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# Fire Regimes of the Southern Appalachian Mountains: Temporal and Spatial Variability over Multiple Scales and Implications for Ecosystem Management

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# **Fire Regimes of the Southern Appalachian Mountains: Temporal and Spatial Variability over Multiple Scales and Implications for Ecosystem Management**

**Final Report to Joint Fire Science Program**

**Project Number 06-3-1-05**



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## **Abstract**

Information about historic fire regimes and the departure of current fire regimes from historic conditions is essential for guiding and justifying management actions, such as prescribed burning programs for ecosystem process restoration and fuel reduction. Such information is noticeably lacking for the southern Appalachian Mountains, where human populations are encroaching onto wildland areas, and where decades of fire exclusion have contributed to the decline of fire-associated communities and also to altered fuel loads. We address this knowledge gap via a multi-scale investigation of the variability in fire regimes over time and space using tree-ring reconstructions of fire history and stand dynamics in pine and mixed hardwood-pine forests. The tree-ring analyses are augmented by soil charcoal analyses and by statistical and GIS analyses of fire records from federal agencies.

We used a multi-spatial scale approach to determine locations for tree-ring reconstructions of fire history. First, we established a network of four sites across the low-elevation pine-hardwood ecosystems in the western Great Smoky Mountains National Park (GSMNP), where we also set up plots for examining vegetation dynamics via age structure and species composition. We established a second network for reconstructing fire history and vegetation dynamics in middle-elevation forests of GSMNP spanning xeric to mesic sites. Together these low- and middle-elevation reconstructions portray patterns of fire and vegetation response across a broad landscape. Finally, we established two additional fire history sites, one in the Ridge and Valley terrain west of the GSMNP, and the other along the eastern escarpment of the Blue Ridge Mountains to the northeast of GSMNP. These sites combine with the GSMNP sites to characterize region-scale patterns and variations in fire history. Analyses of the tree-ring data reveal that fires burned frequently (at about 2–14 year intervals) in the southern Appalachian Mountains from the late 1700s/early 1800s until the early to middle 1900s, when burning declined coincident with fire protection. The density of trees, especially fire-intolerant species, increased in the 1900s as fire frequency declined.

The soil charcoal study was conducted within the low-elevation tree-ring study sites in GSMNP. Charcoal fragments range in age from modern to about 3000 years old. About 75% of the hundreds of charcoal fragments identified in the cores are of pine. These results suggest that fire was a component of the forests long before the beginning of the tree-ring fire chronologies. They also emphasize the association of pine with fire in these humid environments where vegetation succession tends toward the replacement of pines by hardwoods. The GIS and statistical analyses of recent burning patterns clarify relationships among fire, climate, and terrain. Fire occurs most commonly in drier climates within the region, and during dry years. At the scale of local terrain, dry sites (e.g., ridgetops) burn more commonly than moist sites (e.g., valleys). Such topographic patterns are influenced by broader climatic conditions, however. Topographic patterning is more pronounced under wet climatic conditions than under dry conditions, which permit fires to spread into mesic topographic positions.

## **Background and purpose**

Many southern Appalachian ecosystems developed under a regime of periodic burning (Van Lear and Waldrop 1989; Delcourt and Delcourt 1998; Williams 1998; Van Lear and Brose 2002). Reduced fire activity during the 20th century has contributed to an increase in the density of trees and shrubs and has permitted heavy fuel loads to accumulate. Open forests and

woodlands dominated by pine and oak have become less abundant, as have other types of fire-associated vegetation including some grassland and bald communities. These changes have reduced habitat quality for plant and animal species that require open woodland habitat, such as the mountain golden heather, smooth coneflower, red-cockaded woodpecker, and golden winged warbler. The changes have also elevated the risk of wildfires that may burn with much greater intensity than the fires to which fire-dependent species are adapted, and may burn into vegetation types in which fire historically would have been rare. Moreover, because of increasing fuel loads and the rapid expansion of housing and recreational developments up to the boundaries of many public lands in the region, the threat of devastating fires is increasing in the wildland-urban interface.

