

**Fire and Forest History from Soil Charcoal in
Yellow Pine and Mixed Hardwood-Pine Forests in
the Southern Appalachian Mountains, U.S.A.**

A Dissertation
Presented for the
Doctor of Philosophy
Degree
The University of Tennessee, Knoxville

Christopher Aaron Underwood
May 2013

Copyright © 2013 by Christopher A. Underwood
All rights reserved.

Dedication

To my mother, who first taught me about these mountains; to Sherri, who has come to love them as much as I; and to all who seek to know and protect this ancient range, this dissertation is dedicated to you.

Acknowledgments

I thank my advisor, Sally Horn, for the tremendous support she has offered during the duration of this research. Sally, you are a true professional and a facilitator of opportunities. I could write volumes based on the knowledge I have gleaned from your classes and our many conversations. I also thank my committee members, Henri Grissino-Mayer, Carol Harden, and Kandi Hollenbach for their guidance, expertise, and reviews. I must offer special thanks to Kandi for teaching me the art of charcoal identification, a skill that has added depth to this study.

I thank Greg Metcalf, my constant field companion. Greg, you have a quick scientific mind, and this project is better for your assistance and input. I also thank Michael Carson, Liesel Goethert, Andrea Gregg, Jessica Moehl, Timothy Metcalf, Eric Miller, Oscar Osorio, Crystal Yates, and Madeleine Yates for assistance in the field. I thank Jay Bachmann, Hilary Dixon, Liesel Goethert, Andrea Gregg, James Hartsig, Jessica Moehl, Sharon Klavins, Chad Lane, Greg Metcalf, Timothy Metcalf, Oscar Osorio, Chris Pass, Mary Underwood, Sherri Underwood, Tom Wilding, Crystal Yates, and Madeleine Yates for assistance in the laboratory. James Hartsig also provided a wealth of knowledge on pedology in the Southern Blue Ridge. I thank Matthew Valente for teaching me the pretreatment protocol for charcoal samples submitted to the NSF-University of Arizona Accelerator Mass Spectrometry (AMS) Laboratory for radiocarbon dating. The reduced price on pretreated samples offered by the NSF-University of Arizona AMS Laboratory afforded the purchase of many more radiocarbon dates than I could have otherwise obtained. Matthew Valente and Mathew Boehm also provided laboratory assistance for radiocarbon sample pretreatment. Ann Reed in The University of Tennessee Statistical Consulting Center provided assistance and advice with data analyses. I thank Lisa LaForest for the data, photographs, and input she shared from her companion dendrochronological study.

This study required the development of an extensive reference collection of wood and charcoal of southern Appalachian tree taxa. I thank John Beck, David Buckley, Wayne Clatterbuck, Jennifer Franklin, and Eugene Wofford for helping connect me with sources of wood specimens. I thank Richard Evans of The University of Tennessee Forest Resources Research and Education Center and Adam Taylor of The University of Tennessee Forest Products Center for providing specimens for this collection. Hilary Dixson and Chris Pass assisted Richard Evans and me in the collection of specimens at the Oak Ridge Forest and Arboretum.

The input from multiple scientists, in addition to my committee members, has helped shape this project. I thank David Hammond, Justin Hart, Sharon Klavins, Rob Klein, Charles Lafon, Keith Langdon, Evan Larson, James Speer, and Adam Taylor for their thoughtful discussion and input. Ray Albright and Rob Klein supported an application for the Carlos C. Campbell Memorial Fellowship that provided funding for radiocarbon dates. These acknowledgments would not be complete without mentioning a special academic mentor, the late Dr. John Rehder. Dr. Rehder once told me I am “a good Appalachian.” I hold this as the highest compliment he could bestow upon me. He and I shared a strong love for this region, and he is missed by geographers who study these mountains.

Multiple laboratories and agencies made this research possible. I thank the Laboratory of Paleoenvironmental Research and the Laboratory of Tree-Ring Science in the Department of Geography at The University of Tennessee, the University of Wisconsin-Platteville Department of Biology, especially laboratory manager Gloria Stuckey, the TREES Laboratory at the University of Wisconsin-Platteville, the NSF-University of Arizona AMS Laboratory, the Center for Applied Isotope Studies at the University of Georgia, and Beta Analytic. Radiocarbon

determinations at the NSF-University of Arizona AMS Laboratory were supported in part by NSF grants EAR-0622305 and EAR-0929458. I thank the National Park Service and Great Smoky Mountains National Park for granting permission for this research. Funding was provided by the Joint Fire Science Program under a grant to H. Grissino-Mayer, C. Lafon, and S. Horn; the National Science Foundation under grants BCS-0928508 to S. Horn and C. Underwood and DGE-0538420 to S. Horn, K. Orvis, and L. Champion; and a Carlos C. Campbell Memorial Fellowship awarded to C. Underwood and S. Horn from the Great Smoky Mountains Conservation Association.

Abstract

The Holocene history and ecological role of fire in forested ecosystems in the southern Appalachians is incompletely known. Determining how often and when fire has affected forest communities requires us to think about fire over time scales that extend beyond those of written fire records. This research is the first to specifically address the spatio-temporal patterns of forest fires in southern Appalachian xeric forests using radiocarbon dating of taxonomically identified soil charcoal as the primary proxy. Forty-eight soil cores were recovered in eight sites established for a companion study of dendrochronological evidence of fire history. The eight sites were located in three study areas in the western portion of Great Smoky Mountains National Park. Macroscopic charcoal was isolated from core increments by wet sieving to provide samples for taxonomic identification and radiocarbon dating. Three of eight sites produced soil cores that varied significantly in charcoal mass, suggesting the influence of spatially patchy fires, bioturbation, or overland movement of charcoal. Seven of eight sites exhibited a significant and strong negative correlation between charcoal mass and depth in the soil column; however, charcoal fragments were not preserved in chronological order. A fire chronology (9649 to 107 cal yr BP, based on weighted means of calibrations) was developed from radiocarbon dates on 122 taxonomically identified charcoal fragments. Charcoal from six categories is represented in this study: southern yellow pine, mesic conifer, undifferentiated pine, chestnut, oak, and elm. Southern yellow pine charcoal is most common for all study areas, yet mesic conifer charcoal is also well represented, suggesting that the current period of “mesophication” may not be unique in this ecosystem. Soil charcoal from shallow core increments (0–10 cm) was compared with current forest inventories to determine the robustness of soil charcoal as a proxy for past forest vegetation, the results of which show limited potential for application in the western portion of

Great Smoky Mountains National Park. The results from this study provide the first stand-specific evidence of prehistoric fire *and* forest composition for southern Appalachian yellow pine and mixed hardwood-pine forests.

Table of Contents

Chapter	Page
1. Introduction	1
1.1 Purpose.....	1
1.2 Justification	3
1.3 Research Questions, Objectives, and Hypotheses	6
2. Literature Review	11
2.1 An Enduring Alliance: Fire and Forests in the Southern Appalachians	11
2.2 Reconstructions of Forest History in the Southern Appalachians	17
2.3 Reconstructions of Fire History in the Southern Appalachians.....	21
2.4 The Utility of Soil Charcoal in Reconstructing Forest and Fire History	27
3. Environmental and Cultural Setting.....	33
3.1 Selection of Study Areas.....	33
3.2 Climate.....	36
3.3 Physiography	36
3.4 Geology and Soils	37
3.5 Vegetation.....	39
3.6 Land-Use History.....	43
3.7 Description of Study Areas.....	46
3.7.1 Gold Mine Trail	46
3.7.2 Rabbit Creek Trail	47
3.7.3 Pine Mountain.....	48
4. Methods	49
5. Results	67
6. Discussion	127
7. Conclusions and Suggestions for Further Research	142
7.1 Conclusions.....	142
7.2 Suggestions for Further Research	144
References.....	148
Appendix.....	168
Vita.....	176

List of Tables

Table	Page
1. ANOVA results for variation in total charcoal mass by core for each site	77
2. Least squares mean separation of charcoal mass by core	78
3. Spearman's rank correlation coefficient results for total charcoal mass vs. depth in core	80
4. Least squares mean separation of total charcoal mass by site	81
5. Taxonomic identifications and AMS ¹⁴ C dates on randomly selected soil-charcoal samples from eight sites	83
6. Pearson's product-moment correlation coefficient results for ¹⁴ C dates on randomly selected charcoal fragments vs. depth in core at which the fragment was collected	96
7. Least squares mean separation of radiocarbon dates by site	106
8. Percentage of tree category by study area for the period 9649 to 107 cal yr BP	115
9. Mass (mg) and percent of radiocarbon-dated charcoal by site, study area, and cultural period	117
10. Estimation of past vegetation (9649 to 107 cal yr BP) after correction for differences in representation	125
11. Comparison of results with previous studies of fire history in the southern Appalachians .	136
12. Comparison of results with previous studies of forest history in the southern Appalachians	138

List of Figures

Figure	Page
1. Great Smoky Mountains National Park.....	34
2. Location of study areas in the westernmost portion of Great Smoky Mountains National Park.....	35
3. Mesophication of a xeric forest in the Pine Mountain study area.....	42
4. Thick understory growth related to fire suppression in the Pine Mountain study area.....	44
5. The author (left) and middle-school teacher Oscar Osorio collecting soil cores at Gold Mine Trail B.....	50
6. Schematic of transects and cores for each site.....	52
7. Removing charcoal fragments from the sieved remains of a soil sample.....	53
8. Charcoal from a southern yellow pine (<i>Pinus</i> , diploxylon group), magnified 30x.....	57
9. Charcoal from eastern white pine (<i>Pinus strobus</i> L., haploxylon pine), magnified 30x.....	58
10. Charcoal from red oak sp. (<i>Quercus</i> sect. <i>Erythrobalanus</i>), magnified 30x.....	59
11. Charcoal from white oak sp. (<i>Quercus</i> sect. <i>Leucobalanus</i>), magnified 30x.....	60
12. Charcoal from American chestnut (<i>Castanea dentata</i> (Marsh.) Borkh.), magnified 30x.....	61
13. Charcoal from red maple (<i>Acer rubrum</i> L.), magnified 30x.....	62
14. Total charcoal mass at Gold Mine Trail A, by transect and core.....	68
15. Total charcoal mass at Gold Mine Trail B, by transect and core.....	69
16. Total charcoal mass at Rabbit Creek Trail A, by transect and core.....	70
17. Total charcoal mass at Rabbit Creek Trail B, by transect and core.....	71
18. Total charcoal mass at Rabbit Creek Trail C, by transect and core.....	72
19. Total charcoal mass at Pine Mountain A, by transect and core.....	73
20. Total charcoal mass at Pine Mountain B, by transect and core.....	74
21. Total charcoal mass at Pine Mountain C, by transect and core.....	75
22. Total charcoal mass by study area and site (A–C).....	76
23. Weighted mean calibration age (cal yr BP) of charcoal fragments compared to depth in the soil at which the charcoal fragment was collected at Gold Mine Trail A (top) and B (bottom).....	97
24. Weighted mean calibration age (cal yr BP) of charcoal fragments compared to depth in the soil at which the charcoal fragment was collected at Rabbit Creek Trail A (top), B (middle), and C (bottom).....	98
25. Weighted mean calibration age (cal yr BP) of charcoal fragments compared to depth in the soil at which the charcoal fragment was collected at Pine Mountain A (top), B (middle), and C (bottom).....	99
26. Weighted mean calibration age (cal yr BP) of charcoal fragments compared to depth in the soil at which the charcoal fragment was collected for all sites combined.....	100
27. Fire history for all study areas.....	101
28. Fire history of the Gold Mine Trail study area.....	102
29. Fire history of the Rabbit Creek Trail study area.....	103
30. Fire history of the Pine Mountain study area.....	104
31. Taxonomic categorization of charcoal fragments for the Gold Mine Trail study area.....	107
32. Percent radiocarbon-dated charcoal mass by tree type for the Gold Mine Trail study area.....	108

33. Taxonomic categorization of charcoal fragments for the Rabbit Creek Trail study area	109
34. Percent radiocarbon-dated charcoal mass by tree type for the Rabbit Creek Trail study area	110
35. Taxonomic categorization of charcoal fragments for the Pine Mountain study area.....	111
36. Percent radiocarbon-dated charcoal mass by tree type for the Pine Mountain study area...	112
37. Taxonomic categorization of charcoal fragments for all study areas.....	113
38. Percent radiocarbon-dated charcoal mass by tree type for all study areas	114
39. Modern forest composition at Gold Mine Trail A (top) and B (bottom)	118
40. Modern forest composition at Rabbit Creek Trail A (top), B (middle), and C (bottom)	119
41. Modern forest composition at Pine Mountain A (top), B (middle), and C (bottom)	120
42. Surface charcoal mass by tree type at Gold Mine Trail A (top) and B (bottom)	121
43. Surface charcoal mass by tree type at Rabbit Creek Trail A (top), B (middle) and C bottom.....	122
44. Surface charcoal mass by tree type at Pine Mountain A (top), B (middle) and C bottom...	123

Chapter 1

Introduction

1.1 Purpose

The purpose of this research was to investigate long-term fire and forest history in yellow pine and mixed hardwood-pine forests in the southern Appalachians. My study focused on forests in the western portion of Great Smoky Mountains National Park (GRSM), and consisted of two primary components: (1) the use of dated charcoal fragments to reconstruct fire history, and (2) taxonomic identification of dated charcoal fragments to reconstruct past forest composition. This study used the same study areas (*i.e.*, broad forested tracts that encompass approximately 25 ha) and study sites (*i.e.*, 0.1 ha plots located within the study areas) as L. LaForest in her dendrochronological reconstruction of forest-fire history (LaForest 2012). Sampling within these previously established study areas and sites provided an opportunity to complement and extend the fire histories produced by LaForest.

Many southern Appalachian ecosystems, including yellow pine and mixed hardwood-pine forests (*e.g.*, oak-hickory-pine), developed in concert with periodic, low-intensity fires (Pyne 1982, Van Lear and Waldrop 1989, Delcourt and Delcourt 1998, Williams 1998, Van Lear and Brose 2002). Ayres and Ashe (1905) conducted a survey of the southern Blue Ridge Mountains during 1900–1901 and determined that light surface fires occurred frequently over 80% of the region. Reduced burning, associated with fire-suppression practices of the 20th century, has contributed to increased plant density, especially of fire-intolerant species. The long-term role of fire in the southern Appalachians and its interplay with fire-tolerant and fire-adapted trees (*e.g.*, southern yellow pines) has generated research interest because of

successional changes believed to be associated with fire suppression (Harmon 1982, Delcourt and Delcourt 1997, 1998, Williams 1998, Vose *et al.* 1999, Welch 1999, Waldrop *et al.* 2002, Hart *et al.* 2008), but many questions remain to be answered. When did fire become an important process on the southern Appalachian landscape? When and why did fire become an increasingly important disturbance process on particular portions of this landscape? How did Native-American use of fire affect vegetation patterns? Were fire-adapted yellow pines widespread in the southern Appalachians throughout the Holocene, or did they only achieve their present importance when human occupants increased fire frequencies?

Fire and ecosystem researchers across the United States and around the world increasingly recognize the importance of fire in structuring forest communities (Lorimer 1985, McCarthy *et al.* 1987, Delcourt and Delcourt 1997, McEwan *et al.* 2007, Hart *et al.* 2008). Paradoxically, the practice of active fire suppression that began in the early 20th century now threatens the very forests it was enacted to protect. Species that depend on fire, such as the Appalachian-endemic Table Mountain pine (*Pinus pungens* Lamb.), may largely disappear over the next few decades in the continued absence of fire (Waldrop *et al.* 2002, DeWeese 2007).

Although the importance of fire in maintaining healthy forests is better understood today than in the past, fire as an ecosystem process in mixed forests of the Appalachian Highland region is not well understood (Hart *et al.* 2008). Scales (2011) suggested that the scarcity of Appalachian fire studies may be attributed in part to the rugged terrain of and difficult access to these mountains. Regardless of the reasons, research is still needed to determine the long-term ecological role played by fire in these forests. This dissertation explores fire and forest history in the southern Appalachians as revealed by macroscopic charcoal in forest soils in GRSM. Soil-charcoal analysis can provide coarse-resolution fire and forest histories in areas where

dendrochronological and sedimentary evidence is sparse, insufficient, or unavailable (Horn *et al.* 2000, Sanford and Horn 2000, Hart *et al.* 2008).

