FIRE HISTORY IN A SOUTHERN APPALACHIAN DECIDUOUS FOREST

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Abstract.—Because there are few long-term dendrochronological and lake sediment data for the southern Appalachians, little is known regarding the history of fire in this region's forests through the Holocene. Radio-carbon ages for 82 soil charcoal samples collected from local depositional sites along a topographic gradient from mixed hardwood (*Liriodendron tulipifera* and *Quercus* spp.) to oak-pine (*Quercus prinus* and *Pinus rigida*) forest provide a coarse-grained picture of changes in fire frequency within a 10-ha area during the Holocene. Fires were frequent over the past 4,000 years, and their frequency appears to have increased significantly about 1,200 years before present (YBP), coinciding with the advent of the Mississippian Native American culture in this region. Our results are consistent with the widely held view that fires have become less frequent in this region over the past 250 years. The inbuilt error associated with estimating actual fire dates from charcoal fragments inherently limits our ability to infer the specifics of and changes in fire regime over time. Notwithstanding these uncertainties, it is clear that fire has been an important part of eastern deciduous forest ecosystems through much of the Holocene. Nevertheless, fire regimes and forest composition have likely changed during this time owing to changes in human activities and climate. These facts have important consequences for restoration and fire management.

INTRODUCTION

Up to the late 20th century, most ecologists tacitly assumed that fire was not an important factor in eastern deciduous forests. Nowhere is fire mentioned in E. Lucy Braun's monographic treatment of this biome (Braun 1950). Oosting (1942) likewise omitted any mention of fire in his survey of the successional and mature communities of the eastern Piedmont. Whittaker (1956) speculated that wildfire played an important role in the maintenance of ridge top shrub and pine dominated communities of the southern Appalachians but not in deciduous hardwoods. Nevertheless, early explorers and settlers often described the vegetation of these regions as woodlands with open grassy understory conditions indicative of high frequency, low intensity fire regimes (Bartram 1791, Lawson 1701). The prevalence of fire-adapted oaks (*Quercus*), hickory (*Carya*) and chestnut (*Castanea*) supports this assessment. Occasional stand replacement fires may have been important during times of severe drought, particularly if occurring after canopy disturbance (e.g., blowdown) when dead and down fuel levels were high (Abrams 1992, Brown 2002).

Nowadays, there is general agreement that fire played an important role in presettlement deciduous forests, and debate has shifted to the nature and frequency of fire in the array of mixed pine-hardwood and hardwood communities along topographic and moisture gradients (Brose and others 2001, Delcourt and Delcourt 1997, Runkle 1985, van Lear and Waldrop 1989). It is almost certainly the case that fire regimes changed through the Holocene with changes in climate and use of fire by Native Americans (Delcourt and Delcourt 1997, Delcourt and others 1986, Gragson and others 2008, Springer and others 2010), and the changes following European settlement were even more pronounced (MacCleery 1996, Nowacki and Abrams 2008, Yarnell 1998). During the 17th and 18th centuries, increased human access, land clearing, and altered fuel conditions likely increased the frequency of fires (Jurgelski 2008). Over most of the last century, however, active fire suppression and landscape fragmentation have reduced fire frequency in most areas (Jurgelski 2008). Nowacki and Abrams (2008) argue that successional change in the absence of fire has "mesophied" eastern deciduous forests, that is, it has altered forest composition and structure in ways that have greatly diminished flammability and, therefore, fire likelihood across this entire region.

The nature of presettlement fire regimes and the changes that have occurred in those regimes since European settlement are quite relevant to modern forest management. They are key to our interpretation of the likely composition and structure of presettlement forests and, thus, to the establishment of targets for forest restoration (Nowacki and Abrams 2008, Scharf 2010). They are important to our understanding of the likely responses of species to the increased use of prescribed fire for understory fuel management and forest restoration. Finally, land managers need such information in order to emulate historic disturbance regimes through silvicultural practices (Engstrom and others 1999, Kimball and others 1995, Vose and others 1999). While regional understanding of fire occurrence and frequency is useful, we are most in need of stand-level information on fire return intervals and fire behavior.