Resource managers in the southern Appalachian Mountains increasingly use prescribed fire to attempt to restore fire-dependent ecosystems and reduce hazardous fuel loads. New tools, such as Fire Regime Condition Class (FRCC) and LANDFIRE, have been developed to guide restoration planning and implementation. Historical and contemporary fire regime information is fundamental to FRCC and LANDFIRE, but such information is lacking for most of the Appalachian region. Unlike the western U.S., where coniferous forests are extensive, deciduous forests (mostly oak) are the primary land cover type in the Appalachians. Few tree-ring analyses of fire-scarred trees have been conducted to reconstruct past fire regimes in these forests. Our previous JFSP-funded research in the central Appalachian Mountains (project 01C-3-3-09) demonstrated, however, that opportunities to do so are excellent. Living and dead yellow pines that contain multiple, well-preserved fire scars are widespread on Appalachian landscapes, both in pine-dominated stands and as components of hardwood forests. For the current project reported upon here, we discovered many additional fire-scarred pines in the southern Appalachian Mountains. Individual fires often scarred pines in multiple stands, indicating that the fires spread through the pine stands as well as intervening hardwood stands. Our results consequently provide detailed fire history information for the pine- and oak-dominated forests that cover most of the forested uplands of the southern Appalachian Mountains. They also provide insights about fire regimes of the mesophytic forests adjacent to the pine and oak stands, because some of the fires appear to have spread downslope into mesophytic forests.

The work reported here provides a scientific basis for prescribed burning programs in the southern Appalachian Mountains. Applying prescribed fire at the appropriate frequency and intensity, and at the right time of the year, to mimic the historic fire regime requires information about (1) the characteristics of the past fire regime, including fire seasonality, frequency, intensity, severity, variability, and spatial extent; (2) how the contemporary fire regime differs from that of the past; and (3) how vegetation and fuel loads have changed in response to fire exclusion. Lacking such a scientific basis, prescribed burning efforts may inadvertently introduce a fire regime that is outside the historic range of variability for the ecosystems under treatment. The need for better information about historic fire regimes is underscored by citizen concerns over whether ongoing and planned burning treatments on public lands may be more appropriate for the western U.S. than for the Appalachian Mountains (e.g., USDA Forest Service 2004). Detailed fire history records from tree rings, and the coarser-scale but longer records of fire from soil charcoal, can play a useful role in educating the public about the long-term role of fire in certain southern Appalachian ecosystems.

## Study description and location

### *Field data collection*

For the tree-ring sampling, we followed a three-tiered approach to data collection (Fig. 1):

(1) We established a network of four fire history sites across the low-elevation pine-hardwood ecosystems in the western Great Smoky Mountains National Park (GSMNP). We refer to these as Gold Mine Trail, Rabbit Creek Trail, Pine Mountain, and Cooper Road Trail. The four sites exist within a landscape approximately 6 km across (Fig. 1). This area consists of a series of parallel ridges and valleys of relatively low elevation (mostly below about 600–700 m above sea level). The predominant vegetation is oak and other hardwoods. Shortleaf, Virginia, and pitch pines are scattered among the hardwoods as individual trees or small stands. Much of the area never was logged commercially, but scattered small farms occupied the landscape before the park was established. Fire-maintained ecosystems such as pine and oak savannas/woodlands are thought to have existed historically in this and other low-elevation environments of the Appalachian Mountains.

We established a second network in middle-elevation forests of GSMNP spanning xeric to mesic sites. We refer to this area as the Licklog Watershed. The area was within an unlogged watershed approximately 1.5 km across. Apparently no human settlements ever existed in the watershed, but settlements, including Cades Cove, are only a few kilometers away. The vegetation encompassed the typical suite of mid-elevation Appalachian communities, ranging from montane Table Mountain pine-pitch pine forests on the xeric sites, through oak forests on the moderate sites, to mesophytic forests along the valley.

(2) Together, these low- and middle-elevation reconstructions portray patterns of fire and vegetation response across a broader landscape in western GSMNP, approximately 11.5 km across. This landscape is within the western section of the Blue Ridge physiographic province.