Determining how often and when fire has affected forest communities requires us to think about fire over time scales that extend beyond the scales of written fire records. Through the quantification, identification, and dating of soil charcoal, I have produced a record of long-term, site-specific forest composition and fire history that complements and extends the detailed, but temporally limited, dendrochronological records of fire that have been produced in the region (Harmon 1980, 1982; Armbrister 2002; Feathers 2010; LaForest 2012). Understanding how both historic and prehistoric fires have affected the yellow pine and mixed hardwood-pine forests of the southern Appalachians requires a deeper time component than can be obtained via tree-ring analysis alone. Soil-charcoal analysis can provide the basis for such a study by documenting paleofires and past composition of southern Appalachian forests, providing important context for understanding the long-term interplay between fire and these southern Appalachian forest communities.

1.2 Justification

The long-term ecological role of fire in the southern Appalachians and its interplay with fire-associated tree species have generated research interest, but many questions remain. Information regarding the nature and frequency of wildfires in southern Appalachian forests before and after European settlement is important to our understanding of contemporary forests (Fesenmyer and Christensen 2010). Because fire is such an important forest disturbance in much of the southern Appalachians, knowledge of fire is central to our interpretation of the composition and structure of pre-European settlement forests, and therefore, to the formation of

management targets (Nowacki and Abrams 2008, Fesenmyer and Christensen 2010). The information provided by this study will help address this issue. Only a few studies have used taxonomic identification of radiocarbon-dated soil charcoal (*e.g.*, Carcaillet 1998, 2001; Talon 2010). Because this type of research can be performed in many areas and in many soil types, the techniques used in this research may be applicable to other areas in the southern Appalachians and beyond. This could potentially transform and make possible paleoenvironmental reconstructions of spatial and temporal forest composition and fire history where studies of fire-scarred trees or charcoal and pollen in wetland sediments are not feasible.

Wildfire is an important disturbance mechanism that contributes to the determination of forest composition, diversity, and succession (Abrams 1992, Delcourt and Delcourt 1997, McEwan *et al.* 2007, Scales 2011). In the southern Appalachians, yellow pine and mixed hardwood-pine forests flourish under the influence of a high-frequency, low-intensity fire regime that promotes overall ecosystem health and helps control understory species and the encroachment of fire-intolerant species (Delcourt and Delcourt 1998, Williams 1998, Scales 2011). Fire-adapted pine and oak (*Quercus* spp.) communities currently cover about 30% of GRSM, but are threatened by the anthropogenic alteration of fire regimes. Implemented in the 20th century, fire suppression has contributed to an increase in the density of woody plants in many forest types in GRSM. The result is unhealthy and weakened forests that are more susceptible to destructive insects such as the southern pine beetle (*Dendroctonus frontalis* Zimm.) and the invasive hemlock wooly adelgid (*Adelges tsugae* Annand). Forests once dominated by fire-tolerant pines, such as Table Mountain pine, shortleaf pine (*Pinus echinata* Mill.), pitch pine (*P. rigida* Mill.), and Virginia pine (*P. virginiana* Mill.), are now dominated by less fire-tolerant species such as red maple (*Acer rubrum* L.) and eastern white pine (*P. strobus*

L.) (DeWeese 2007, LaForest 2012). In GRSM, the overall extent of open yellow pine and mixed hardwood-pine forests has declined over recent decades, changing not only the distribution of plant species, but also resulting in a widespread loss of habitat diversity (LaForest 2012, R. Klein, pers. communication).

Great Smoky Mountains National Park is the most visited national park in the United States. Many visitors come to enjoy the tremendous biological diversity of GRSM that contributed to its designation as a UNESCO (United Nations Educational, Scientific, and Cultural Organization) World Heritage Site. The park harbors over 3500 plant species and almost as many tree species as in all of Europe (UNEP 2000). Fire suppression could ultimately decrease biodiversity within GRSM. In addition to pine and oak species, GRSM is home to at least 147 other species of vascular plants that appear to require fire or are enhanced by fire (Discover Life in America, n.d.). The park provides habitat for 40 species of reptiles that seem favored by fire because they prefer or require forest canopy openings (Discover Life in America, n.d.). Black bears (*Ursus americanus* Pallas) also may be favored by fire, and the use of prescribed fire may be an effective tool for enhancing black bear habitat (Weaver 2000). In the dry, lower elevations of GRSM, decades of fire suppression have led to the development of a forest structure that is less desirable for mammal and bird species, such as the red-cockaded woodpecker (*Picoides borealis* Vieill.) (Dimmick *et al.* 1980), than the open forest structure of the 19th century. Dozens of species in these groups are state-listed regional endemics or federally listed threatened and endangered species (K. Langdon, pers. communication).

As the density of trees and woody shrubs has increased because of fire suppression, so have fuel loads. With heavier fuel loads, forest fires now have the potential to burn with much greater intensity than in the past. Decades of fire suppression have actually increased the

likelihood of catastrophic fires. Low-intensity fires that once burned only the forest floor, where they would scar but not kill fire-tolerant trees, may now have the capability to reach the forest canopy, kill mature trees, and incinerate the rootstocks and seeds of the forest floor. Two of the largest and most severe wildfires in GRSM history occurred during the past decade, largely as a result of the unnatural accumulation of fuels. Thus, fire management is becoming increasingly important, particularly in the expanding wildland-urban interface along the park boundary. The use of prescribed burning to achieve forest health in GRSM has grown steadily over the last decade, but land managers at GRSM and throughout the southern Appalachians have to rely on inadequate knowledge of the natural role of fire in the ecosystems they are charged to protect. The use of fire as a forest management tool is a complex procedure, and expected results are not always achieved (Elliott *et al.* 1999). More information is needed to fully understand forest response to the increased use of prescribed fire for fuel and forest management (Fesenmyer and Christensen 2010). This research will help provide a long-term context for the development of policies to manage and create forests that mimic the conditions of pre-European-settlement southern Appalachian forests (Engstrom *et al.* 1999, Vose *et al.* 1999, Fesenmyer and Christensen 2010).

1.3 Research Questions, Objectives, and Hypotheses

Seven major research questions are addressed in this dissertation.

1. Does the distribution of macroscopic charcoal vary among replicate cores in a study site?
2. Does the distribution of macroscopic charcoal vary by depth in a soil core?
3. Does macroscopic charcoal mass differ among sites?

4. Does the age of charcoal fragments vary by depth in the soil column?
5. Does the mean age of charcoal fragments vary by site?
6. Were southern yellow pine and mixed hardwood-pine forests maintained by lightning-ignited and Native American-set fires before the arrival of Euro-American settlers? Were mesophytic taxa also present during this period?
7. Is there a relationship between species composition of macroscopic soil charcoal in surface samples and current forest community composition?

To obtain answers to these research questions, the following objectives and hypotheses were applied:

1. **obtain multiple soil cores from multiple sites and quantify, date, and identify macroscopic soil charcoal in all depth increments of the cores**

H₀: Macroscopic charcoal will not be present in most (> 90%) soil core increments from all depth levels, thus prohibiting soil-charcoal investigation of long-term fire and forest history at these sites.

H_A: Macroscopic charcoal will be present in most (> 90%) soil core increments from all depth levels, thus allowing further soil-charcoal investigation of long-term fire and forest history at these sites.

2. **using analysis of variance and Fisher's least significant difference test, compare intra-site patterns of macroscopic soil-charcoal abundance**

H₀: Macroscopic charcoal abundance will not differ significantly based on spatial proximity of soil cores.

H_A : Soil cores located in close proximity to one another in the same study site will exhibit greater similarity in macroscopic charcoal abundance than cores separated by greater distances.

3. **using Spearman's rank correlation coefficient, compare macroscopic charcoal abundance versus depth in cores for individual study sites and for a combination of all sites**

H_0 : Macroscopic charcoal abundance will not differ significantly based on core depth.

H_A : Macroscopic charcoal abundance will be greatest in shallow core increments and least in deep core increments.

4. **using analysis of variance and Fisher's least significant difference test, compare macroscopic charcoal abundance among study sites**

H_0 : Macroscopic charcoal abundance will not differ significantly from site to site.

H_A : Macroscopic charcoal abundance will differ significantly from site to site, presumably in response to taphonomic factors that can break apart charcoal, and to variations in fire frequency and behavior.

5. **using Pearson's product moment correlation, compare charcoal age versus depth in cores for individual study sites and for a combination of all sites**

H_0 : Charcoal dates will not differ significantly among different core depths.

H_A : Charcoal dates will be youngest in shallow portions of a core and oldest in deeper portions of a core.

6. **using analysis of variance and Fisher's least significant difference test, compare mean age of charcoal among sites**

H_0 : Mean charcoal age will not differ significantly from site to site.

H_A : Mean charcoal age will differ significantly from site to site, indicating a temporal mosaic of fire occurrence.

7. **using the calibrated age range ($\pm 2 \sigma$, 95% confidence interval) of radiocarbon-dated charcoal fragments, analyze the periodicity of fires over the Holocene**

H_0 : Periodicity of fire will not vary over the Holocene.

H_A : Multiple periods of fire will be apparent, driven by natural and anthropogenic ignitions.

8. **determine whether forest communities composed of fire-dependent species were maintained by lightning-ignited and Native American fires**

H_0 : Yellow pine and fire-associated hardwoods, such as oak and chestnut, will not be well represented in macroscopic charcoal samples that predate Euro-American settlement.

H_A : Yellow pine and fire-associated hardwoods, such as oak and chestnut, will be well represented in macroscopic charcoal samples that predate Euro-American settlement.

9. **calculate the robustness of macroscopic soil charcoal as a proxy for forest community composition, based on a modified *R*-value model (Davis 1963), by comparing macroscopic charcoal assemblages from the 0–10 cm core increments with current forest inventories of mature trees**

H₀: No relationship will be found between species composition of surface-sample (from the 0–10 cm core increments) macroscopic charcoal and current forest community composition.

H_A: The taxonomic composition of surface-sample macroscopic charcoal assemblages will reflect current forest composition as documented by vegetation surveys.

Chapter 2

Literature Review

2.1 An Enduring Alliance: Fire and Forests in the Southern Appalachians

The rugged terrain of the ancient mountains of the southern Appalachians is a major factor in the distribution and development of forest communities (Copenheaver *et al.* 2006, Scales 2011), and variations in relief can have significant effects on community composition and fire behavior (Wimberley and Reilly 2007, Flatley *et al.* 2011, Scales 2011). Researchers have established that the pine trees that dominate ridge tops and many south- and west-facing aspects of the southern Appalachians are adapted to frequent fires (Whittaker 1956, Barden and Woods 1976, Harrod and White 1999, Fesenmyer and Christensen 2010). However, the relationship between fire and mixed hardwood-pine forests is less apparent (Runkle 1985, van Lear and Waldrop 1989, Delcourt and Delcourt 1997). Early written records often describe these forests as open with grassy understories and numerous chestnut (*Castanea dentata* (Marsh.) Borkh.), hickory (*Carya* spp.), and oak trees. This description suggests forests that experienced frequent, low-intensity fires (Delcourt and Delcourt 1997, Brose *et al.* 2001, Fesenmyer and Christensen 2010, Lafon 2010). Stand-replacement fires may have occurred, especially during periods of drought or after major canopy disturbances, such as ice storms or strong winds, that increased fuel levels (Abrams 1992, Brown 2002, Fesenmyer and Christensen 2010).

Sporadic, low-intensity, lightning-ignited fires likely helped promote the presence and survival of fire-associated species in the pre-Euro-American southern Appalachians (Barden and Woods 1973, 1976; Harmon 1982; Van Lear and Waldrop 1989; Williams 1998; Van Lear and Brose 2002). Research once suggested that lightning-ignited fires in the Appalachians were

limited to dry, rocky ridges and only occasionally moved downslope (Williams 1998). We now know that fires in the southern Appalachians are not limited to xeric areas, but can in some cases burn across multiple ridges and vegetation types, and, in instances of drought or intense fires, across streams and other natural firebreaks (Lafon 2010, Scales 2011). Harmon (1982) suggested that fire ignitions from lightning strikes are relatively infrequent because of high annual precipitation in the southern Appalachians. Precipitation events, however, do not always stop or even slow a lightning-ignited fire. The fire may persist in a lightning-struck tree or snag until surrounding fuels have dried sufficiently for the fire to spread (Cohen *et al.* 2007).

Through the Holocene, except for the period following Euro-American contact (Denevan 1992), Native American populations generally increased in the eastern United States. Native-American use of fire as a management tool also increased during this time (Pyne 1983, Pierce 2000). Fires were intentionally set in particular portions of the landscape and excluded from others and may have served as an important disturbance mechanism (Guffey 1977, Chapman *et al.* 1982, Harmon 1982, DeVivo 1991, Delcourt and Delcourt 1997, Abrams and Nowacki 2008). Delcourt and Delcourt (1997) reasoned that Late Archaic (5000–3000 yr BP), Woodland (3000–950 yr BP), and Mississippian (950–350 yr BP) cultures burned two distinct areas of the landscape: (1) alluvial bottoms and coves where crops were cultivated, and (2) upper slopes and ridge tops where hunting and gathering activities occurred, where fire would favor berries and other gatherable foods (Cronan 1983, Delcourt and Delcourt 1997, Scarry 2003) and create grassy openings that would attract game animals such as white-tailed deer (*Odocoileus virginianus* Zimm.) and elk (*Cervus canadensis* Linn.) (Delcourt and Delcourt 1997). Native-American burning on upper slopes and ridge tops also would have favored yellow pines at these

locations. Native Americans were less likely to burn mesic areas, aside from alluvial bottoms and north- and east-facing lower slopes (Delcourt 1987, Delcourt and Delcourt 1997).

The extent of intentional burning by Native Americans has been debated (Russell 1983, Vale 2002). Raup (1937) argued that climate change was a more plausible explanation for changes in vegetation than Native-American burning. Forman and Russell (1983) stated that “regular and widespread Indian burning [is] an unlikely hypothesis that regretfully has been accepted in the popular literature and consciousness.” However, Deneven (1992), based on his observations of contemporary indigenous burning in Central and South America, as well as evidence of the extent of prehistoric fires in North America (*e.g.*, Lewis 1982), argued that fire was broadly employed by Native Americans, and that widespread prehistoric burning significantly affected the composition and structure of forests. Eastern forests, however, likely experienced a period of decreased exposure to fire after Euro-American contact with Native Americans, as indigenous populations were decimated, primarily by Old-World diseases (Denevan 1992).

The act of intentionally burning the landscape was continued by European settlers (Barden and Woods 1976, Shields 1981, Pyne *et al.* 1996). The first Euro-American settlement in present-day Great Smoky Mountains National Park (GRSM) was established in 1818 in Cades Cove. During the early- to mid-19th century, fires were most common in the lower elevations of the mountains where the majority of settlements were located (Lambert 1958). Eastern old-growth forests, then heavily populated with large, valuable chestnut trees, proved highly profitable for the Euro-American timber industry (Gravatt and Gill 1930). Logging practices greatly altered the forest dynamics of these areas. Southern Appalachian forests became even more susceptible to fire because of increased fuel in the form of slash from timber operations

(Brose *et al.* 2001, Scales 2011). Fires were also common along railroads, as steam locomotives hauling timber out of low-elevation forests constantly ejected cinders from their smokestacks (Pierce 2000). Intentional and accidental burning by Euro-American inhabitants resulted in a fire regime of frequent, low-intensity fires over broad areas that allowed the persistence and expansion of yellow pine and mixed hardwood-pine forests in the southern Appalachians (Harmon 1982, Williams 1998).