Dendrochronological studies in the Appalachians have provided useful information regarding fire frequency in oak-pine dominated forests during the past several centuries (Abrams and others 1995, Guyette and Cutter 1991, Nowacki and Abrams 1997, Ruffner and Abrams 2002, Schuler and McClain 2003, Shumway and others 2001). However, fire-scarred trees older than 400 years are exceedingly rare in this region.

Charcoal in wetland or lake sediments has been used to evaluate changes in fire occurrence at watershed or regional scales (Delcourt and Delcourt 1997, Delcourt and others 1986), but appropriate depositional environments are rare over much of this biome. Springer and others (2010) combined analyses of isotopic anomalies in stalagmite carbon with radiocarbon dates of sediment charcoal from a West Virginia cave to infer changes in fire regimes and human land use in the area surrounding the cave. These studies provide insights into long-term changes in the frequency of fire on landscapes surrounding the sample sites. They do not reveal much information about fire regimes at the scale of individual stands or variation in fire regimes among forest communities within a watershed. Welch (1999) used soil charcoal to verify the past occurrence of fire in southern Appalachian pine stands, but charcoal fragments were not carbon dated and it is not clear when these fires occurred.

Here we summarize our recent study (Fesenmeyer and Christensen 2010) in which we used radiocarbon dating of small pieces of charcoal in soil to reconstruct the presettlement, stand-level fire history along a topographic gradient in a southern Appalachian forest. We discuss both the limitations and the values of that study both to our understanding of the changing role of fire during the Holocene and the application of that understanding to restoration management.

METHODS

Our study was carried out in the Wine Spring Creek Ecosystem Management Area (WSCEMA) of the Nanatahala National Forest in Macon County, North Carolina (35°N latitude, 83°W longitude). The WSCEMA is located on the western slope of the Nantahala Mountains. Sampling was done over an area of approximately 10 ha at 1,280-1,430 m elevation, extending from a perennial stream across a south-southwest-west facing slope to a ridge top. The sample area was selected because it included the gradient of vegetation from hemlock-hardwood cove near streams through mixed-oak hardwood on hill slopes to chestnut oak-pine forests on the ridge top. Live pitch pine trees were widely scattered on the ridge top; dead boles and logs of this species were more abundant, suggesting that its abundance has decreased over the past several decades. The well-developed soil A horizon indicated that this site had never been subjected to agriculture. A 1997 prescribed fire at this site provided abundant charcoal of recent age for comparison. Other research from WSCEMA has focused on the effects of this prescribed fire and is described in Elliott and others (1999) and Vose and others (1999). There was no record nor was there any evidence at this site of any other fires in the past century.

Wood charcoal is an inert and recalcitrant form of carbon that can persist in soils for millennia following fires (De Lafontaine and others 2011). Although charred material may be transported significant distances by wind and water, the vast majority of charcoal that accumulates in depositional locations (such as small depressions) within a forest likely originated within a few tens of meters of those locations (Blackford 2000, Higuera and others 2007). Thus, the range of charcoal ages at sites likely reflects the history of fire at or very near that site.

Sediments containing significant amounts of charcoal often accumulated immediately upslope and downslope from rock outcrops (height = 0.5 to 3 m) scattered across the study area. Using a slide hammer soil sampler, we obtained 5 cm diameter intact soil cores from 33 rock-outcrop locations. After removing the O horizon (duff layer), we collected soil cores varying from 10 to 30 cm depending on the depth to bedrock at each sample location. For purposes of comparison, sample sites were divided into two groups—xeric (ridge top and upper slope oak-pine sites) and mesic (downslope hardwood sites)—based on overstory vegetation cover.

