the period of time when fire scars were found at the site (1714–1842) and to create a fire-history chart. We assumed the data provided by our samples were insufficient to make strong conclusions regarding fire activity or inactivity before or after this window.

Results

We crossdated 37 cross sections collected from 14 trees at the Nichols Preserve (Table 1, Fig. 2). Most of the material originated from stumps ($n = 12$) rather than snags ($n = 2$). Due to decay and recent prescribed burning, only a few of the trees sampled ($n = 4$) included the pith. None of the samples still included bark and many outermost rings are likely missing from each sample. Innermost rings ranged from c. 1568 (estimated pith date for NT13, innermost rings not crossdated on this sample due to suppressed growth) to 1786, while outer dates ranged 1839 to 1917. For most trees, we dated more than 1 cross section (range: 1–7 cross sections, mean: 3 cross sections). For trees with two or more cross sections, we found many fire events ($n = 15$, 45%, Table 1) at the tree level that were only recorded by one cross section.

Our fire-history record (Fig. 3) indicated that low-severity fires occurred frequently at our study site, at least during the period in which fire scars were detected (1714–1842). The fire scars on our samples provided evidence of 33 unique fires that occurred at the Nichols Preserve. Three trees (NT 03, NT 12, and NT 14) were particularly strong recorders and provided evidence for the majority (76%) of all fires. A third of all fires ($n = 11$) scarred more than one tree. The mean fire interval for the analysis period (1714–1842) was 4 years while the median fire interval was 3 years for that same period. Some 1-year fire intervals did occur ($n = 4$) and the longest fire interval for the analysis period was 15 years. We expect that our fire-history record is missing fire events during the analysis period due to the limited sample size and the inclusion of some non-recording trees ($n = 3$ trees).

We were able to assign a seasonality classification to most of the fire scars we dated (91%). Although we used a classification system with six possible categories, the fire scars for which we could assign a season fell into only two categories: dormant ($n = 38$, 88%) or early earlywood ($n = 5$, 12%) (Fig. 4), using the system described by Rother et al. (2018). We did not observe any notable changes in seasonality through time.

Discussion

To our knowledge, our study is the first refereed tree-ring-based fire history using longleaf pine in the piedmont region of the eastern US and is one of only a few published tree-ring-based fire-history studies of longleaf pine throughout its distribution (Stambaugh et al. 2011; White and Harley 2016; Klaus 2019; Rother et al. 2020). We used novel methods of sampling (Huffman 2006; Huffman and Rother 2017) to target both internal and external fire scars and discovered ample evidence of historical fire activity in the eighteenth and nineteenth centuries. Given that most old-growth longleaf pine in the Piedmont was cleared by the early twentieth century

Table 1 Summary information about each sample included in the study

Sample ID	Sample type	Inner year	Outer year	Cross sections dated (*n*)	Fire years (number of cross sections recording that fire year)	Fire years (*n*)
NT01	Stump	1645 (pith)	1856	3	1715 (2)	1
NT02	Stump	1678	1890	2	1800 (2), 1805 (2), 1811 (2)	3
NT03	Stump	1626 (pith)	1917	7	1743 (1), 1774 (3), 1779 (2), 1786 (1), 1792 (1), 1826 (3), 1828 (3), 1832 (3), 1834 (3), 1837 (3), 1842 (2)	11
NT04	Stump	1677 (pith)	1839	5	1714 (4), 1746 (1), 1800 (1)	3
NT05	Stump	1709	1881	2	1758 (2)	1
NT07	Snag	1736	1882	2	1743 (1), 1801 (1)	2
NT08	Snag	1755	1842	1	-	0
NT09	Stump	1753	1857	1	-	0
NT10	Stump	1763	1861	1	-	0
NT12	Stump	1676	1885	4	1725 (1), 1731 (4), 1735 (3), 1737 (4), 1739 (2), 1741 (4), 1743 (4), 1746 (4), 1749 (2), 1758 (4), 1763 (4), 1773 (1), 1779 (1), 1792 (1)	14
NT13	Stump	c. 1568 (pith)	1882	2	1725 (1)	1
NT14	Stump	1723	1848	5	1743 (3), 1749 (4), 1751 (4), 1752 (2), 1758 (1), 1763 (3), 1765 (1), 1774 (1)	8
NT15	Stump	1786	1878	1	1788 (1)	1
NT16	Stump	1718	1885	1	1783 (1), 1786 (1)	2

Data were collected in 2019–2021 at the Nichols Preserve in the piedmont of North Carolina, USA