(3) We established two additional sites that, when combined with the GSMNP sites, permit characterizations of region-scale patterns and variations in fire history. One of these sites is at the House Mountain State Natural Area in the Ridge and Valley physiographic province. House Mountain is a sharp ridge a few kilometers long. It is covered with second-growth forests of pine (Virginia pine, shortleaf pine, Table Mountain pine), oak, and other hardwoods. The mountain is surrounded by agricultural lowlands northeast of Knoxville, Tennessee, and has been influenced heavily by human land use (especially agriculture) since the earliest European settlements of eastern Tennessee during the late 1700s. The other site, Linville Mountain, is located on the Pisgah National Forest in northwestern North Carolina. This site occupies rugged terrain along the eastern escarpment of the Blue Ridge physiographic province. It lies within a large forested landscape. The pine stands we sampled are dominated by Table Mountain and pitch pines, and are within a matrix of hardwood (mostly oak) forests.

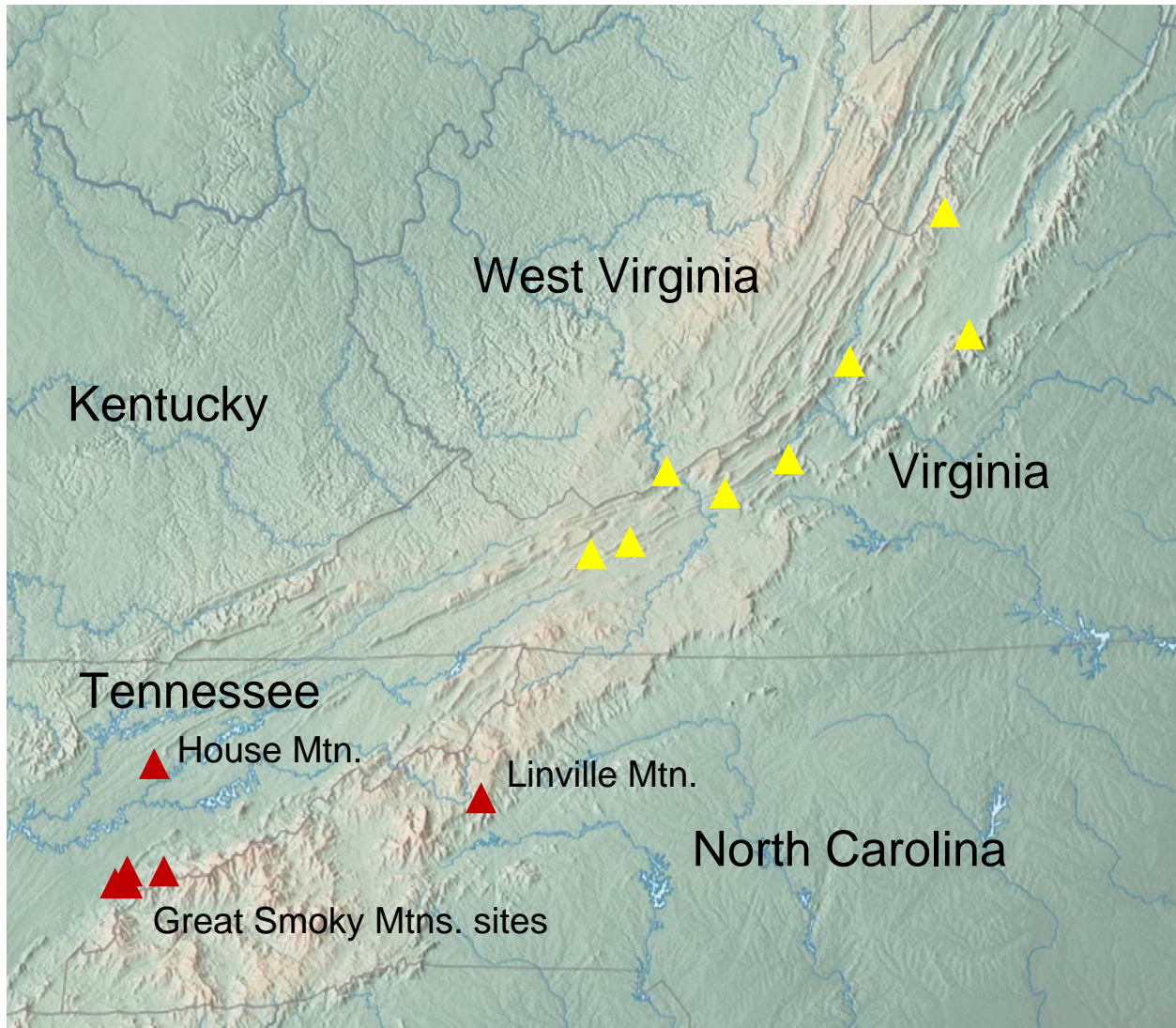


Figure 1. Study sites for the current project in the southern Appalachian Mountains (red triangles) and our previous JFSP-funded project in the central Appalachian Mountains (yellow triangles). Shaded relief base map courtesy of Tom Patterson.

At each study site, we used a chain saw to cut cross-sections (Arno and Sneek 1977) from fire-scarred logs, snags, and remnant pieces of wood. We also established  $50 \times 20$  m plots to investigate successional dynamics with respect to fire history. For the low-elevation landscape in GSMNP, we set up 13 plots, three per site (four at Copper Road), in the pine and adjacent hardwood stands. At the middle elevation watershed in GSMNP, we established 15 plots throughout four different vegetation types arranged along a topographic moisture gradient to identify the influences of fire on the mesic sites, where fire regimes are poorly understood, as well as on the xeric sites, where fire regimes are better understood. These forest types were, from dry to moist, xerophytic yellow pine forest, oak forest, lower-slope transitional forest dominated by eastern white pine, and mixed mesophytic forest along the valley bottom. All canopy tree species with diameter at breast height (DBH)  $\geq 5$  cm were cored in each plot. We inventoried and measured DBH of all trees (having DBH  $\geq 5$  cm) and saplings (height  $> 50$  cm), excluding understory specialists (e.g., serviceberry). We selected one  $10 \times 20$  m subplot and tallied every