In the laboratory, soil cores were divided into 2 cm sections, taking care to preserve the stratigraphy of the sample. The details of laboratory treatment and selection of charcoal fragments (1-50 mg each) are described in Fesenmeyer and Christensen (2010). A total of 82 individual charcoal fragments from 18 sample locations were selected for carbon dating. This number was determined by funding available for carbon dating. Fragments were selected to represent entire core horizons among different vegetation types on the site. The calibrated ^{14}C radiocarbon date and radiometric error of each fragment was determined using accelerator mass spectrometry (AMS) (Reimer and others 2004). The radiometric (2 sigma) error associated with AMS dates varied among samples from as little as 20 years to as much as 400 years. These data were subjected to cumulative probabilities analysis (Meyer and others 1992) using the "sum probabilities" option in CALIB 5.0.1 (Lafortune and others 2006, Stuiver and others 2005). This analysis allowed us to represent for a given year the relative probability that any fire represented in our dataset occurred at the site.

The calibrated radiometric age and error of a charcoal fragment corresponds not to the age of a fire event, but to the time when the wood that comprises a charcoal fragment was actually produced. The so-called "inbuilt error" of a date is estimated by the probability distribution of the difference between the date of carbon assimilation into wood and the date of the fire event that consumed and converted the wood to charcoal (Carcaillet 1998, Gavin 2001). The inbuilt error is additive to the radiometric error, and it is typically assumed to depend on stand age structure and the rate of wood decay in the ecosystem (Gavin 2001, Gavin and others 2003). However, the age distribution of charcoal remaining after a fire is also influenced by the prevailing fire regime itself, because fire frequency and intensity affect both the amount of available fuel and how much is actually charred (Higuera and others 2005).

RESULTS

Calibrated carbon dates ranged in age from 0 (probably corresponding to the 1997 prescribed fire in this area) to 4,000 years before present (YBP), with the exception of one fragment dated at 10,560 ±120 years. This was so far outside the range for all other samples that it was not considered in subsequent analyses. However, this very old fragment is evidence that fires occurred at this site in the early Holocene at about the same time that humans first occupied this region (Gragson and others 2008). Charcoal sample ages (± 2 sigma) are arrayed according to age and site, and the summed probability distributions for the two site groups are plotted in Figure 1. This distribution of relative probabilities suggests that fires have regularly occurred at xeric oak-pine sites over the past 4,000 years. The record of fire events at mesic hardwood sites begins about 2,000 yr ago. There is a relatively abrupt increase in the relative probability of a year being represented in our charcoal sample at about 1,000 YBP in both xeric and mesic sites.