With the turn of the 20th century, changes in land-use practices further altered southern Appalachian forests. Logging practices declined as accessible old-growth forests were fully exploited for their timber. The Weeks Act of 1911 ushered in a new paradigm of fire suppression, and by the 1930s, fire observation towers dotted the landscape and governmental land management agencies endeavored to exclude fire from forests (Brose *et al.* 2001). The official establishment of GRSM in 1934 firmly cemented the new policy of active fire suppression in this region. These highly effective fire-suppression programs slowed or reversed pine forest expansion (Williams 1998). Today, pine-dominated forests are a widespread, yet patchy, component of southern Appalachian ecosystems (Williams 1998). Five species of pines occur in the region (for descriptions, see Section 3.4), with distributions controlled by elevation, soil type, slope aspect, and other site characteristics (Williams 1998). The yellow pines native to the southern Appalachians favor or require open, highly illuminated, scarified mineral soil seedbeds for seed germination and seedling establishment (Bramble and Goddard 1942, Barden and Woods 1976, Ledig and Little 1979, Williams and Johnson 1992). Such conditions may occur after low-intensity fires. In the absence of fire, increased leaf litter forms a barrier to pine seedling radicles (embryonic roots), causing eventual death by desiccation (Williams *et al.* 1990).

The southern pine beetle is also a major contributor to yellow pine death in the southern Appalachians, especially for trees that are already stressed by drought, injury, or competition for resources (Kloeppel *et al.* 2003). Southern pine beetle infestations are often involved in positive-feedback loops with fire (Gibson and Negron 2009). Fire-scarred trees are more susceptible to beetle infestation. Beetle infestations lead to more dead trees and more fuel for fires; thus, fire-scarred trees, in the presence of southern pine beetles, can lead to even more fire-scarred trees (Gibson and Negron 2009). Nonetheless, frequent low-intensity fires thin densely populated stands and effectively remove unhealthy trees that are most susceptible to beetle attacks (Hain *et al.* 2011).

Oaks, too, are becoming less important in eastern United States forests, where a lack of oak advanced regeneration has been reported (Lorimer 1984, Abrams and Downs 1990, McCarthy and Bailey 1996, Abrams 2003, Hart *et al.* 2008). Oak stands in eastern forests developed in response to a complex mix of anthropogenic and ecological factors (McWilliams *et al.* 2002) and were likely maintained by frequent, low-intensity fires (Crow 1988, Abrams 1992, Brose *et al.* 2001, Lorimer 2001, Hart *et al.* 2008). Oaks are characterized by multiple anatomical and physiological adaptations (for descriptions of these adaptations, see Section 3.4) that allow them to survive regimes of frequent fire (Van Lear and Brose 2002). Unlike southern yellow pines, oaks do not necessarily thrive under the influence of fire (Blankenship and Arthur 2006), but fire can in some situations promote oak regeneration (Thor and Nichols 1974). An understory dominated by shade- and fire-intolerant species often inhibits the maturation of oak seedlings (Lorimer 1993, Lorimer *et al.* 1994) that are often abundant in early growth stages but are quickly outcompeted for light and resources (Hart *et al.* 2008). Frequent, low-intensity fires

remove fire-intolerant species from the understory and reduce competition for the more fire-tolerant oak species.

In the absence of frequent, low-intensity fires, oaks are being succeeded by shade-tolerant, mesophytic species such as sugar maple (*Acer saccharum* Marsh.), red maple, and black gum (*Nyssa sylvatica* Marsh.) (Abrams 1992, Lorimer *et al.* 1994, Hart *et al.* 2008, Nowacki and Abrams 2008). This trend is a relatively recent phenomenon that is likely linked to active fire suppression (Little 1974, Van Lear and Johnson 1983, Lorimer 1993). Foresters were encouraged for most of the 20th century to avoid the use of fire as a management tool in hardwood forests, because fires are known to lead to heartrot in hardwoods (Nelson *et al.* 1933, Wendel and Smith 1986). As a result, fire research in hardwoods has not been viewed with the same importance as fire research in pines (Van Lear and Brose 2002).

The role of fire in pine and mixed hardwood-pine forests is receiving increased attention because of successional changes believed to be associated with 20th-century fire suppression (Lorimer 1985, McCarthy *et al.* 1987, Crow 1988, Goebel and Hix 1997, Lafon *et al.* 2005, DeWeese 2007, Lafon and Grissino-Mayer 2007, McEwan *et al.* 2007, Aldrich *et al.* 2009, Aldrich 2011). The proliferation of fire-intolerant species such as red maple, sugar maple, and mountain laurel (*Kalmia latifolia* L.) in southern Appalachian forests has inhibited the regeneration of fire-tolerant pines and oaks in southern yellow pine and mixed hardwood-pine forests, resulting in the more spatially restricted distributions seen today. Ecologists, including Abrams (1992) and Lorimer (2001), have stressed the importance of fire in suppressing the establishment of fire-intolerant species. However, the role of fire as a natural disturbance is still uncertain, and many aspects of the effects of fire on southern Appalachian forests remain unexplained (Hart 2007). More information is needed to properly conserve these unique

communities before some are pushed beyond a threshold of viability in the southern Appalachians.

2.2 Reconstructions of Forest History in the Southern Appalachians

Pollen grains and charcoal fragments preserved in undisturbed sediment in lakes, ponds, and bogs, and charcoal preserved in soils hold the potential to unveil thousands of years of vegetation history in the southern Appalachians. The spatial and temporal assemblages of plant species documented by pollen and charcoal also provide information about past climate and disturbances.

Vegetation change during the past 25,000 years in present-day mixed-mesophytic forests on the eastern Highland Rim in Tennessee was documented by pollen analysis of sediment cores from Anderson and Mingo Ponds by Delcourt (1979). The Anderson Pond sediment core extends to 25,000 yr BP (uncalibrated ^{14}C years before A.D. 1950). During the Farmdalian Interstadial (25,000 yr BP) northern yellow pines, spruce (*Picea* spp.), and deciduous trees lived around Anderson Pond, suggesting a cool, moist climate (Delcourt 1979). During the late Wisconsin glacial maximum (19,000–16,300 yr BP), jack pine (*Pinus banksiana* Lamb.), spruce, and fir (*Abies* spp.) dominated the forests around Anderson Pond. Deciduous species such as ash (*Fraxinus* spp.), American hornbeam (*Carpinus caroliniana* Walt.), hickory, birch (*Betula* spp.), butternut (*Juglans cinerea* L.), willow (*Salix* spp.), and elm (*Ulmus* spp.) began to replace these conifers 16,300 yr BP, followed by an increase in beech (*Fagus* spp.) and sugar maple (Delcourt 1979). During the early Holocene (12,500–8000 yr BP), mixed-mesophytic forest taxa increased in importance, but a warmer and drier climate from 8000–5000 yr BP led to increased oak, ash, and hickory (Delcourt 1979). Mingo Pond provided a pollen record estimated to extend to about

14,000 yr BP. Mixed-mesophytic forest taxa dominated this record during the late glacial and early Holocene, while oak and sweetgum (*Liquidambar styraciflua* L.) pollen dominated the mid- and late-Holocene record (Delcourt 1979).

Delcourt *et al.* (1986) obtained pollen data from three sites in the Little Tennessee River Valley in east Tennessee: Icehouse Bottom, Black Pond, and Tuskegee Pond. Native American occupation of this area was most intense during the late Holocene (Delcourt *et al.* 1986). Pollen data from the sediments at these sites were interpreted to reflect the composition of vegetation that was local (within a 20 m radius of the site) and extralocal (within a 200 m radius of the site), with a lesser regional component, following the model of Jacobson and Bradshaw (1981).

The pollen data from Icehouse Bottom were obtained from backswamp deposits underlying the Icehouse Bottom archaeological excavation, and correspond to the early Holocene (about 9400 yr BP). The pollen assemblage indicated that at this time, the arboreal vegetation of the lower Little Tennessee River Valley consisted of closed, mixed hardwood forest (Delcourt *et al.* 1986). Oak-hickory forest dominated the uplands; eastern hemlock (*Tsuga canadensis* (L.) Carr.), beech, and white basswood (*Tilia heterophylla* Vent.) occupied mesic sites; and birch, ash, and eastern cottonwood (*Populus deltoides* Bartr.) occupied valley bottoms. Pines were of minor importance and likely grew on xeric, rocky areas and upland knolls (Delcourt *et al.* 1986).

Pollen records from Black Pond (3000 yr BP to Present) and Tuskegee Pond (1500 yr BP to Present) were developed by Delcourt *et al.* (1986). At Black Pond, the high arboreal pollen/non-arboreal pollen ratio from 3000 to ca. 400 yr BP indicated minimal forest clearing (Delcourt *et al.* 1986). In the late Holocene, oaks and pines dominated the upland forests near Black Pond, with subdominants of hickory and chestnut (Delcourt *et al.* 1986). The Tuskegee Pond record, however, showed high percentages of ragweed (*Ambrosia* spp.) pollen as early as

1500 yr BP, indicating forest clearing. The establishment of Fort Loudoun, a British colonial fort, appears in the pollen record at Tuskegee Pond in the form of a sudden decrease in pollen of oak and hickory, two taxa favored for building by Euro-Americans (Delcourt *et al.* 1986). Finally, the 20th-century decline of chestnut in southern Appalachian forests is reflected by a decline in chestnut pollen in near-surface sediments at both Black and Tuskegee Ponds (Delcourt *et al.* 1986).

Delcourt *et al.* (1986) also studied charcoal (ca. 9500 yr BP to Present) in archaeological cultural deposits from a lower Little Tennessee River Valley archaeological excavation. The wood charcoal they recovered was from the carbonized remains of hearth fires and dwelling sites and indicates the materials selected for human use from the surrounding forests. The charcoal tallied reflected the species that were most appropriate for the task at hand and most readily accessible to humans, but was not necessarily a true representation of forest composition (Delcourt *et al.* 1986). The charcoal record demonstrated that species of closed upland forests (*e.g.*, oak, hickory, chestnut) and bottomland forests (*e.g.*, ash, maple, elm) were dominant in the Early (10,000–8000 yr BP) and Middle Archaic (8000–5000 yr BP) periods (Delcourt *et al.* 1986). However, by the Late Archaic period (5000–3000 yr BP), disturbance-favored species, such as pines, had increased to comprise 25% of the wood charcoal (Delcourt *et al.* 1986). The Woodland period (3000–950 yr BP) was a time of increased settlement in the lower Little Tennessee River Valley. The increase in anthropogenic disturbance in the valley during this period coincided with an increase in pine charcoal and a decrease in oak, hickory, and walnut charcoal (Delcourt *et al.* 1986).

Delcourt and Delcourt (1997) sampled a 40 cm vertical column of peat from Horse Cove Bog in the southern Blue Ridge Mountains of North Carolina for pollen analysis. The pollen

record demonstrated the dominance of oak (approximately 30% of all pollen) and chestnut (approximately 30% of all pollen) for the past 4000 years, with chestnut declining (to approximately 10% of all pollen) during the past 100 years. Pine pollen increased in the past 100 years and comprised approximately 15% of all pollen (Delcourt and Delcourt 1997).

Pollen assemblages from Cliff Palace Pond, Kentucky, a perched woodland hollow on the Western Escarpment of the northern Cumberland Plateau, showed changes in forest composition over the last ca. 9500 years of the Holocene (Delcourt *et al.* 1998). The Early-Holocene climate in the southern Appalachians consisted of cold winters and warm summers. This climate supported spruce and northern white cedar (*Thuja occidentalis* L.) forests around Cliff Palace Pond. The climate transitioned to warm temperate around 7300 yr BP, allowing for succession to mixed-mesophytic forests. The mixed-mesophytic forest contained a significant number of eastern hemlock trees that were decimated by an insect outbreak around 4800 yr BP. Eastern red cedar (*Juniperus virginiana* L.) became locally important as it filled gaps created by the loss of eastern hemlock. After 3000 yr BP, mixed oak-chestnut and pine forests became dominant as anthropogenic burning increased (Delcourt *et al.* 1998).

During the period of Euro-American settlement of the eastern United States (ca. early-1600s to the late 1800s), the use of witness trees was a common land-surveying technique (Abrams 2002). The record of witness trees can be an important source of information about species composition and distribution during European settlement. White oak (*Quercus alba* L.), chestnut oak (*Q. montana* Willd.), black oak (*Q. velutina* Lam.), southern red oak (*Q. falcata* Michx.), northern red oak (*Q. rubra* L.), chestnut, and hickory were most often recorded as witness trees in the eastern United States (Abrams 2002). White oak was typically the most common witness tree, likely because of its concentration on valley floor sites where most farms

were located and, therefore, where most metes and bounds surveys were conducted. In contrast, trees such as chestnut, chestnut oak, and red oak appear less frequently in witness-tree records because of their dominance on ridges and side slopes, where considerably fewer farms and homes were located (Abrams 2002). Because of the biased nature of witness tree selection, these records should be interpreted with extreme caution when studying vegetation history.

2.3 Reconstructions of Fire History in the Southern Appalachians

A widely used method for studying fire history is the analysis of fire-scarred wood samples. Fire histories from tree rings can be developed for forests where trees produce annual rings and are scarred by non-lethal fires (Grissino-Mayer and Swetnam 2000). Using techniques of dendrochronology, researchers can analyze these fire-scarred samples to create detailed reconstructions of the spatial and temporal extent of past fires, including the exact years that fires occurred (Stokes and Smiley 1968, Harmon 1980, Fritts 2001, Armbrister 2002). The dating of fire scars has provided evidence of periodic fire occurrence in southern Appalachian forests for the past several hundred years (Harmon 1980, Armbrister 2002, Feathers 2010, LaForest 2012). Dendroecological reconstructions of fire history in southern Appalachian mixed hardwood-pine forests span the last 150–400 years and indicate fire-return intervals of approximately 5 to 15 years (Lafon and Grissino-Mayer 2007) prior to the early 20th century, when active fire suppression began (*e.g.*, Harmon 1982, Feathers 2010, LaForest 2012).

A fire-return interval for the period 1855–1940 was determined from an early, limited study of fire-scarred samples of yellow pine collected in the western portion of GRSM (Harmon 1980, 1982). Warm, xeric southern-aspect slopes were targeted as study sites because they often support greater numbers of yellow pines. Harmon’s collection sites are in close proximity to the

sites used in this dissertation. His oldest fire date was ca. 1856; however, the size and temporal depth of the data set were constrained by past research restrictions. During the time of his study, GRSM policy excluded the use of chainsaws for research purposes, so Harmon used a handsaw for sample collection. This limited the number of samples he could obtain and may have prevented him from obtaining the oldest fire scars, located close to the pith of standing trees. The mean fire-return interval from 1855–1940, based on his analysis of 43 yellow pine cross sections, was 12.7 years on southern-aspect slopes. Fire was almost non-existent on the landscape from 1910–1940.

Armbrister (2002) investigated the fire history of Table Mountain pine stands in the north-central portion of GRSM. Armbrister's data set was also constrained by sample-collection restrictions, as well as by a lack of quality samples. Using 17 cross-sections from fire-scarred pine trees, the fire-return interval was determined to be 6.8 years prior to the 1930s. No fires occurred during the period of active fire suppression after the 1930s. Age-structure analysis of the Table Mountain pine trees indicated that the current cohort was established in the mid-1930s. No evidence of regeneration was found after that period.

Brose and Waldrop (2006) conducted a study of canopy-release events in four upland yellow pine forests in Tennessee (GRSM), South Carolina, and Georgia. Cross sections of hardwood trees were collected and examined for fire scars. At each site, two to six fires were detected between 1900 and 1949. The authors interpreted their findings to indicate decreased fire frequency after 1950.

Feathers (2010) developed fire histories from yellow pines at two sites located near Cades Cove in the western portion of GRSM. The fire return interval from 1720–1818 was 5 years, compared with 2.5 years from 1819–1934. The mean fire-return interval for both sites

across the entire chronology was 3.2 years. As with most other fire history research in southern Appalachian forests, fire was found to be almost non-existent throughout much of the 20th century.