tree seedling in the subplot. We recorded the depth of the duff layer within the plot at 20 systematically chosen points.

To sample soil charcoal, we used a root auger (Horn et al. 1994, 2000) to recover soil cores in contiguous 10-cm intervals to the depth of refusal or 1 m at eight locations within the low-elevation study sites in GSMNP. Core sections were extruded into plastic bags, and later wet sieved in the laboratory using screens with a mesh size of 2 mm. Charcoal fragments were picked from the retained material using forceps and a dissecting scope, rinsed free of adhering soil using distilled water, and transferred to glass vials for drying. Through ongoing taxonomic identification and AMS radiocarbon dating of charcoal fragments, we are developing coarse-resolution fire and forest histories that reach beyond the tree-ring records, and may reveal intervals of higher fire occurrence associated with climate variability.

### *Data Analyses*

We sanded all cores and cross-sections down to 400-grit to produce a polished wood surface that accentuated the visibility of all tree rings. We then crossdated all tree rings to their exact year of formation. The fire-scar data were input into FHX2 software (Grissino-Mayer 2001) to graph and analyze fire frequency and its relation to variations in human land use and climate. Tree age and composition data were summarized to investigate how past fires—and the more recent period of reduced fire activity—affected vegetation development.

We calculated the frequency of occurrence and dry mass of charcoal for each depth increment across all cores at each site. Because we expected charcoal in the upper 0–20 cm of the soil cores to overlap with our tree-ring records of fire, we focused on deeper charcoal for AMS radiocarbon dating, obtaining multiple AMS dates on individual, small (5–20 mg) fragments from different depths at each site. We supplemented funds budgeted for radiocarbon dates in the JFSP award with additional funding from the National Science Foundation (DGE-0538420 and BCS-0928508) and the Great Smoky Mountains Conservation Association, and further reduced sample analysis costs by carrying out radiocarbon sample pretreatment in our laboratory at the University of Tennessee. In this way, we have managed to leverage the JFSP funds to obtain ca. 100 AMS radiocarbon dates, enough to establish coarse-resolution soil charcoal records (Sanford and Horn 2000) with 12–13 dates per site. As of the completion of this report, we are awaiting the results of these AMS radiocarbon analyses.