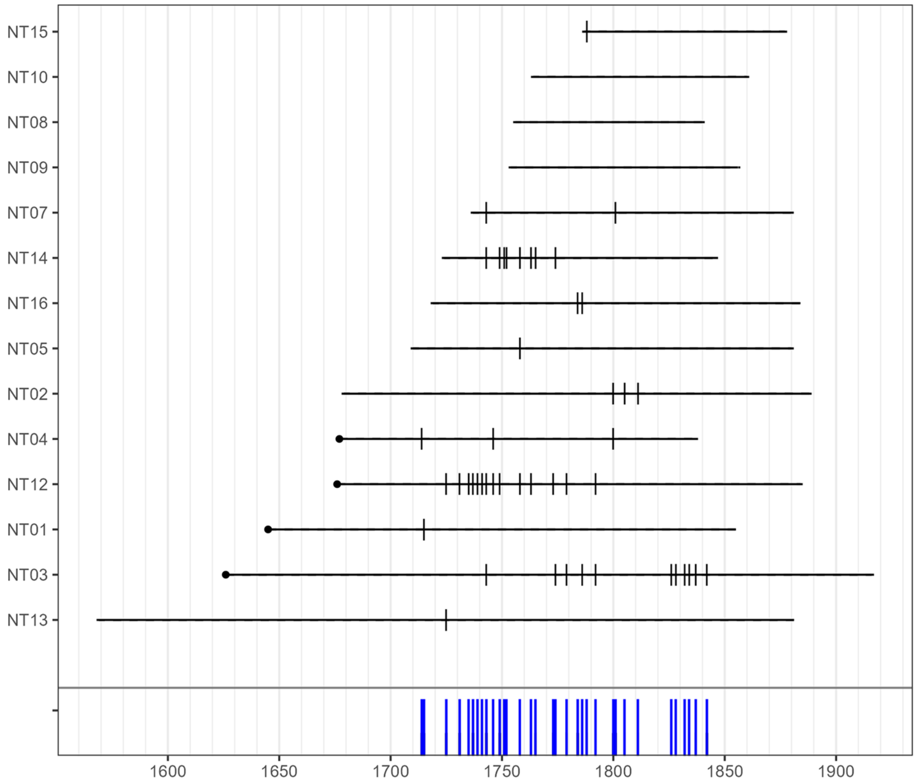

Fig. 3 Fire-history chart for the Nichols Preserve in the piedmont of North Carolina. Horizontal lines show the time series of an individual tree. Vertical tick marks on the horizontal lines represent fire scars. The composite fire-scar series at the bottom of the figure displays all fire events through time. This figure was generated in the R package *burnr* (Malevich et al. 2018). Data were collected in 2019–2021

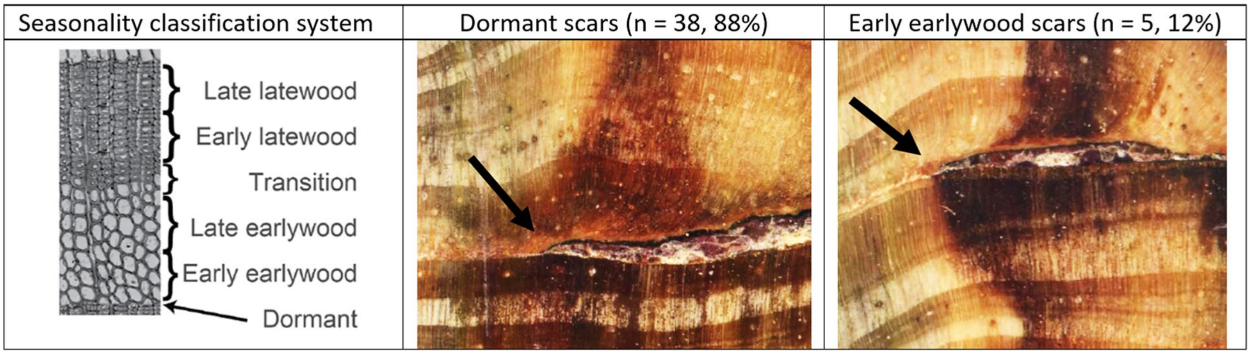

Fig. 4 Fire-scar seasonality of sampled trees at the Nichols Preserve in the piedmont of North Carolina. Intra-annual fire scar positions were assigned based on the system described in Rother et al. (2018), depicted at the far left (microtome image provided by G. Harley). Imagery of fire-scarred longleaf pine shows the positioning of dormant (center) vs. early earlywood (far right) fire scars. All fire scars at the Nichols Preserve were classified as either dormant or early earlywood. Data were collected in 2019–2021

(Spooner et al. 2021), our small but informative study provides a rare glimpse into historical fire activity in an important but now scarce ecological setting.