LaForest (2012) constructed a 300-year fire history in the western portion of GRSM using cross sections of yellow pine (LaForest 2012). As with Harmon (1980), LaForest targeted warmer, more xeric sites because these areas have traditionally supported greater numbers of yellow pines. LaForest was granted permission to use a chainsaw to collect cross sections from trees, snags, stumps, and logs in GRSM. The relaxation of sampling restrictions allowed her to collect many more yellow pine cross sections ($n = 133$) than either Harmon (1980; $n = 43$) or Armbrister (2002; $n = 17$). Analysis of crossdated fire-scarred tree-ring samples revealed patterns and relationships of fire, climate, and human activity. Climate oscillations in the Atlantic and Pacific Oceans affected wildfire frequency. Wildfires occurred frequently before the establishment of GRSM in 1934. During the period 1700–1834, fires occurred once every 6 to 12 years. From 1834 to 1934, fires occurred once every 1.7 to 2.3 years, but the fire-return interval increased to 6.5 to 8.8 years after the establishment of GRSM in 1934. Fire suppression practices have encouraged the establishment and proliferation of fire-intolerant species such as red maple and eastern white pine (LaForest 2012).

While tree-ring evidence provides highly detailed records of past fire in the southern Appalachians, such records can only trace fire history as far back in time as the number of tree rings in living and preserved dead wood allows. In humid areas such as the southeastern United States, where dead wood does not persist very long, fire records from tree rings are typically no more than a few centuries in length (Fesenmyer and Christensen 2010). To document still earlier fires requires a different technique, such as the paleoecological analysis and dating of charcoal in

sediments and soils. Charcoal records developed from sediment cores from lakes and wetlands can provide much longer temporal coverage than tree-ring records, at potentially high resolution in sites characterized by slow sedimentation (Delcourt *et al.* 1998). Analyses of sedimentary pollen and charcoal demonstrate that fires occurred frequently during the last 3000 to 4000 years, and were likely important for maintaining the dominance of chestnut, oak, and pine species in the southern Appalachians (Delcourt and Delcourt 1998).

At Horse Cove Pond, North Carolina, microscopic charcoal influx began to increase during the Early Woodland period, with a peak ca. 600 years ago in the Mississippian period, coinciding with increased Native American population (Delcourt and Delcourt 1997). Charcoal influx then declined until AD 1830. The decline in charcoal is most likely associated with a decline in Native American populations during this period. After 1830, charcoal influx increased, peaking at around AD 1900, along with Euro-American population. Charcoal influx tapered off slightly after 1900, but remained relatively high, even after the introduction of active fire suppression. Delcourt and Delcourt (1997) interpreted this to be a consequence of arson, accidental, and lightning-set fires, as well as an expanded source area for microscopic charcoal once the region was opened by human disturbances. These findings, however, do not correspond with those of more recent dendrochronological records (*e.g.*, Feathers 2010, LaForest 2012) that show a significant decrease of fires during the 20th century.

The charcoal record from Cliff Palace Pond, Kentucky, indicated a charcoal spike around 4800 yr BP that coincided with a decline in pollen percentages from eastern hemlock (6% to 0%) (Delcourt *et al.* 1998). Davis (1981) interpreted the decline in eastern hemlock pollen throughout the eastern U.S. as a response to an infestation by mournful thorn (*Lambdina fiscellaria* ssp. *fiscellaria* Guen.), a defoliating moth known to target conifers. Oswald and Foster (2011),

however, attributed the decline to dry conditions. Regardless of the reason for mortality, afflicted trees provided fuel for wildfires. The charcoal record also indicated that Late Archaic and Woodland peoples cleared forested areas on the northern Cumberland Plateau to plant agricultural crops (Delcourt *et al.* 1998). Delcourt *et al.* (1998) credited anthropogenic fires during the Late Holocene with increasing populations of fire-associated oaks, chestnut, and pines in upland forests of the northern Cumberland Plateau.

Research using macroscopic charcoal can provide a more localized record of fire history, because macroscopic charcoal is not readily transported from its point of origin. Hass (2008) constructed two local fire histories based on macroscopic sedimentary charcoal. One record is from Gum Swamp in Cades Cove, GRSM, and the other from Black Pond in the Little Tennessee River Valley. The sediment profile from Gum Swamp extended to ca. 425 yr BP. At the conclusion of Hass's thesis, radiocarbon dates from Black Pond were pending, but the sediment profile was expected to extend to ca. 3000 yr BP based on the previous study by Delcourt *et al.* (1986) at Black Pond. Charcoal influx increased at Gum Swamp from the early 1800s through the 1950s, in concert with Euro-American settlement and land clearing. Charcoal influx decreased after 1950 because of fire suppression in GRSM. The fire history from Black Pond indicated high charcoal concentrations during times of indigenous activity, based on comparisons with Delcourt *et al.* (1986). Relatively moderate charcoal influx coincided with Euro-American settlement, followed by a decrease during the 20th century, corresponding with fire suppression.

Most areas of the southern Appalachians lack ponds, lakes, or other wetlands that can provide stratigraphic charcoal records. In such areas, radiocarbon-dated soil charcoal can provide coarse-resolution fire histories (Sanford and Horn 2000) that often span multiple millennia (*e.g.*, Bryson *et al.* 1965; Horn and Sanford 1992; Carcaillet 1998; Horn *et al.* 2000; Carcaillet 2001a,

b; Lertzman *et al.* 2002; Gavin *et al.* 2003a, b; Talon *et al.* 2005; Sanborn *et al.* 2006; Di Pasquale *et al.* 2008; Hammond *et al.* 2006; Titiz and Sanford 2007; Hart *et al.* 2008; Fesenmyer and Christensen 2010). Macroscopic soil charcoal has been used as a proxy for studying forest fires for decades (*e.g.*, Heyward 1937), and in a variety of locations and forest types. These include temperate rainforests of the Pacific Northwest of North America (Lertzman *et al.* 2002; Gavin *et al.* 2003a, b), mixed hardwood and pine forests of the central and southern Appalachians (Welch 1999, Hart *et al.* 2008, Fesenmyer and Christensen 2010, Scales 2011), montane forests of the Alps (Carcaillet 1998, Hajdas *et al.* 2007), neotropical rain forests (Sanford *et al.* 1985, Horn and Sanford 1992, Piperno and Becker 1996, Hammond *et al.* 2006, Titiz and Sanford 2007), and highland pine forests of the Caribbean (Horn *et al.* 2000).

In one of the first soil-charcoal studies of past fire occurrence in the southern Appalachians, Welch (1999) documented the presence or absence of macroscopic charcoal in yellow pine dominated stands on the Cumberland Plateau. Soil cores were taken from erosional and depositional slope positions. Eighty-five percent of soil samples per site contained charcoal, and the presence or absence of charcoal did not vary with depth or slope position. Although the study was not able to answer questions regarding fire dates or frequencies, it did show that fire had occurred in yellow pine stands on the Cumberland Plateau (Welch 1999).

Hart *et al.* (2008) documented the occurrence and amount of macroscopic charcoal in soil of mixed hardwood forests on the Cumberland Plateau. A coarse-resolution fire history was developed using charcoal from multiple soil cores. Five samples were submitted for radiocarbon dating. All but one of the radiocarbon samples consisted of multiple charcoal pieces taken from the same core and depth interval. The weighted means of the calibrated probability distributions of the five radiocarbon dates ranged from 6735 to 174 cal yr BP. No overlap occurred within the

2-sigma calibrated age ranges of the dated charcoal samples, indicating a minimum of five unique fire events (Hart *et al.* 2008).

To reconstruct the pre-Euro-American, stand-level fire history of a southern Appalachian forest, Fesenmyer and Christiansen (2010) used 82 radiocarbon dates for soil charcoal collected from depositional sites along a topographic gradient in the Nantahala National Forest in western North Carolina. They sampled a broad array of forest types that included pine forest, xeric-oak hardwood forest, and mesic cove forest. Charcoal ages ranged from 10,570 to 0 cal yr BP, but only one date exceeded 4000 cal yr BP. The prevalence of charcoal from 4000 to 0 cal yr BP indicated that fires occurred regularly throughout the study area during the Late Holocene. Charcoal fragments were preserved in chronological order at 10 of 18 sites. Fires were not exclusive to dry oak- and pine-dominated ridges, but also burned downslope into areas that support present-day mesic hardwood forests. The charcoal record suggests that fires became more frequent 1000 years ago, and less frequent ca. 250 years ago (Fesenmyer and Christensen 2010).

2.4 The Utility of Soil Charcoal in Reconstructing Forest and Fire History

Soil charcoal is produced when forest fires incompletely burn wood and the carbonized material is subsequently incorporated into forest soils (Welch 1999, Gavin 2003). Soil charcoal is a ubiquitous environmental proxy that is found in all vegetation types except for extreme polar biomes (Bryson *et al.* 1965, Carcaillet *et al.* 2002). The prevalence of soil charcoal makes it an effective proxy for fire and forest history reconstructions, especially in regions that lack palynological sampling sites, tree taxa that scar easily during fires (*e.g.*, *Pinus*), or trees that are sufficiently old to record extensive fire histories (Hart *et al.* 2008).

Although physical and biotic processes can break down charcoal, resulting in diminished fragment size over time (Carcaillet and Talon 1996), this relatively inert carbonized material can remain preserved in forest soils for thousands of years after a forest fire passes through an area (Aitken 1990, Hopkins *et al.* 1993, Fesenmyer and Christensen 2010). Fire history records derived from soil charcoal may long predate the oldest living trees, easily covering many thousands of years and potentially extending to the late glacial interval—prior to known indigenous occupation of the southern Appalachians.

Charcoal fragments can in some cases be identified to genus or species based on morphological characteristics, thus providing evidence not just of the occurrence of fires, but of the nature of the vegetation that burned (Talon *et al.* 2005, Di Pasquale *et al.* 2008, Hart *et al.* 2008). The taxonomic identification of soil-charcoal samples, a relatively new tool in paleoenvironmental studies, provides a way to reconstruct stand-scale changes in forest composition for which no other evidence may exist. Hart *et al.* (2008) classified the tree-ring structure of charcoal fragments as either diffuse porous or ring porous in their study of fire history from soil charcoal on the Cumberland Plateau of Tennessee, but the technique of taxonomic identification is not yet routine in soil-charcoal studies in North America. Taxonomic identification of soil charcoal was used in this research to contribute to the testing and broad-scale application of a relatively new technique that might prove useful in the study of soil charcoal in the southeastern United States.

Charcoal in forest soils is a reliable data source for reconstructing fire histories at point locations (Sanford *et al.* 1985, Carcaillet 1998). If sampling is repeated across a broad area, then coarse-scale fire histories may also be determined for large landscape units (Sanford and Horn 2000, Titiz and Sanford 2007). If radiocarbon-dated soil charcoal is to be used to provide

estimates of fire dates to reconstruct a fire history, the spatial and temporal precision of fire occurrences inferred via this method must be considered (Gavin *et al.* 2003a). Potential problems include charcoal transportation after a fire, the taphonomic processes of charcoal burial and mixing within a soil profile, and the accuracy and precision of radiocarbon-estimated fire dates (Gavin *et al.* 2003a). However, with careful research design, these potential problems can be minimized.

Movement of relatively large charcoal fragments from the site of the fire is highly unlikely (Gavin *et al.* 2003a, Talon *et al.* 2005). Charcoal fragments > 0.5 mm generally do not remain airborne more than a few tens of meters during a fire (Clark and Patterson 1997, Blackford 2000, Ohlson and Tryterud 2000, Lynch *et al.* 2004, Talon *et al.* 2005, Higuera *et al.* 2007), and are therefore typically representative of local forest fires (Whitlock and Larsen 2001). However, not all studies agree on the issue of airborne charcoal transport. Tinner *et al.* (2006) found that, under certain conditions, airborne macroscopic charcoal can be transported outside the fire periphery. Their traps collected macroscopic charcoal (mean length = 2.7 mm, mean area = 5.5 mm^2) up to 5.3 km from the fire edge. This was, however, an intense crown fire that occurred in the presence of locally strong winds, and the authors stated that macroscopic charcoal typically does not travel far (Tinner *et al.* 2006).

Surface runoff may also transport charcoal, especially on steep, barren slopes after a fire (Meyer and Wells 1997). Fire-induced debris flows may carry high amounts of charcoal and bury beneath them the forest floors that just burned. In a scenario such as this, both fire and geomorphic disturbance histories may be preserved (Meyer *et al.* 1992), albeit at some distance away from the site of the original fire. Because surface runoff can remove charcoal from a fire site, care should be taken when selecting sites for soil charcoal studies. Concavities and level

ground are ideal to minimize erosional loss of soil charcoal from a study site (Reneau and Dietrich 1990, Lavee *et al.* 1995, Gavin *et al.* 2003a).

At some point after a fire, charcoal fragments are buried beneath the soil surface by geomorphic (*e.g.*, burial by upslope-derived debris) and biotic processes (Gavin *et al.* 2003a). Typically, charcoal from Holocene fires is buried and redistributed in soil by bioturbation, such as earthworm (Topoliantz and Ponge 2003, 2005; Eckmeier *et al.* 2007) and insect activity, burrowing vertebrates (Gavin 2003, Gavin *et al.* 2003a, Talon *et al.* 2005, Phillips 2007), wind-thrown trees that create pit-and-mound topography (Beatty and Stone 1986, Bormann *et al.* 1995, Phillips and Marion 2006, Phillips 2007), displacement of soil by tree roots, and infilling of stump-rot pits (Phillips and Marion 2006). The estimated time scale for complete regolith turnover via tree-induced bioturbation is comparable to the length of the Holocene, with displacement via roots being the fastest method, followed by uprooting, and stump-rot pits (Phillips and Marion 2006).

The various disturbances that cause charcoal to become buried and mixed in soils are also responsible for the distortion of the temporal order of the charcoal record (Sanford and Horn 2000, Gavin *et al.* 2003a, Hart *et al.* 2008); thus, soil charcoal will only rarely be preserved in layers that provide relative temporal chronologies of accumulation (Carcaillet and Talon 1996; Carcaillet 2001a, b). Because of taphonomic disturbances, soil-charcoal chronologies cannot be based simply on the depth distribution of charcoal (Carcaillet 2001a, b; Talon *et al.* 2005) as they may be with sediment cores from lakes or wetlands. Instead, soil-charcoal chronologies must be based on multiple radiocarbon dates.

Nevertheless, older soil charcoal often occurs at deeper levels in the soil column and younger charcoal closer to the surface, as demonstrated by radiocarbon dating of charcoal from

soil cores (Hallett *et al.* 2003, Titiz and Sanford 2007, Fesenmyer and Christensen 2010). The reason for this is not fully understood, but it may be because net movement of charcoal in soils is down-profile, and because older charcoal typically has had greater exposure to biotic and geomorphic processes that could move it farther downward in the soil profile (Gavin 2003, S. Horn, pers. communication).

Radiocarbon dates reflect the time that the carbon, which was later converted to charcoal during a forest fire, was fixed by the plant, not the time of the fire event (Horn and Sanford 1992, Hart *et al.* 2008). This error, termed “inbuilt age” (Gavin *et al.* 2003a), can be problematic for fire history reconstructions in areas where trees are very long-lived and remnant wood persists for many centuries after tree death (Gavin *et al.* 2003a). In the southern Appalachians, warm, humid conditions lead to rapid decay of dead woody material, and age spans of trees are measured in centuries, not millennia. Thus, the inbuilt-age error for southern Appalachian charcoal samples is minimal compared to the four to six centuries of inbuilt age possible in cooler or drier climates where dead wood tends to persist (Harmon *et al.* 1986, Gavin 2001). The potential inbuilt-age error of charcoal from pine and mixed hardwood-pine forests of the southern Appalachians is likely between 50 and 100 years (Hart *et al.* 2008, Fesenmyer and Christensen 2010). Inbuilt-age error is not an issue for coarse reconstructions of forest history from soil charcoal, because the radiocarbon age of the sample is indicative of the period for which the tree was actually growing in that forest. If a large amount of soil-charcoal fragments are taxonomically identified and dated from a forest stand, this method can provide a relatively precise depiction of forest composition for the time that the carbon was fixed by the tree.