We also analyzed spatial and temporal patterns of recent fires that were archived in the National Interagency Fire Management Integrated Database (NIFMID) and in GIS databases of fire occurrence in the GSMNP and Shenandoah National Park (SNP). We obtained climate data from the National Climatic Data Center (NCDC).

## **Key findings**

### *Fire history from tree rings*

All the tree-ring records of fire history extend back to the 1700s, before European settlement. At four of the sites (Gold Mine Trail, Pine Mountain, Cooper Road Trail, and Linville Mountain), the earliest scars formed in the 1720s, while the earliest scars formed in the 1760s at the other three sites (Licklog watershed, House Mountain, and Rabbit Creek Trail). Fire frequency was high at all the sites. In the low-elevation landscape of GSMNP, the Weibull

median fire interval (considered the optimum descriptor of the typical fire interval) ranged between 3.0 and 4.4 years among the sites. These results do not indicate that fires burned every point on the landscape at 3.0–4.4 year intervals. They simply reveal that fire burned at least one tree within each of the sites at that frequency. Some fires may have been small, not affecting the entire site. Calculating the frequency of widespread fires that scarred at least 25% of all the trees provides a more conservative, and probably more reliable, estimate of fire frequency. This calculation shows that historically these widespread fires burned at intervals of 5.6–8.4 years in the low-elevation landscapes of western GSMNP.

The mid-elevation Licklog watershed in GSMNP had a fire return interval of 1.6 years for any fire in the watershed, and 3.8 years for a widespread fire. The finding of higher fire frequency in the middle-elevation landscape than in the low-elevation landscape was unexpected, given the increase in moisture with increasing elevation. The House Mountain site in the Ridge and Valley province had a similar frequency of burning: 1.9 years for any fire on the mountain, and 3.3 years for widespread fires. The high frequency at House Mountain was expected given its situation in a relatively dry part of the southern Appalachian region, combined with the intensity of human land use on the entire landscape surrounding the study site. The Linville Mountain site had an interval of 3.7 years for any fire occurring in the area, and 5.9 years for widespread fires.

#### *Forest age structure and composition*

Tree age structure data for the low-elevation landscape of western GSMNP reveal that many of the dominant pines and oaks established during the era of frequent fire in the 1800s and early 1900s. We found little indication that major cohorts of pines established following severe fires. Rather, tree establishment appears to have been relatively continuous, consistent with a frequent surface fire regime maintaining open pine-oak woodlands/savannas. A pronounced shift in tree establishment pattern occurred as fire frequency declined in the 1920s–1930s, when a pulse of tree establishment occurred. Relaxation of the constraints imposed by frequent fire permitted the survival of many more trees, including species such as eastern hemlock and red maple, which have fire-intolerant seedlings. Today, the stands appear to be transitioning toward more diverse, mesophytic assemblages. Species richness likely will decline, however, as the dominant pine and oak trees die and fail to be replaced because of the dense stand conditions that inhibit the regeneration of these shade-intolerant species.

At the mid-elevation Licklog watershed, the age structure of the pine stands suggests that under the frequent burning regime of the past, occasional severe fires occurred and permitted establishment of large new cohorts of Table Mountain and pitch pine. As fire frequency declined in the 20th century, mesophytic species have moved upslope from the mesic valley-bottom sites to the dry slopes. Today, the pine and oak stands have numerous small individuals of mesophytic, fire-intolerant species such as red maple, Fraser magnolia, and eastern hemlock. The lower-slope forest dominated by white pine has arisen during the fire-exclusion era. Previously, the xerophytic yellow pine and oak forests extended down onto the lower slopes. Fires even burned onto the streamside areas on occasion, as evidenced by fire scars on hemlock and hardwood trees. These fire scars were not collected for dating, however, because of decay.