Our findings of frequent low-severity fire (on average, every c. 3–4 years) in a piedmont longleaf site are consistent with studies that used other lines of evidence (e.g., climate, topography, etc.) to estimate historical fire frequency (Frost 1998; Guyette et al. 2012). The fire scars we dated were assigned exclusively to the dormant and early earlywood positions. The complete absence of fire scars in other positions strongly suggests that either all or most of these fires were human ignited. Although local or regional cambial phenology data are needed to confidently associate a given fire-scar position with a certain time of year, existing data from Florida indicates that dormant and early earlywood scars correspond with winter and early spring fires (Rother et al. 2018) which is before the natural lightning fire season begins in late spring (Fill et al. 2012; Platt et al. 2015; Noss 2018; Spooner et al. 2021).

Tree-ring reconstructions of past fire activity are rare in longleaf pine ecosystems for several reasons including the limited amount of suitable remnant material (i.e., logs, snags, stumps) available to sample following logging and land-use development (Huffman and Rother 2017). Additionally, a long-standing, unsupported belief assumed that fire traits (sensu, Keeley et al. 2011) of longleaf pine (e.g., thick bark, high resin production to seal wounds) coupled with low-intensity historical fire regimes associated with this species limited the recording of fires through cambial scarring. In recent years, researchers have observed that fire scars do frequently occur in this species and have established special methods for targeting internal scars (Huffman 2006; White and Harley 2016; Huffman and Rother 2017). Working in longleaf pine generally requires a specialized approach that includes sampling many trees and examining multiple cross sections per tree. The fire scars are often small and may occur only at one height along the tree bole, as we observed in the present study. If we did not include multiple sections per tree, we would have missed nearly half of all fires that we identified at our site and underestimated fire frequency. We expect that the collection of multiple sections per tree may be especially important in either more mesic ecosystems or where winter and early spring fires are common due to the possible lower likelihood of scarring.

The Piedmont is comprised of a diverse array of ecosystem types (Schafale and Weakley 2012). Although there is uncertainty in the historical distribution of different ecosystem types in this region, it is likely that longleaf pine was restricted to areas where fires burned more frequently (Spooner et al. 2021). Historical records suggest that longleaf pine was relatively widespread in the piedmont of the Carolinas including in Montgomery County, where our site occurs (Hale 1883; Ashe 1894; Pinchot and Ashe 1897). In piedmont locations where old-growth longleaf occurs (such as at the Nichols Preserve), the presence of both living and dead old-growth longleaf pine of varying ages strongly suggests that fire has a reasonably long history (at least several hundred years) because successful longleaf pine regeneration is promoted by bare mineral soil exposed by fire. Whether historical fires were either largely anthropogenic for the many millennia prior to Euro-American settlement or resulted from frequent lightning ignitions remains a question of debate. It is possible that the Nichols Preserve, as a site located on the distributional edge of longleaf pine, might be a product of mostly Native American burning that pushed the species into an area where it otherwise might not occur. While speculative, this assertion is plausible given a complex of Paleo-Indian artifacts dating 10,000 YBP at the nearby Hardaway site approximately 20 km west of the Nichols Preserve (Coe 1964) and the discovery of Native American stone tools on the Nichols Preserve (Ramona Bates, North Carolina Plant Conservation Program, Personal Communication). Alternatively, it is possible that a less-developed landscape with more continuous and flammable vegetation would have burned more frequently by lightning fire historically than it does today. Future tree-ring studies that involve more data collection and examine earlier evidence of fire alongside Native American history (i.e., pre-European arrival) may shed additional light on this ecological uncertainty.

Conclusion

Our record of the historical fire activity at the Nichols Preserve provides a snapshot of fire history for a relatively narrow window of time, beginning in the early eighteenth century and extending to the mid-nineteenth century. Given limitations of our records, our fire history should not be interpreted as evidence for the full, natural fire regime (i.e., fire regime supported by lightning and Native American ignitions) for this setting, but instead provides documentation of the relatively recent use of fire by people in the eighteenth and nineteenth centuries. Based on a broader body of literature (see Spooner et al. 2021; Stambaugh et al. 2017), a frequent, low-severity fire regime is appropriate for piedmont ecosystems with living or remnant old-growth longleaf pine when the goal is to promote a regenerative longleaf pine ecosystem.

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Authors' contributions

MR, TP, and PK designed the study. All authors took part in data collection. MR, TP, and PK analyzed the data. MR was the largest contributor to writing the manuscript. The authors read and approved the final manuscript.

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Availability of data and materials
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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