The issue of modern carbon contamination of soil-charcoal samples can also be problematic, and should not be overlooked when interpreting radiocarbon data. Potential *in situ*

sources of contamination include humic acids and calcium carbonate (CaCO_3) in groundwater, and penetration of soil charcoal by living roots. However, this potential source of dating error is greatly reduced by proper laboratory treatment. Charcoal is a highly inert substance, and pretreatment of the sample with an acid/alkali/acid regimen greatly reduces the likelihood of potential dating errors by removing extraneous organic material that may have contaminated the sample (Taylor 1987). Even with the problems related to charcoal taphonomy in soils, charcoal is a good material for radiocarbon dating for many reasons. A unique black sheen makes it easily identifiable in soil samples, and soil residues and other impurities are removed from its surface with relative ease.

Chapter 3

Environmental and Cultural Setting of Study Area

3.1 Selection of Study Areas

This study of soil charcoal in GRSM was designed as a companion study to the dendrochronological reconstruction of fire carried out by L. LaForest for her dissertation research, which was also funded by the Joint Fire Science Program. I used the same three study areas that LaForest had selected following consultation with GRSM ecologists and examination of near-infrared aerial photographs of the western portion of the park (LaForest 2012). LaForest scouted the area and selected sites with a substantial component of fire-scarred yellow pine trees that were also easily accessible via trails or park roads (LaForest 2012). These study areas traditionally supported xeric and fire-associated forests.

Two of the study areas, Rabbit Creek Trail and Pine Mountain, are located within the Abrams Creek watershed and one study area, Gold Mine Trail, is located within the Little River watershed (Figures 1 and 2). LaForest (2012) constructed three 0.1 ha dendrochronological study plots (*e.g.*, Rabbit Creek Trail A, B, and C) within each of the study areas. Soil samples for charcoal analysis were collected within eight of these 0.1 ha dendrochronological study plots. The soil-charcoal sampling sites are Gold Mine Trail A and B, Rabbit Creek Trail A, B, and C, and Pine Mountain A, B, and C. Sampling within these previously established dendrochronological study plots was intended to provide the opportunity to complement and extend the fire histories produced by LaForest.

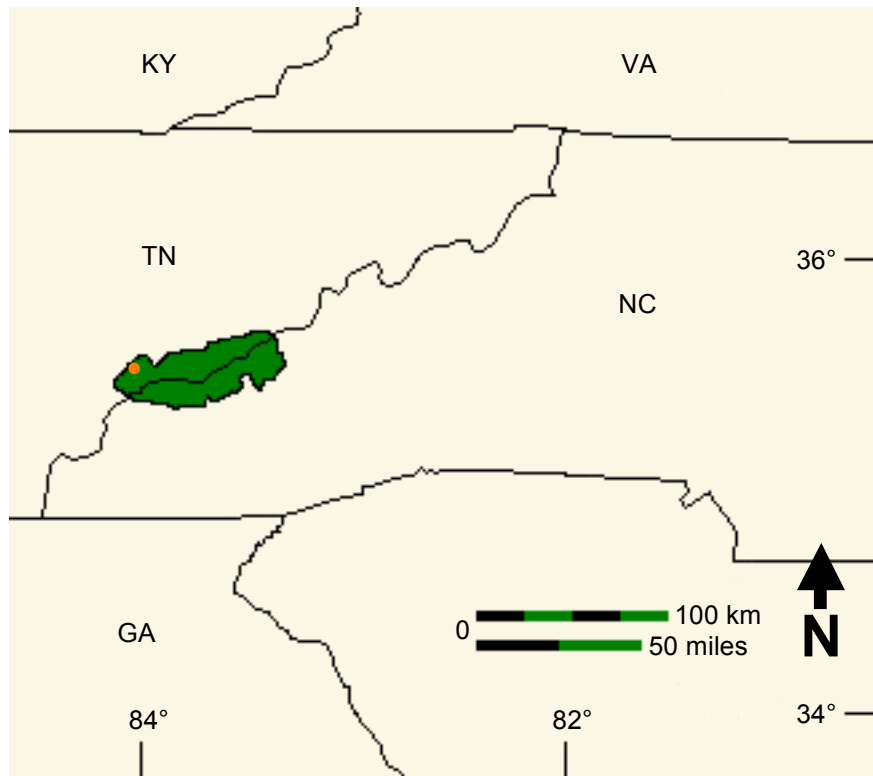


Figure 1. Great Smoky Mountains National Park. Park area is shaded in green. Location of study areas is indicated by the orange marker. Map created by author.

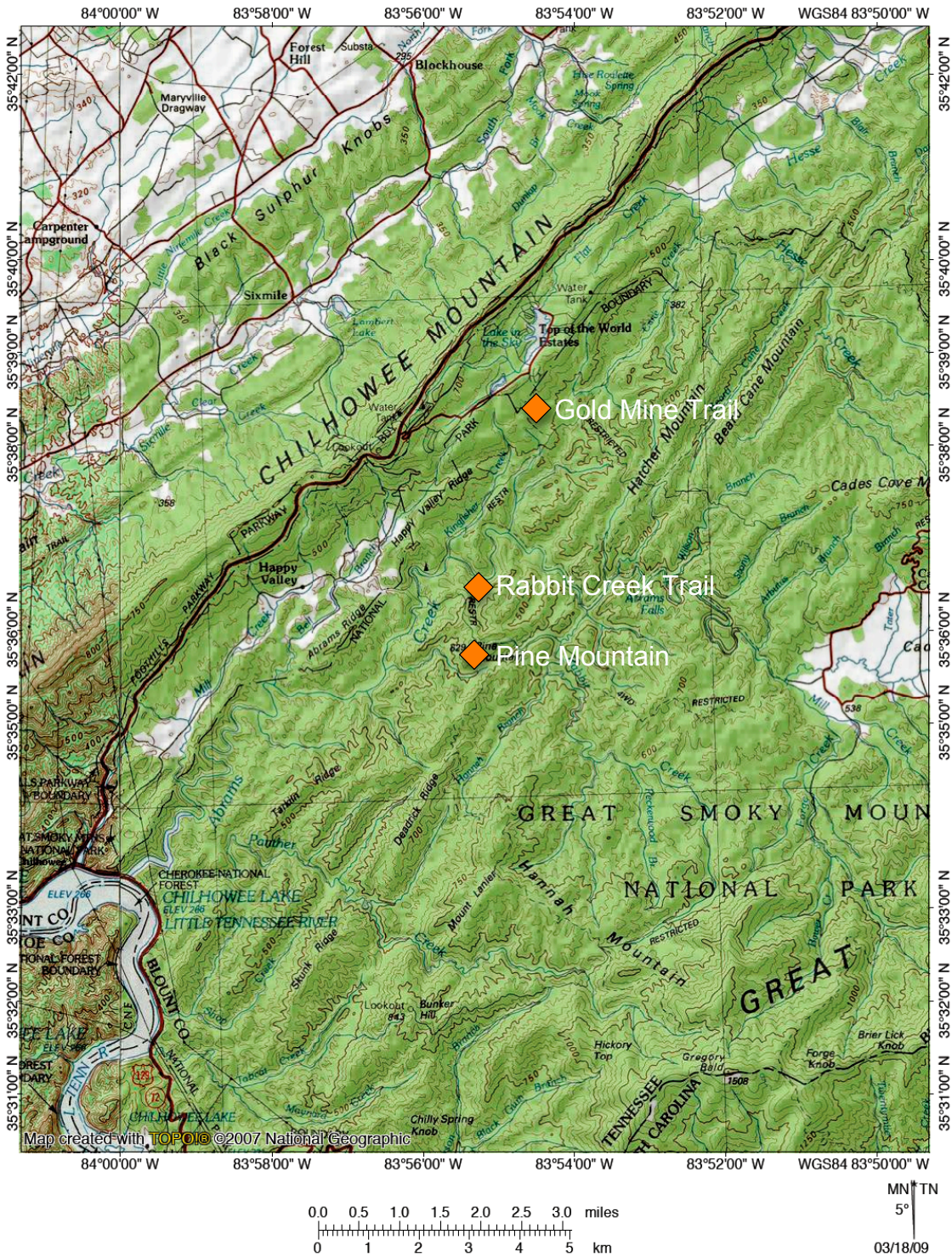


Figure 2. Location of study areas in the westernmost portion of Great Smoky Mountains National Park. The study areas of Gold Mine Trail, Rabbit Creek Trail, and Pine Mountain are indicated, north to south, by orange markers. Map created by author, using National Geographic (2007) mapping software.

3.2 Climate

The climate is classified as mesothermal humid subtropical (Köppen 1931, Thornwaite 1931). Great Smoky Mountains National Park receives uniform seasonal precipitation, much of it from warm, moist air masses that originate in the Gulf of Mexico (Konrad 1995). Average annual precipitation is 137 cm. The wettest and driest months are May and October, respectively (National Climatic Data Center, n.d.). The western, low-elevation portion of GRSM is considerably drier than the higher-elevation areas of the park and generally drier than most of the eastern low-elevation areas of the park. The mean monthly temperature range for low elevations is 11/–2 °C in January to 31/15 °C in July (National Park Service 2012). The terrain of GRSM creates a diversity of microclimates. High elevations are generally cooler and wetter, while southern-aspect slopes are warmer and drier (Whittaker 1956).

3.3 Physiography

The study areas are located in the southern section of the Blue Ridge province in the Appalachian Highlands physiographic region (Fenneman 1938, 1946). This portion of GRSM is characterized by steep-walled, V-shaped valleys and narrow, winding ridges (Elder 1959). The Appalachian Highland physiographic region has a long tectonic history, reaching back as early as the Precambrian Supereon (Miller 1974). The last major deformation episode, the Allegheny orogeny, occurred 325–260 million years ago (MYA) during the Carboniferous Period. Ancient sediments that today compose the sedimentary and metamorphic rocks of much of the Blue Ridge had accumulated on the eastern margin of present-day North America for millions of years. During the Allegheny orogeny, these horizontally bedded sedimentary rocks were thrust upward, folded, and broken along faults, forming the Appalachian Mountains (Miller

1974). At their highest point, the ancient Appalachian Mountains likely rose to an average elevation that would have fallen somewhere between the present-day Himalayas and the Rocky Mountains, but millions of years of erosion have worn them down to their current elevations. The sampling sites are at relatively low elevations, ranging from 487 m (Rabbit Creek Trail C) to 614 m (Gold Mine Trail A).

3.4 Geology and Soils

The Gold Mine Trail sites are underlain by two major rock types of the Chilhowee Group, both formed during the Lower Cambrian Period (542–511 MYA) of the Paleozoic Era. The sites are located in a transitional area between the Murray Shale, composed of a greenish-gray, argillaceous to silty shale, and the Hesse Quartzite, composed of thick-bedded, white quartzite (Southworth *et al.* 2005).

The Rabbit Creek Trail and Pine Mountain sites are underlain by rocks of the Walden Creek Group, formed during the Neoproterozoic Era (1000–542 MYA). Rabbit Creek Trail A and B and Pine Mountain A, B, and C are underlain by the Shields Formation. At these sites, the formation consists of dark-gray to greenish-gray laminated siltstone and slate (Southworth *et al.* 2005). Rabbit Creek Trail C is located in a transitional area between the Shields and Wilhite Formations. The Wilhite Formation consists of shale, siltstone, and slate, with some vitreous quartzite at Rabbit Creek Trail C (Southworth *et al.* 2005).

The soils of the study areas are Inceptisols (Udepts) (Natural Resources Conservation Service, n.d.) that belong to the Ramsey series, an upland soil series derived primarily from its underlying bedrock (Elder 1959). In general, these soils consist of shallow, well-drained or excessively drained soils on steep slopes. These soils formed from acid sandstones, quartzites,

shales, and slates (Elder 1959). Relief in the pedogenetic areas for these soils tends to range from hilly to very steep, but is dominantly steep to very steep (Elder 1959). The parent material for Ramsey series soils weathers very slowly, but the material, once eroded, is removed downslope almost immediately; thus, Ramsey series soils tend to be very shallow with poorly developed profiles. Bedrock outcrops and loose, surface rock fragments are common in the area. The native vegetation associated with these acidic (pH 5.1 to 6.0), relatively infertile soils consists of mixed pine and hardwood forests (Elder 1959).

The soil at the Gold Mine Trail sites is Ramsey stony fine sandy loam, very steep phase (derived from $\geq 50\%$ slope). The depth to bedrock for this soil is typically 30.5 to 46 cm, but in places can be as much as 76 cm. A typical profile consists of 0 to 18 cm of yellowish-brown very friable stony fine sandy loam and ≥ 18 cm of yellowish-brown or brownish-yellow friable sandy loam soil material mixed with fragments of sandstone and quartzite (Elder 1959). The soils at the Rabbit Creek Trail and Pine Mountain sites consist primarily of Ramsey slaty silt loam, very steep phase ($\geq 50\%$ slope), with pockets of Ramsey slaty silt loam, steep phase (25 to 50% slope). The very steep phase of this soil occurs in mountainous landscapes with sharp peaks and narrow, broken ridge crests. Even though depth to bedrock can be up to 46 cm for both Ramsey slaty silt loams, the very steep phase of this soil tends to be much shallower to bedrock than the steep phase, and thus has a very poorly developed profile (Elder 1959). A typical profile for the steep phase consists of 0 to 5 cm of grayish-brown or dark-grayish-brown friable slaty silt loam, 5 to 23 cm of pale-brown or yellowish-brown friable slaty silt loam, and ≥ 23 cm of partly weathered slate fragments and yellowish-brown or brownish-yellow friable silt loam soil material (Elder 1959).

3.5 Vegetation

Trees of the genus *Pinus* migrated onto the present-day North American landscape over 100 MYA (Richardson and Rundel 1998). By the end of the Mesozoic (ca. 65 MYA), the genus *Pinus* had diversified into two major subgenera: *Strobus*, the haploxylon (*i.e.*, soft, white) pines, and *Pinus*, the diploxylon (*i.e.*, hard, yellow) pines (Richardson and Rundel 1998). During the last full glacial period, about 18,000 yr BP, pine forests dominated the southeastern United States (Webb 1988). While varying with changes in climate and disturbance regimes, *Pinus* has remained an important taxon in the southeastern United States throughout the Holocene.

Yellow pines often occur in association with *Quercus* and *Carya* in the southern Appalachians, especially on xeric sites (Braun 1950). However, yellow pines can also occur in virtually pure stands on extremely rocky, dry, and nutrient-poor sites. Four yellow pines are native to the southern Appalachians. Shortleaf pine (*Pinus echinata* Mill.) has the broadest range of the southern yellow pines and is commonly found on low-elevation slopes, ridges, and plateaus, up to approximately 1000 m elevation (Lawson 1990). Under ideal environmental conditions, shortleaf pines can reach over 30 m in height and up to 1 m in diameter. Cones are 4 to 6 cm in length, and needles occur in bundles of two or three (Lawson 1990). Shortleaf pines are well adapted to fire, as seedlings and early-stage saplings often exhibit sprouting after fires (Keeley and Zedler 1998). The range of Virginia pine (*P. virginiana* Mill.), from 30 m to 762 m elevation, overlaps that of shortleaf pine in GRSM. Average size is 9 to 18 m in height and 0.3 to 0.5 m in diameter. Bark is thin compared with other yellow pine species in the southern Appalachians. Cones are 4 to 7 cm in length, and needles occur in bundles of two (Carter and Snow 1990). Pitch pine (*P. rigida* Mill.) occurs primarily on mid-elevation slopes and ridges up to 1300 m elevation (Little and Garrett 1990). Pitch pine is capable of hybridization with

shortleaf pine (Gucker 2007). Average size is around 25 m in height and 1 m in diameter. Cones are 3 to 7 cm in length, and needles usually occur in bundles of three (Little and Garrett 1990). Table Mountain pine (*Pinus pungens* Lamb.), the only southern yellow pine endemic to the Appalachian Mountains, most commonly occurs on high-elevation slopes and rocky ridge tops up to 1200 m elevation (Della-Bianca 1990). Average size is 6 to 12 m in height and 0.3 to 0.6 m in diameter. Cones are 5 to 9 m long and remain on the tree for multiple years. Needles usually occur in bundles of two (Della-Bianca 1990).