### *Fire history from charcoal*

The core sections yielded hundreds of taxonomically identified charcoal fragments, mostly to genus, but some to species. A preliminary set of AMS radiocarbon dates range from approximately 50 to 2800 years before present. Radiocarbon dates were calibrated using the CALIB 5.0.1 program (Stuiver and Reimer 1993) and latest calibration datasets. Of the hundreds of taxonomically identified charcoal fragments, approximately 75% are pines. These results suggest that fire was a component of the forests long before the beginning of the tree-ring fire chronologies. They also emphasize the association of pine with fire in these humid environments where vegetation succession tends toward the replacement of pines by hardwoods.

### *Contemporary fires recorded in the NIFMID and GIS databases*

NIFMID afforded a view of all the known fires that occurred on federally managed land throughout the southern Blue Ridge physiographic province during the last 35 years (Baker 2009). Analyzing NIFMID data revealed a strong correlation between fire occurrence and drought. The area burned by both anthropogenic and lightning-ignited fires was greatest during drought years (i.e., there was a negative correlation with Palmer Drought Severity Index, or PDSI). The relationship with anthropogenic fires was particularly strong. Anthropogenic fires also showed a negative relationship with ENSO, that is, more area was burned during La Niña years than El Niño years. NIFMID does not have precise coordinates that could be used to investigate fine-scale spatial patterns of fire, but it does permit comparison among different ranger districts, thus portraying coarse spatial patterns. Fire activity was highest along the western slope of the Blue Ridge (the Tennessee side) and also in the northern portion of the eastern slope of the Blue Ridge in North Carolina. The southern and interior parts of the Blue Ridge province had the lowest incidence of anthropogenic and lightning-ignited fire. In general, these spatial patterns correspond to climatic variations across the region, with greatest fire activity in the driest, most continental areas.

The GIS databases for GSMNP and SNP permitted an assessment of topographic and regional patterns of fire over the period 1930 to present (Flatley et al., in press). Dry topographic positions, such as ridgetops and south-facing slopes, burned more frequently than moist sites, such as valleys and north-facing slopes. The relatively dry SNP, likewise, had more burning than the wetter GSMNP. A multiple-scale interaction was evident in burning patterns. Climate imposed a “top-down” influence on topographic patterns of fire. Dry climatic conditions weakened the topographic influence on fire. Fire was less topographically constrained in SNP than in GSMNP. It was also less topographically constrained — in both parks — during dry years than during wet years. During dry years (or in SNP) fires are able to burn into the topographically moist sites, while during wet years (or in GSMNP) fires are mostly limited to the driest topographic positions.

### **Relationship to other recent findings and ongoing work**

These results complement and extend recent work on fire regimes in the eastern U.S. generally, and the Appalachian Mountains specifically. For nearly a century, fire has been recognized as an indispensable component of subtropical Coastal Plain ecosystems such as longleaf pine forests (e.g., Chapman 1932; Heyward 1939), which are thought to have burned at

intervals of approximately 1–3 years historically. The role of fire in the temperate forest ecosystems, particularly the central area containing the Appalachian Mountains, has become widely appreciated only during the last two decades (e.g., Abrams 1992; Lorimer et al. 1994; Frost 1998). Consensus is growing that many eastern temperate landscapes had a long history of fire prior to the 20th century, and that these fires helped maintain the extensive forests of oak and pine that characterize much of the region. Burning would have kept these forests more open and would have supported the existence of fire-dependent herbaceous species (e.g., Hoss et al. 2008).

A few other tree-ring studies of fire history have been conducted in or near the southern Appalachian Mountains, including Harmon (1982), Shumway et al. (2001), Schuler and McClain (2003), and McEwan et al. (2007). Through our previous JFSP project 01C-3-3-09, we have developed a network of fire history sites in the central Appalachian Mountains of Virginia (DeWeese 2007; Hoss et al. 2008; Aldrich et al. 2010). The results of that work are similar to those reported here: fire occurred frequently from presettlement times until the beginning of fire protection in the 20th century, promoting fire-associated species such as Table Mountain pine and chestnut oak. With these two projects, we have developed a broad regional network comprising sites throughout a large section of the southern and central Appalachian Mountains (Fig. 1).