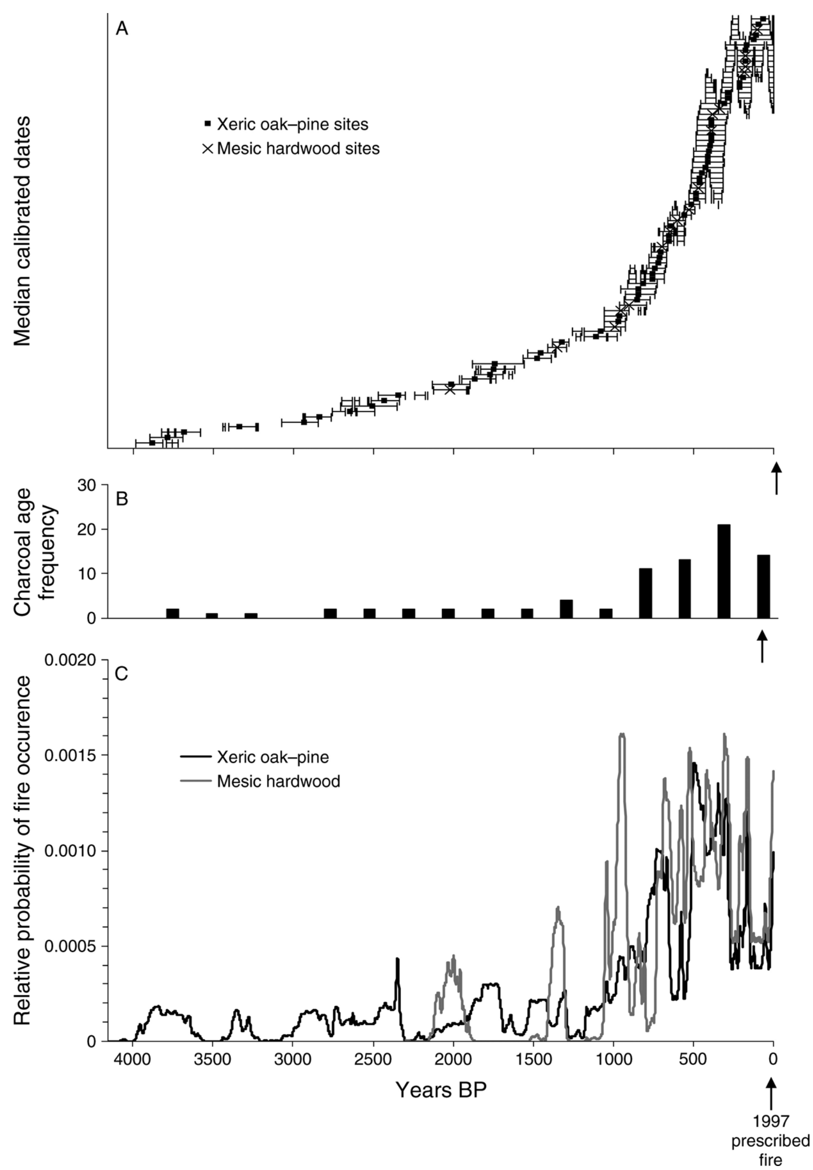

Figure 1.—A) Ages of 82 charcoal fragments arrayed by calibrated ARM date with 2-sigma error bars. Note that 2-sigma errors are discontinuous for some ages. B) The frequency of charcoal ages in 250 year time bins. C) The summed probability that any fire represented in our dataset occurred at the site. (Figure used with permission from Fesenmeyer and Christensen 2010).

Using Gavin's methodology and age-distributions (Gavin 2001, Gavin and others 2003) for existing forests and wood decay rates for this region suggested by Harmon and others (1986), the inbuilt error for the oak-pine forests is likely between +50 and +100 years, although without knowledge of the actual fire regime, this estimate is quite uncertain. Therefore, the most probable dates of fire events are, on average, 50-100 years younger than the most probable radiometric dates of charcoal fragments. Furthermore, the radiometric errors used in the summed probability analysis underestimate the total error surrounding estimated dates of fire events. Thus, it is not possible to determine whether charcoal fragments with ages that differ by less than 150-200 years are products of the same fire or of different fires.

Fires clearly have occurred regularly on this forested slope over the past 4,000 years. Furthermore, fires were not confined to ridge top sites that currently support oak-pine forests, but they extended into areas that are today dominated by mesic hardwood communities. That no charcoal fragments > 2020 YBP were found in mesic hardwood sites may have been due to unequal sampling effort rather than inherent differences in fire regime between site types. However, it is well established that their moist, flaccid litter renders mesic hardwood ecosystems more resistant to fire than other forest types (Nowacki and Abrams 2008).

The number of samples represented in particular age bins diminishes with increasing charcoal age. This pattern of diminishing data with time is inherent in virtually all historical data sets (Egan and Howell 2001). However, the abrupt appearance 4,000 YBP of regular fires and the marked increase in the summed relative probability of charcoal ages at 1,000 years are consistent with historical trends in human activity and fire frequency hypothesized for the southern Appalachians by Delcourt and Delcourt (1986, 1998).