Yellow pines have evolved many adaptations that assist survival or regeneration after fire (Agee 1998). The basal sprouting habit of pitch and shortleaf pine, and to a lesser extent Table Mountain and Virginia pine, is one such evolutionary adaptation to fire (Keeley and Zedler 1998). Table Mountain and Virginia pine produce highly pyriscent cones. Pitch pine can, in some cases, exhibit pyriscence, whereas shortleaf pine does not exhibit this fire adaptation anywhere in its range (Keeley and Zedler 1998). With pyriscent cones, seeds are sealed until high temperature melts the resin within the cone. If this occurs immediately following a fire, seeds are more likely to fall on bare mineral soil that is more conducive to germination (Agee 1998). Shortleaf and Table Mountain pine self-prune their lower branches. This increases the distance of potential “ladder fuel” from the ground and could prevent a relatively intense ground fire from developing into a crown fire that would likely kill the tree (Keeley and Zedler 1998). Of the southern yellow pines, pitch pine exhibits the thickest bark, while Virginia pine has relatively thin bark that can be heavily damaged by intense fires (Keeley and Zedler 1998). The fine, needled leaves of all southern yellow pines promote or perpetuate the spread of fires (Nowacki and Abrams 2008).

Eastern white pine, the only haploxyton pine that occurs in the southern Appalachians, is found primarily on mesic slopes and in valleys at relatively low elevations (Wendel and Smith 1990). However, eastern white pine also occurs with species comprising open oak and pine stands (Shanks 1954) as well as with subxeric-classified trees that often occur in drier oak-chestnut forests (Whittaker 1956). Eastern white pine exhibits a very low tolerance to fire. The policy of active fire suppression has allowed this species to successfully spread outside of its historic habitat in GRSM (Figure 3), and it is now a dominant species in many traditional yellow pine and mixed hardwood-pine forests in GRSM.

Quercus also occurred in the southeastern United States during the last full glacial period, but accounted for only 1 to 5% of total pollen in sediment samples, compared with 20 to 40% for *Pinus* (Webb 1988). By the beginning of the Holocene, the occurrence of *Quercus* increased as this genus began to dominate many forests in the eastern United States (Delcourt 1979, Webb 1988). On a local scale over the Holocene, the abundance of *Quercus* was variable and often shifted with cycles of moisture, temperature, and exposure to fire (Abrams 1992).

On xeric sites, a few hardwood species often occur in association with southern yellow pines to form mixed hardwood-pine forests. The dominant upper-canopy hardwoods in these forests are often black oak (up to 1463 m elevation), scarlet oak (*Q. coccinea* Muenchh.) (up to 1067 m elevation), white oak (up to 1798 m elevation), and chestnut oak (up to 1219 m elevation) (Stupka 1989).

Oak seedlings resist root kill from fire better than mesophytic competitors (Swan 1970, Waldrop *et al.* 1987, Augspurger *et al.* 1987). Mature oaks, compared to other hardwood species, have relatively thick bark that resists damage from low-severity fires (Lorimer 1989). Acorns undergo hypogeal germination (Rogers 1990) that protects oak cotyledons from potential above-



Figure 3. Mesophication of a xeric forest in the Pine Mountain study area. In the absence of high-frequency, low-intensity fires, eastern white pine is encroaching into xeric habitats once dominated by southern yellow pine and oak. Here, the seedling and sapling cohorts are dominated by eastern white pine. Photograph by Lisa LaForest.

ground fire damage. Oaks tend to be more successful at vegetative reproduction (*i.e.*, sprouting) after fire than many other hardwood competitors (Waldrop and Lloyd 1991). Thus, fire favors oaks by reducing competition from fire-intolerant mesic species (Green *et al.* 2010).

A historically important species, the American chestnut, was once prominent in mixed hardwood-pine forests in GRSM. Chestnut blight (*Cryphonectria parasitica* (Murrill) Barr.) was introduced to the southern Appalachians ca. 1925 (Woods and Shanks 1957). This fungus decimated American chestnut trees, killing 99.9% of trees over the entire range of the species (Anagnostakis 1987). American chestnut root systems are still living throughout much of the southern Appalachians. Sprouts routinely appear from remnant root bundles, but these rarely reach 6 m in height before being affected by chestnut blight (Anagnostakis 1987, Feathers 2010).

Dominant hardwood trees in the lower canopy are often red maple and blackgum. In the absence of high-frequency, low-intensity fires, these trees, along with eastern white pine, are becoming more common in native mixed hardwood-pine forests in the southern Appalachians. In many instances, these lower-canopy trees are now growing into the upper canopy (LaForest 2012). The understory of pine and mixed hardwood-pine forests in GRSM largely consists of flowering dogwood (*Cornus florida* L.), sourwood (*Oxydendrum arboreum* (L.) DC.), sassafras (*Sassafras albidum* (Nutt.) Nees), mountain laurel (*Kalmia latifolia* L.), galax (*Galax urceolata* (Poir.) Brummitt), and a variety of blueberry (*Vaccinium*) species (Stupka 1989, Feathers 2010, LaForest 2012) (Figure 4).

3.6 Land-Use History

Native Americans arrived in the present-day area of GRSM during the Archaic period around 8000 years ago (Pierce 2000). During this time, Native Americans lived mostly along



Figure 4. Thick understory growth related to fire suppression in the Pine Mountain study area. In the absence of a high-frequency, low-intensity fire regime, mountain laurel forms dense, almost impenetrable thickets in the understories of pine and mixed hardwood-pine forests. Photograph by Lisa LaForest.

waterways in campsites that would shift seasonally. Archaic-period Native Americans practiced a hunting and gathering lifestyle that often took them into the surrounding mountains (Davis 1986, Ward and Davis 1999). They used fire as a hunting tool, and also to clear the landscape of unwanted vegetation and to promote the growth of desirable, fire-adapted plants (Pierce 2000). The Woodland period began around 3000 yr BP, and is viewed as the time during which Native Americans in the southern Appalachians began the shift toward a horticulturally based economy (Ward and Davis 1999). Corn (*Zea mays* L.) became a major food crop ca. 1000 yr BP (Scarry 2003). Soon thereafter, settlements became much larger and more permanent, and Native Americans in the southern Appalachians began to lead a fully sedentary lifestyle (Ward and Davis 1999).

The first documented European contact occurred in the 16th century, when an expedition of 600 people led by Hernando de Soto skirted either the Pigeon River gorge to the east or the Little River gorge to the west of the Smoky Mountains (Pierce 2000). A rapid and severe decline of Native American populations soon followed, as Old World diseases decimated settlements throughout the region. William Bartram journeyed through the Little Tennessee River valley in Georgia and North Carolina in the 1770s, recording notes on vegetation and Native American lifestyles (Van Doren 1955). Andrew Ellicott retraced Bartram's route in 1812, and in 1820, Robert Love surveyed nearby Macon and Swain counties, North Carolina (Fesenmyer and Christensen 2010).

The first documented Euro-American inhabitants of present-day GRSM settled in Cades Cove in 1818. By the mid-19th century, Euro-American settlers had taken control of most major stream valleys in the area, displacing the Cherokee Indians (Pierce 2000, Rehder 2004). They continued and expanded upon many practices initiated by Native Americans, including

agriculture in low-elevation areas, hunting and gathering, and the periodic use of fire as a management tool (Harmon 1982, Pierce 2000).

During the late-19th century, logging operations, and the subsequent Little River Railroad, descended upon present-day GRSM. This was a period of intense anthropogenic disturbance, during which two-thirds of the original forest cover was removed (Pierce 2000). Heavy erosion and stream sedimentation occurred, as logging operations stripped the landscape of its protective vegetation cover (Pierce 2000). The western portion of GRSM, however, was largely excluded from large-scale logging operations (Pyle 1988). Nationwide grassroots campaigns for the preservation of natural resources began to occur around this time, and an influx of tourists converged on the southern Appalachians. Two conservation organizations, the Great Smoky Mountains Conservation Association and the North Carolina Park Commission, acquired land in 1926 for the purpose of creating a national park (Pyle 1988). In 1934, the United States Congress chartered GRSM. At over 211,415 ha, GRSM is now one of the largest contiguous protected areas in the eastern United States (Pierce 2000).

3.7 Description of Study Areas

3.7.1 Gold Mine Trail

The Gold Mine Trail study area (35°38'N, 83°54'W) is located on the far western edge of the park. I sampled two sites within this study area: Gold Mine Trail A (northeast aspect, 1.5% slope), and Gold Mine Trail B (south-southwest aspect, 14% slope). This area may have been farmed as recently as the late 1920s (Pierce 2000). A large part of the western portion of GRSM was held by the Morton Butler Lumber Company prior to park establishment (Harmon 1982); however, much of this portion of GRSM was never logged (Pierce 2000). Gold Mine

Trail originally served as an access route from Montvale Springs, a popular tourist resort in operation before the establishment of GRSM, to Cooper Road Trail (DeFoe *et al.* 2003). The study area extends approximately 0.5 km from each side of the trail, beginning at the park boundary and continuing south to Cooper Road Trail, and covers approximately 35 ha (LaForest 2012). The elevation range of the study area is approximately 460 to 600 m. Vegetation at this site varies from xeric pine-oak dominated stands on ridge tops to rhododendron (*Rhododendron* spp.) thickets with eastern hemlocks along stream valleys (LaForest 2012).

3.7.2 Rabbit Creek Trail

The Rabbit Creek Trail study area (35°36'N, 83°55'W) is located near a sharp bend in Rabbit Creek Trail, approximately 1.5 km southeast of the Abrams Creek Ranger Station (LaForest 2012). I sampled three sites within this study area: Rabbit Creek Trail A (east-southeast aspect, 57% slope), Rabbit Creek Trail B (north-northwest aspect, 13% slope), and Rabbit Creek Trail C (west-northwest aspect, 30% slope). Rabbit Creek Trail is part of a Cherokee Indian trail system that was widened by the Civilian Conservation Corps during the 1930s (DeFoe *et al.* 2003). The upper half of the study area straddles Rabbit Creek Trail for approximately 0.5 km along a ridgeline that increases in elevation toward the direction of Pine Mountain. The lower half of the study area extends across the nose of the ridge that points northeasterly toward Abrams Creek (LaForest 2012). A tributary of Abrams Creek flows along the eastern side of the study area. The elevation range of the 20 ha study area is approximately 500 to 600 m. Vegetation at this site is dominated by mesic species such as eastern white pine, eastern hemlock, and red maple.

3.7.3 Pine Mountain

The Pine Mountain study area (35°35'N, 83°55'W) is located 250 m west of the junction of Hannah Mountain Trail and Rabbit Creek Trail, and encompasses approximately 20 ha (LaForest 2012). I sampled three sites within this study area: Pine Mountain A (south-southwest aspect, 40% slope), Pine Mountain B (north-northwest aspect, 42% slope), and Pine Mountain C (south-southeast aspect, 34% slope). Most of the Pine Mountain study area lies on a three-pronged ridge, located downslope from Rabbit Creek Trail and the summit of Pine Mountain (629 m). Split forks of the headwaters of Pardon Branch flow along each side of the study area (LaForest 2012). Hannah Mountain Trail was blazed in the 1840s to provide a route between the resort at Montvale Springs and Gregory Bald, which rises to the southwest of Cades Cove (DeFoe *et al.* 2003). The trail junction is located in Scott Gap, an area that was farmed by Euro-American settlers (DeFoe *et al.* 2003). The elevation range of the study area is approximately 500 to 600 m. The northern-aspect slopes of the Pine Mountain study area are relatively mesic and support mixed hardwood trees such as oaks and blackgum, while the xeric, southern-aspect slopes support numerous yellow pine specimens, albeit many recently killed by southern pine beetles (LaForest 2012).

Chapter 4

Methods

LaForest (2012) established dendrochronological plots in areas of GRSM where southern yellow pine currently exists or has existed in the past. In establishing these plots, she was most concerned with finding areas that would produce the best dendrochronological specimens, especially fire-scarred southern yellow pines; slope position was not a significant concern. Therefore, most of the study sites she established were located on relatively steep terrain. When choosing soil-coring sites within these dendrochronological study plots, I sought out concavities and level ground to minimize erosional loss of soil charcoal from each study site (Reneau and Dietrich 1990, Lavee *et al.* 1995, Gavin *et al.* 2003a). Limiting coring sites to concavities and level ground, when possible, should not introduce bias to the study because fire behavior is not typically affected by such small topographic features (Chandler *et al.* 1983).

At each of the eight study sites, I used a tubiform root auger to recover soil cores in contiguous 10 cm intervals to the depth of refusal or 1 meter (Figure 5), following methods described by Horn *et al.* (1994, 2000). Collecting cores with a root auger was chosen over studying profiles in soil pits for consistency with prior and ongoing soil-charcoal research in the University of Tennessee Laboratory of Paleoenvironmental Research (Horn and Sanford 1992, Horn *et al.* 2000, Hart *et al.* 2008, Horn *et al.* unpublished) and because: (1) root auger samples allow for easy comparison of multiple samples, all consisting of the same volume (500 cc), (2) collection of soil cores is an easily repeatable procedure, (3) time constraints precluded digging and interpreting multiple soil pits in the field and subsequently processing the vast amounts of soil sampled in each pit, and (4) the National Park Service requires research within parks to be as



Figure 5. The author (left) and middle-school teacher Oscar Osorio collecting soil cores at Gold Mine Trail B. Photograph by Crystal Yates.

nonintrusive as possible. Soil core extraction leaves small holes that can be filled with forest debris to leave hardly a trace on the landscape, whereas multiple soil pits create significant visual, and potentially ecological, disturbance.

At each of the eight sites, I collected six cores, one each at 0 m, 10 m, and 20 m (designated core A, B, and C) along two transects (designated transect 1 and transect 2) spaced 3 m apart (Figure 6). The starting point of the first transect at each site was chosen by blindly tossing an easily identifiable marker into a concavity or level area, where available. Transects were aligned parallel to the slope. Core sections were extruded into 1 liter zipper-type plastic bags in the field.

In the laboratory, core sections were soaked overnight in approximately 0.75 L of water to disaggregate the soil. Hue, value (lightness), and chroma (color purity) were determined for each wet core section based on the Munsell color system (Munsell Color 2000) (Appendix 1). Samples were then wet-sieved using a 20.5 cm diameter brass sieve with a mesh size of 2 mm. This sieve gauge was chosen because charcoal of this size is not easily transported by wind during or after fires or by overland flow on hillslopes (Hart *et al.* 2008). Such charcoal is typically considered primary charcoal (*i.e.*, deposited during or shortly after a fire), and its occurrence in soils is evidence of local fire (Gavin 2003, Gavin *et al.* 2003a, Hart *et al.* 2008).