Longer fire history reconstructions based on charcoal are sparse in the eastern U.S. and Appalachian region. Sediment charcoal that has accumulated in bogs or ponds provides evidence of burning on Appalachian landscapes for the last 3000 years or more (Delcourt and Delcourt 1997, 1998). Our study is one of the first attempts to use macroscopic soil charcoal to investigate fire history in the Appalachian Mountains. These macroscopic fragments provide evidence of fire and tree taxa at the local scale (the sampling site), and can be linked directly to fire-scar analyses from the same site. Hart et al. (2008) and Fesenmyer and Christensen (2010) have also used soil charcoal to reconstruct local-scale, coarse-resolution fire histories for sites in the southern Appalachian region, although their soil samples were not collocated with fire-scarred trees. Fesenmyer and Christensen dated a large number of charcoal fragments, but did not perform taxonomic identification of their charcoal samples.

The broader-scale analyses of fire-climate relations and spatial patterns of fire for recent decades is related to much recent work on fire climatology, most of which has been conducted in the western U.S. (e.g., Westerling et al. 2006; Trouet et al. 2006). It also contributes to research in landscape ecology concerning spatial patterns of disturbance and interactions between local- and regional-scale processes (e.g., Parker and Bendix 1996; Rollins et al. 2002).

Our work has been of interest to other researchers as well as to resource managers throughout the region. We have engaged many resource managers, who have enthusiastically supported our work and who use our results to inform their resource management plans, such as National Forest plan revisions. Our participation in JFSP's recently funded Consortium of Appalachian Fire Managers and Scientists (CAFMS) will help make resource managers more aware of our work.

### **Future work needed**

With the completion of this and our previous JFSP-funded fire history research, we have begun to develop a regional network of fire chronologies in the Appalachian Mountains. This network is important for several reasons. It is one of the largest forested areas, with an extensive network of public lands, in the eastern U.S. It has a wide range of climate, terrain, vegetation,

and human land uses. It also appears to provide some of the best locations remaining in the eastern U.S. for finding fire-scarred trees, i.e., minimally disturbed sites where the fire-scarred trees have not been destroyed by forest clearing. We are pleased to have been able to make this contribution to understanding landscapes and ecosystems of eastern U.S. temperate forests. Our network, however, is still quite limited in comparison to those developed in the western U.S. over the last several decades.

More work of this nature is needed to accomplish several goals. First, the fire history network should be extended geographically to cover areas farther to the south (to the southern end of the Blue Ridge Mountains in Georgia), to the north (into Pennsylvania), and to the west (into the mixed mesophytic forests of the Appalachian Plateau). Second, the network needs infilling to increase its reliability and its usefulness to resource managers. Some of the sites are quite distant from each other. Third, it would be useful to conduct additional sampling in the areas where we have discovered the deepest record of past fires to attempt to uncover fire scars dating to the early 1600s or even the late 1500s. Fourth, our success with soil charcoal suggests that much potential exists to conduct similar research over a much greater range of sites. Funding would be needed for radiocarbon dating of numerous charcoal fragments at each site. Fifth, a good understanding of fire-climate relations has emerged for only a few areas in the country, most notably parts of the western U.S. At this point, too little work has been conducted to permit many useful generalizations about fire climatology. More work on this topic is needed for the humid southeastern U.S. and elsewhere, particularly in the face of projected climate change.

We are interested in pursuing additional work in all these areas, and we encourage JFSP to broaden its research funding opportunities to incorporate fire regime research again. Recent task statements have been quite narrowly focused on a few issues that, while having immediate applications, cannot provide resource managers with broad perspectives relevant to restoring fire-associated ecosystems or planning for the effects of climate change on fire regimes.