DISCUSSION AND MANAGEMENT IMPLICATIONS

Abrams and Nowacki (2008) argued that Native Americans used fire widely to manipulate vegetation in the eastern United States. Delcourt and Delcourt (1986, 1998) noted that Native Americans of the Woodland Tradition appeared in the vicinity of our study area about 4,000 years ago, and they attribute fires during that period to these hunter-gatherers. Mississippian people appeared in this area about 1,000 YBP, coinciding with the appearance of *Zea maize* and a number of weedy herbs in the pollen record. The widespread use of fire by Mississippian Native Americans is well documented (Delcourt and others 1998, Hatley 1993).

In eastern Kentucky, Delcourt and others (1998) linked Native American use of fire to the dominance of oak-hickory forests starting 3,000 yrs ago (also see Ison 2000). Springer and others (2010) recent analysis of pollen and charcoal deposits in a West Virginia cave suggests an increase in fire in that location beginning 4,000 YBP and lasting until the arrival of Europeans. Here, too, Native Americans were implicated. In the only additional soil charcoal study in the southern portion of the Eastern Deciduous Biome, Hart and others (2008) described a comparable range of fire occurrence (events spanning 6785 to 174 YBP) in a hardwood deciduous forest on the Cumberland Plateau of middle Tennessee (located 185 km from our study area).

Because of the uncertainties associated with radiometric and inbuilt errors, it was not possible to estimate fire return intervals for our study area. Nevertheless, the summed probability plot (Fig. 1c) is consistent with frequent, low severity fires during the past millennium. This time period coincides with the expansion of Mississippian people into this area. If our charcoal samples are representative of the fire events during the period 4,000-1,000 YBP, then we might speculate that fires during that period were less frequent and, therefore, more severe during that time interval.

After accounting for the prescribed fire, a simple histogram of charcoal ages suggests that fires may have become less frequent during the past 250 years (Fig. 1b). This coincides with the decline in Native American populations in this region after the beginning of European exploration and settlement. Changes in fire frequency over the past millennium were undoubtedly influenced by changes in climate as well.

The actual composition of the forests that burned during the past four millennia remains unknown. However, this amount of fire suggests that pines were likely far more abundant in presettlement times than today. The nature of presettlement fires (e.g., their seasonality and severity) also remains unknown. But these data suggest that fire regimes changed considerably from Woodland to Mississippian to European Settlement times.

These results eliminate any doubt about whether fire played a significant role in presettlement deciduous forest ecosystems; it most certainly did. Given its historical importance, we can also presume that many deciduous forest species are in various ways adapted to fire regimes of one kind or another. Although the specifics are far from clear, changes in fire regimes (fire frequency and severity) undoubtedly caused changes in the relative abundance of different tree species from one time period to another. As fires became more common during the past 4,000 years, they likely contributed to increased prevalence of pines and fire tolerant hardwoods such as oaks and hickories. The significant diminution in fire occurrence over the past two centuries has contributed to the increased prevalence of fire intolerant species such as red maple (Abrams 1992) and to the "mesophication" of eastern forests (Nowacki and Abrams 2008).

These very general conclusions are directly relevant to restoration and fire management in eastern deciduous forests. First, the historic range of variation in fire regimes and ecosystem structures over the past several millennia appears to have been very large compared to the expected range of variation in these features over decadal time intervals. It is variation over these shorter time intervals that is most relevant to restoration and fire management today. Second, even though the specifics are vague, changes in fire regimes over time suggests that the choice of particular historical restoration targets, whether for forest composition or fire prescriptions, is arbitrary. Furthermore, even if we knew the specifics of the relationship between forest composition and fire regime change, restoration to a particular historical target may not be possible. Given ongoing climate change, land fragmentation, and abundant non-native species, restoration of a particular fire regime will not necessarily restore the community of species that were historically associated with it.

This does not mean that detailed information on past fire regimes and their relationship to forest composition is not important. The end goal of fire restoration management is not fire itself, but the diversity, structure and key processes in eastern deciduous forest ecosystems. A clear understanding of the details of the historical relationship between fire regimes and these ecosystem features is critical to achieving that goal, and we have much yet to learn.

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