I used a dissecting scope with an incident light source at 7 to 40x magnification to isolate and remove charcoal from the material retained on the sieves (Figure 7). Charcoal fragments were rinsed with distilled water and transferred to glass scintillation vials for drying. Each vial of charcoal was dried at 100 °C for 36 to 48 hours. Once dry, the charcoal from each core section was weighed to determine an aggregate mass. Each charcoal fragment was then placed for

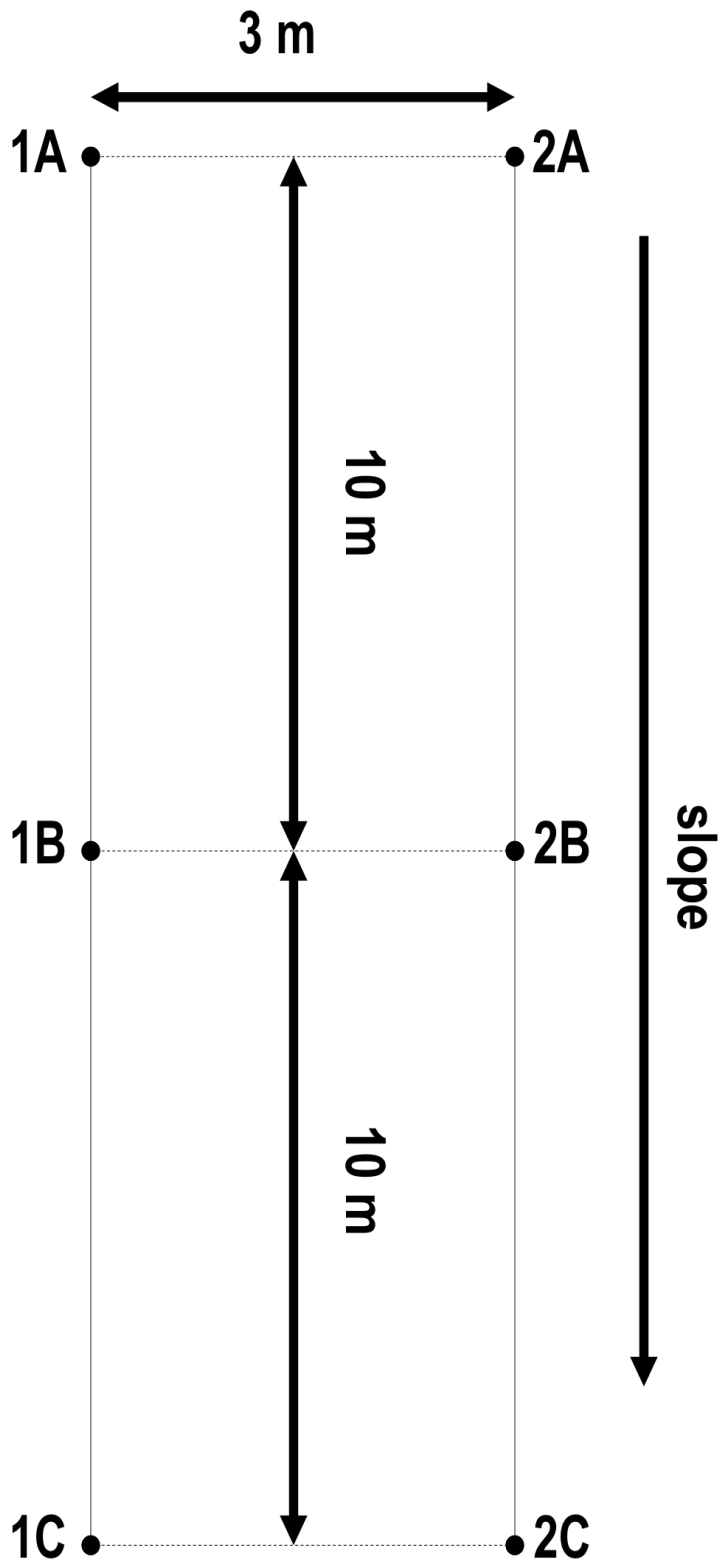


Figure 6. Schematic of transects and cores for each site. Schematic is not to scale.



Figure 7. Removing charcoal fragments from the sieved remains of a soil sample. Soil samples from the bottom of a core, such as the sample pictured, often contained abundant weathered bedrock. Photograph by Andrea Gregg.

storage in an individual well of a cell culture tray, assigned a unique identification number, and treated as an individual sample. The individual identification numbers included site, core, and depth of recovery. The assignment of individual identification numbers facilitated the stratified-random selection of charcoal fragments for radiocarbon dating.

Since the primary goals of this study were to extend the dendrochronologically based fire history (LaForest 2012) and develop a forest history at each site, I considered it important to achieve equal representation of dated samples at all sites (Talon *et al.* 2005). Charcoal fragments were selected from core increments deeper than 20 cm using a stratified random sampling method in which I selected a roughly equivalent sample population, in both number and mass, of charcoal fragments from each site without regard to depth of core increment or location of cores within each site. Charcoal fragments from the upper 20 cm of cores were not selected for radiocarbon dating because those charcoal fragments have the highest probability of overlapping the tree-ring records of fire, and dating them may have created redundant fire history data. The stratified random selection of samples ensured that the chosen charcoal fragments were representative of the charcoal population at each site and allowed for a robust statistical analysis of charcoal data.

The possibility exists that a single soil-core increment could contain charcoal evidence for the same or multiple fire(s) from the same tree. In the scope of this study, it was impossible to determine whether charcoal fragments with the same taxonomic identification (from the same core or transect) were derived from the same tree, fire event, or both (D. Hammond, pers. communication). To create the most accurate fire and forest history possible, it is desirable to obtain radiocarbon dates on carbonized wood from different trees. Stratified random sampling

reduced the likelihood of choosing samples that originated from the same tree for radiocarbon dating.

Charcoal fragment size and the clarity of anatomical features for the purposes of identification were also considered when choosing samples for radiocarbon dating. The dry mass of charcoal to be analyzed should be ≥ 1.0 mg, with a suggested mass of 5.0 mg (NSF-Arizona AMS Laboratory, n.d., a). Each sample, however, must be pretreated using an acid-alkali-acid procedure to remove allocthonous sources of carbon that could skew age estimations (NSF-Arizona AMS Laboratory, n.d., b). The pretreatment procedure invariably removes some of the mass of the original sample; therefore, only those samples with a dry, pretreatment mass of ≥ 6.0 mg were considered for radiocarbon analysis.

If a charcoal fragment selected at random was ≥ 6.0 mg, it was cut transversely with a razor blade to analyze wood anatomy (*e.g.*, cell structure and ring boundaries) to identify the type of tree that produced the charcoal. I developed an extensive reference collection of both carbonized and non-carbonized wood from the southern Appalachians. The carbonized collection was created following the methods of Orvis *et al.* (2005). I used these collections, as well as multiple high-resolution anatomical images available online (InsideWood, n.d.; Maryland Archaeological Conservation Laboratory 2010; Swiss Federal Institute for Forest, Snow, and Landscape Research 2010) or in the published literature (Brown and Panshin 1934, Record 1934, Titmuss 1949, Harlow 1970, Jane 1970, Schweingruber 1978, Core *et al.* 1979, Panshin and de Zeeuw 1980, Carlquist 1988, Hoadley 1990, Hough 2002, Schweingruber *et al.* 2006) to taxonomically identify the type of tree that produced individual charcoal samples. If a randomly chosen sample could not be taxonomically identified because of indistinct anatomical features, it

was returned to its container and a different charcoal fragment from the same site was randomly selected instead.

I categorized charcoal samples selected for dating as Pinales or non-Pinales, based on the presence or absence of prominent tracheids. Samples that retained sufficient anatomical structure after carbonization were identified to family, genus, or even species based on other anatomical characteristics (Talon *et al.* 2005) (Figures 8–13). Within the Order Pinales, the only genus other than *Pinus* likely to exist in samples younger than the last glacial period in North America is *Tsuga*, but in most cases I could differentiate *Tsuga* from *Pinus* by the presence of resin canals in *Pinus* samples. If a fragment of *Pinus* charcoal could not be specifically identified as either yellow pine or eastern white pine, I placed it in an undifferentiated pine category.

Approximately 75% of the samples submitted for radiocarbon analysis were pretreated in the Laboratory of Paleoenvironmental Research, following methods established by the NSF-University of Arizona Accelerator Mass Spectrometry Laboratory (NSF-Arizona AMS Laboratory n.d., a). The other samples submitted for radiocarbon dating were pretreated by the laboratory that conducted the analyses.

Radiocarbon years were converted to calibrated ages using the CALIB radiocarbon calibration program, version 6.0.2 (Stuiver and Reimer 1993), and the dataset of Reimer *et al.* (2004). I used the weighted mean of the calibration probability distribution to assign a single calendar year to each sample (Telford *et al.* 2004). Radiocarbon dating placed the taxonomically identified charcoal fragments into chronological context, thus allowing for the coarse reconstruction of past forest composition and fire history.

Data analyses were generated using SAS software, Version 9.3 of the SAS System for Microsoft Windows (SAS Institute, Inc. 2011). Charcoal content of intra-site soil cores was

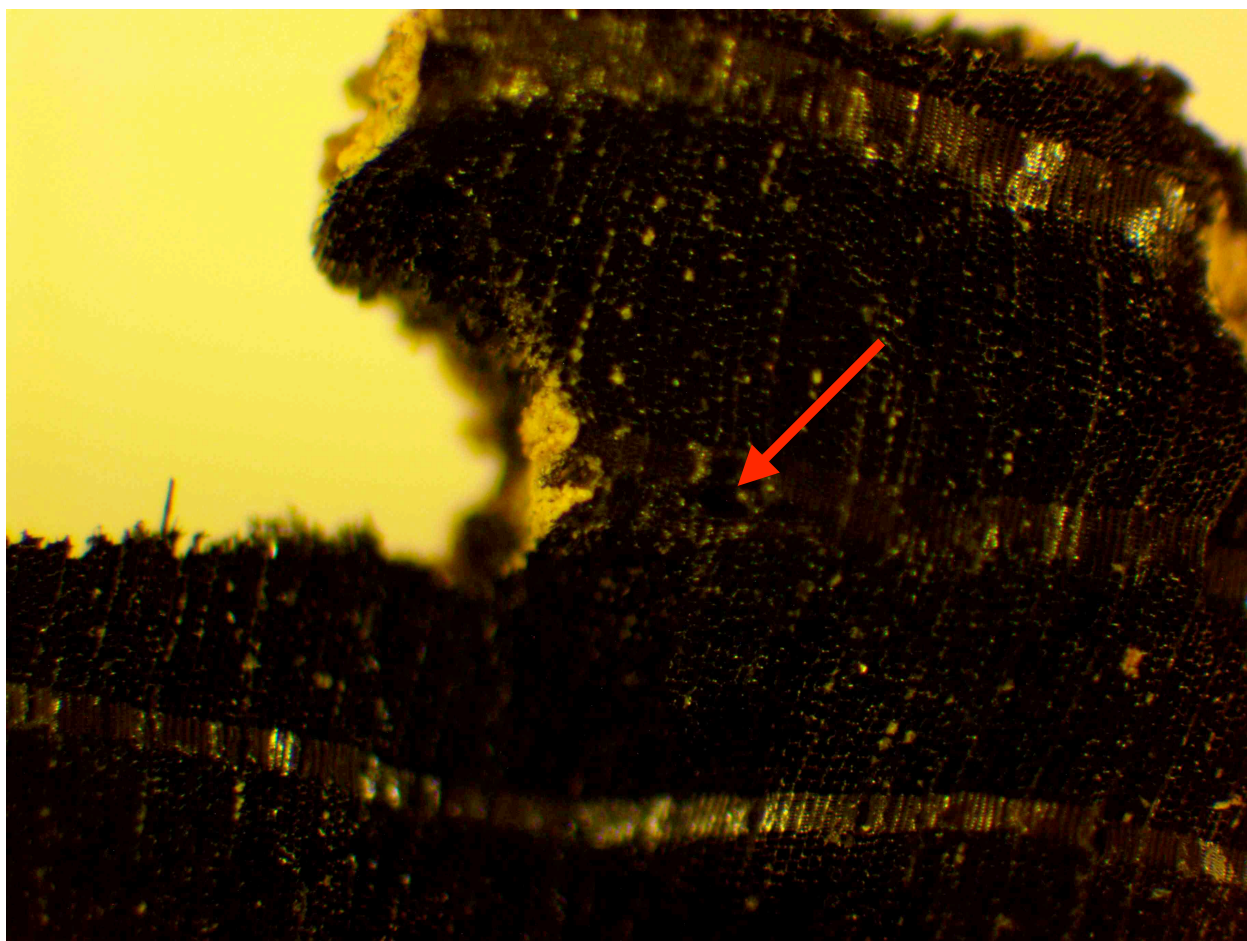


Figure 8. Charcoal from a southern yellow pine (*Pinus*, diploxylon group), magnified 30x. Anatomical features that allow identification of southern yellow pine are tracheids, resin canals (indicated by arrow), and pronounced earlywood to latewood transition at ring boundaries. The anatomy of the diploxylon pines that live in the southern Appalachians is too similar to allow differentiation by species. Photograph by the author.

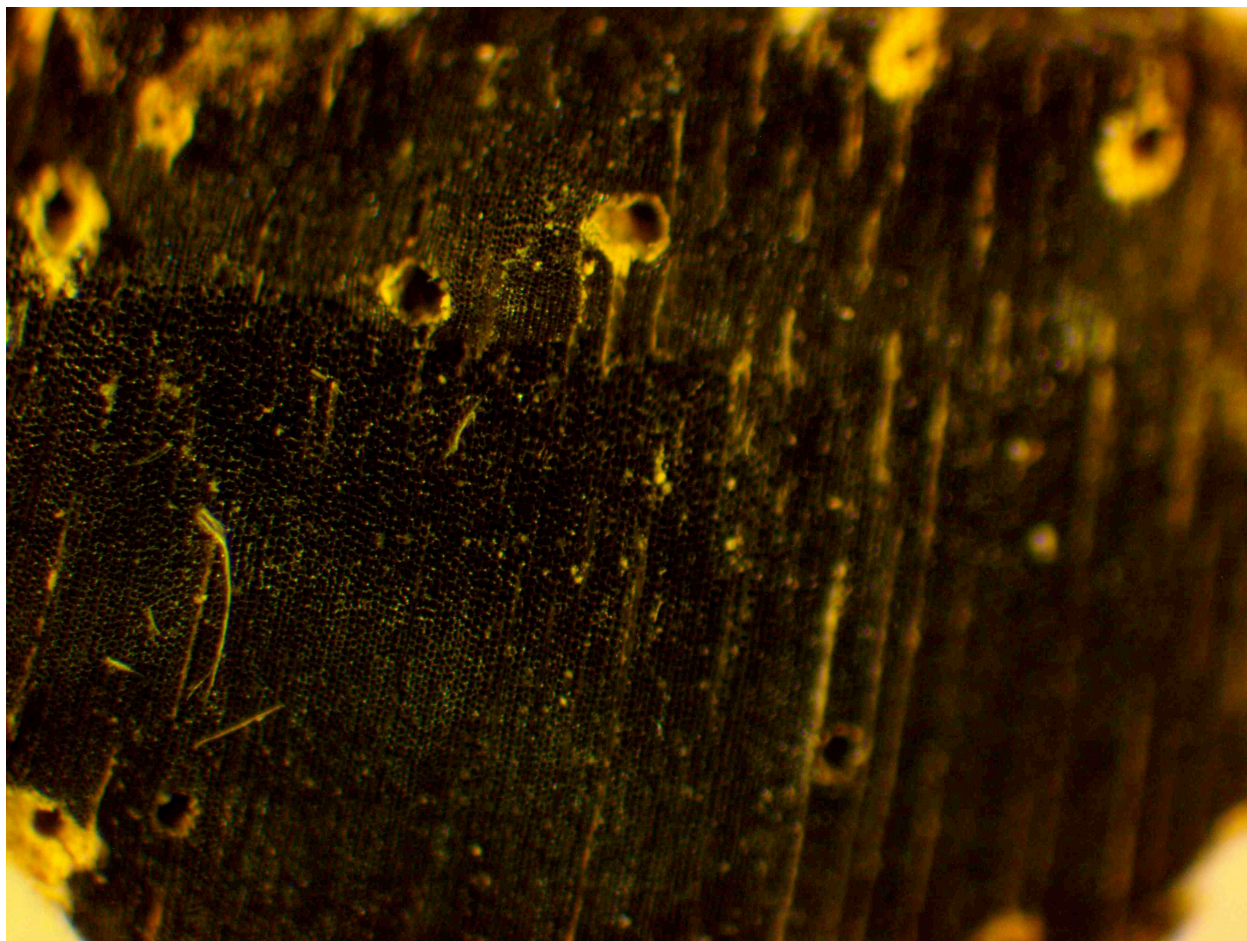


Figure 9. Charcoal from eastern white pine (*Pinus strobus* L., haploxylon pine), magnified 30x. Anatomical features that allow identification of eastern white pine are tracheids, resin canals, and gradual earlywood to latewood transition at ring boundaries. Photograph by the author.