### Deliverables crosswalk

| Proposed  | Delivered   | Status   |
|---|---|--|
| Annual progress reports                             | Annual progress reports for 2007, 2008, and 2009  | Complete   |
| Published article on contemporary fire regime       | Flatley, W.T., Lafon, C.W., and Grissino-Mayer, H.D. In press. Climatic and topographic controls on patterns of fire in the southern and central Appalachian Mountains, USA. <i>Landscape Ecology</i> . | Complete   |
| Published article on GSMNP fire history             | Two or more articles on this topic will be published.   | In progress awaiting completion of dissertations.                          |
| Published articles on regional fire history network | Two or more articles on this topic will be published.   | In progress awaiting completion of dissertations.                          |
|   | Lafon, C.W. Fire in the American South: Vegetation Impacts, History, and Climatic Relations. <i>Geography Compass</i> 4/8:919–944.  | Complete. (This is an additional article that was not proposed initially). |

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|---|---|--|
| Published article on regional climate history | White, P.B., S.L. van de Gevel, L.B. LaForest, G.G. DeWeese, and H.D. Grissino-Mayer, 2011. Climatic Response of Oak Species across an Environmental Gradient in the Southern Appalachian Mountains, U.S.A. <i>Tree-Ring Research</i> . | Complete. (This is an additional article that was not proposed initially).               |
| Ph.D. Dissertations                           | LaForest, L.B. <i>Fire Regimes of Lower-elevation Yellow Pine (Pinus) and Pine-Oak (Quercus) Stands in Great Smoky Mountains National Park, Tennessee</i> . Ph.D. Dissertation, University of Tennessee, Knoxville.                     | In progress.   |
|   | Flatley, W.T. Ph.D. Dissertation, Texas A&M University, College Station, TX   | In progress. (This is an additional Ph.D. dissertation that was not proposed initially). |
|   | Underwood, C. <i>Fire and Forest History in Native Yellow Pine and Mixed Hardwood-Pine Communities of the Southern Appalachian Mountains, U.S.A.</i> Ph.D. Dissertation, University of Tennessee, Knoxville.                            | In progress. (This is an additional Ph.D. dissertation that was not proposed initially). |
| M.S. Theses                                   | Pipkin, A.R. <i>Role of Fire Suppression in Creating Habitat Conducive to the Expansion of the Ericaceous Shrub Layer in the Southern and Central Appalachian Mountains</i> . M.S. Thesis, Texas A&M University, College Station, TX.   | In progress. (This is an additional M.S. thesis that was not proposed initially).        |
|   | Li, N. <i>Dendroclimatic Analysis of Oscillations for the Southeastern United States from Tree-Ring Network Data</i> . M.S. Thesis, The University of Tennessee, Knoxville.   | In progress. (This is an additional M.S. thesis that was not proposed initially).        |
|   | Biermann, C.P. 2009. <i>Twentieth Century Changes in the Climate Response of Yellow Pines in Great Smoky Mountains National Park, Tennessee, U.S.A.</i> M.S. Thesis, The University of Tennessee, Knoxville. 171 pp.                    | Complete. (This is an additional M.S. thesis that was not proposed initially).           |
|   | Feathers, I.C. 2010. <i>Fire History from Dendrochronological Analyses at Two Sites near Cades Cove, Great Smoky Mountains National Park, U.S.A.</i> M.S. Thesis, University of Tennessee, Knoxville.                                   | Complete. (This is an additional M.S. thesis that was not proposed initially).           |
| B.S. Theses                                   | Baker, R.C. 2009. <i>Climate-Fire Relationships in the Southern Appalachian Mountains</i> . Undergraduate   | Complete. (This is an undergraduate thesis that was not proposed initially).             |

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|  | Research Scholar thesis, Texas A&M University, College Station, TX.   |  |
|  | White, P.B. 2007. <i>Dendroclimatological Analysis of Oak Species in the Southern Appalachian Mountains</i> . B.S. Honors Thesis, University of Tennessee, Knoxville. | Complete. (This is an undergraduate thesis that was not proposed initially).   |
| Fire history data and metadata                                 | To be submitted to the ITRDB and the IMPD in required formats.  | In progress awaiting completion of dissertations and articles.   |
| Final report   | Final report  | Complete   |
| All reports, dissertations, theses, publications, and metadata | To be made accessible through FRAMES.   | Awaiting completion of dissertations, theses, and articles.  |
|  | Conference presentations, public lectures, and site visits with resource managers.  | Many completed, and additional talks to be presented. (These were discussed in the proposal but not listed formally in the table of deliverables). |

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