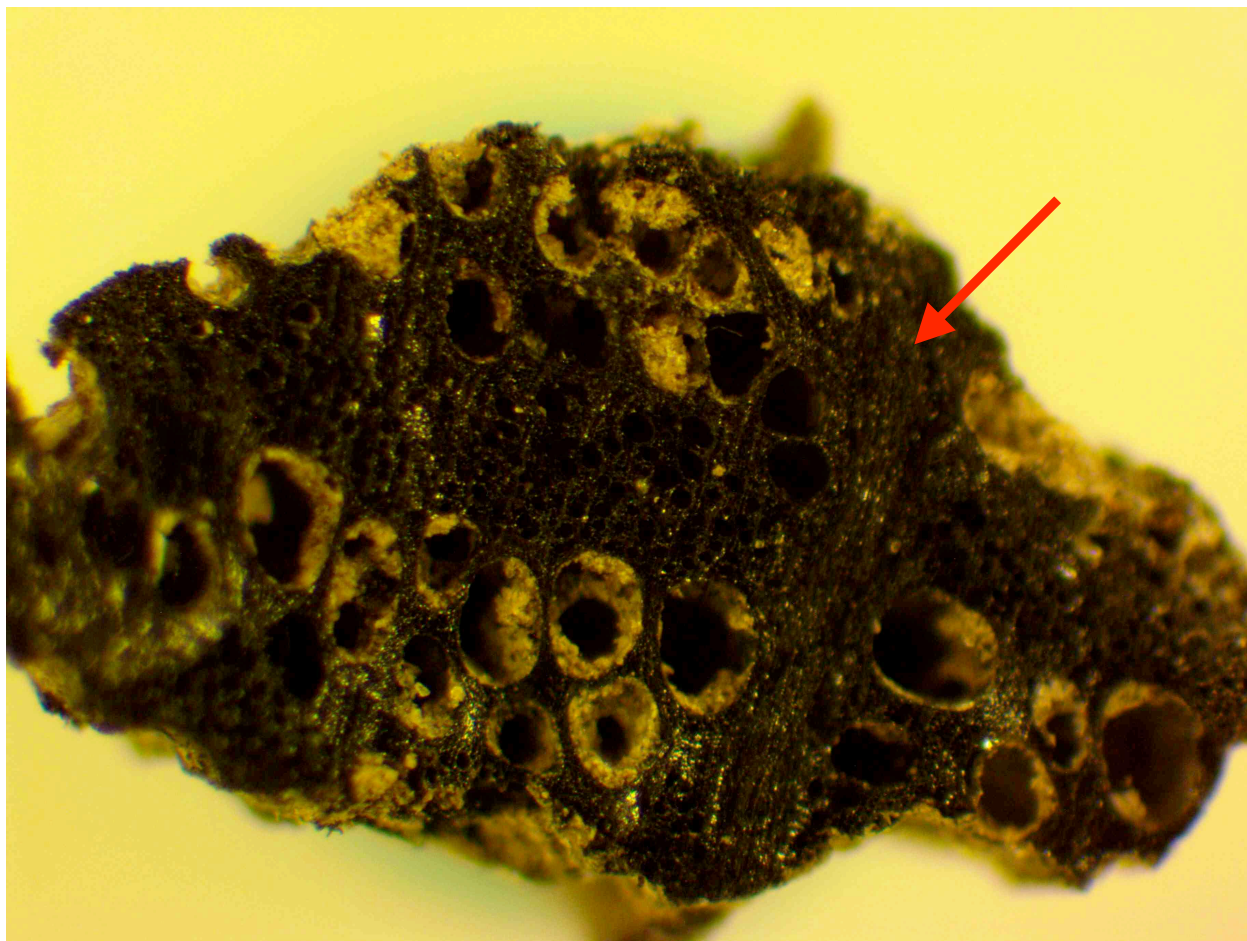


Figure 10. Charcoal from red oak sp. (*Quercus* sect. *Erythrobalanus*), magnified 30x. Anatomical features that allow identification of red oak are wide aggregate rays (indicated by arrow), a general lack of tyloses, pronounced earlywood pores clustered linearly along ring boundaries, and flame-like arrangement of latewood pores. Photograph by the author.

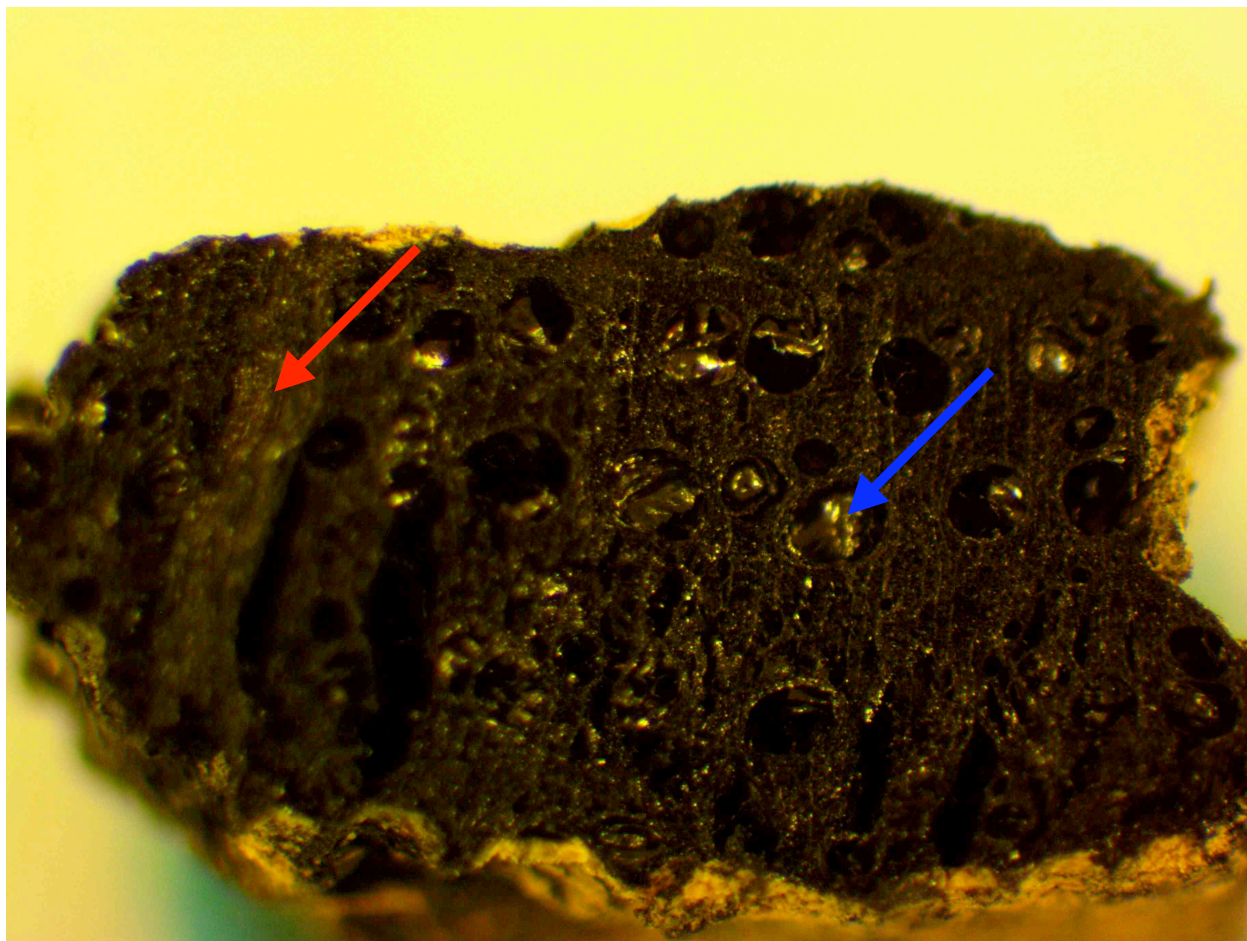


Figure 11. Charcoal from white oak sp. (*Quercus* sect. *Leucobalanus*), magnified 30x. Anatomical features that allow identification of white oak are wide aggregate rays (indicated by red arrow), multiple tyloses (an example of a tylose is indicated by blue arrow), pronounced earlywood pores clustered linearly along ring boundaries, and flame-like arrangement of latewood pores. Photograph by the author.

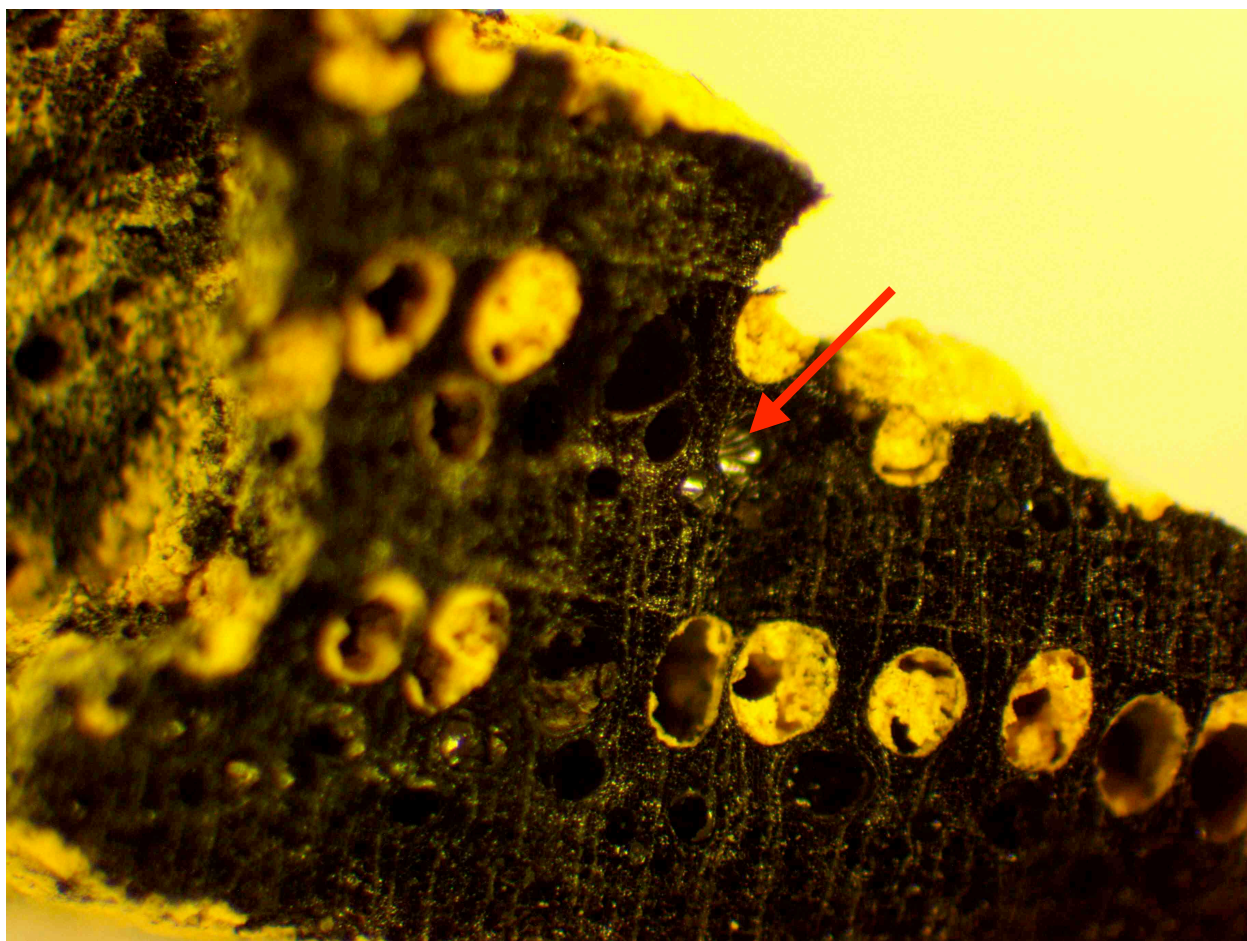


Figure 12. Charcoal from American chestnut (*Castanea dentata* (Marsh.) Borkh.), magnified 30x. Anatomical features that allow identification of American chestnut are an absence of wide rays, tyloses (indicated by arrow), pronounced earlywood pores clustered linearly along ring boundaries, and flame-like arrangement of latewood pores. Photograph by the author.



Figure 13. Charcoal from red maple (*Acer rubrum* L.), magnified 30x. Anatomical features that allow identification of red maple are narrow rays that are approximately the same width as the widest pores, no tyloses, and diffuse-porous wood. Photograph by the author.

compared using multiple ANOVAs (one ANOVA per site, $\alpha = 0.05$) to determine whether cores in close proximity to one another exhibited greater similarity in charcoal abundance than cores separated by greater distances. Normality was tested using the Shapiro-Wilk test (Delwiche and Slaughter 2012). Equality of variance was tested using the Levene's test (Delwiche and Slaughter 2012). A log-transformed value of total charcoal mass by core was used for sites where the normal distribution or the equal variance assumption was not met. Any log-transformed data were subsequently back transformed. I used Fisher's least significant difference test ($\alpha = 0.05$) to determine separation of mean charcoal mass by core. The Fisher's least significant difference test assigns the letter "A" to the mean(s) with the highest value. Subsequent letters of the alphabet are assigned to groups with significantly smaller means. Means in the same letter group are not significantly different from each other (Delwiche and Slaughter 2012). The relationship between charcoal mass and mid-point depth of core sections was tested using the Spearman's rank correlation coefficient ($\alpha = 0.05$, 2-tailed). The mid-point depth (*e.g.*, 25 cm) of each core section was used because depth ranges of core sections (*e.g.*, 20–30 cm) cannot be entered into a statistical test. This non-parametric Spearman's rank correlation coefficient was used because charcoal mass by depth was not normally distributed, and a log transformation did not produce a normal distribution of these data. Differences in mean charcoal mass by site were tested with an ANOVA ($\alpha = 0.05$). Normality was tested using the Shapiro-Wilk test. Equality of variance was tested using the Levene's test. Both ANOVA assumptions were met after a log transformation of the data, which were subsequently back transformed. I used Fisher's least significant difference test ($\alpha = 0.05$) to determine separation of mean charcoal mass by site. The relationship between charcoal age and mid-point depth of core sections was tested using the Pearson's product-moment correlation coefficient ($\alpha = 0.05$, 2-tailed). The parametric test was used because the

data were normally distributed. The association between charcoal age and site was tested using rank-transformed data in a non-parametric fixed-factor ANOVA ($\alpha = 0.05$). The non-parametric test was used because these data were not normally distributed, and a log transformation did not produce a normal distribution of these data. I used Fisher's least significant difference test ($\alpha = 0.05$) to determine separation of mean charcoal age by site.

I compared charcoal assemblages from surface samples (0–10 cm depth increments of every soil core) with basal area (m^2/ha) of currently living mature trees at each site to help determine the robustness of soil charcoal as a proxy for past forest community composition. Mature trees were defined as those with > 5 cm diameter at breast height (DBH). Modern vegetation data were provided by LaForest (2012). Charcoal is initially deposited on the soil surface following a fire and is later moved downward and mixed throughout the biomantle by geomorphic and biotic processes (Phillips and Marion 2006). Because of this, charcoal recovered from surface soils has the greatest likelihood of being of an age that is contemporary with current vegetation and was thus considered “modern” for this comparison.

To determine surface sample charcoal assemblages to compare with modern forest community composition, charcoal fragments recovered from each 500-cc surface soil sample were counted and haphazardly scattered on a 20 cm x 20 cm numbered grid. Charcoal fragments were dispersed so that each square on the grid was occupied by only one charcoal fragment. Charcoal fragments from the grid were randomly selected until exactly half the number of charcoal fragments per surface soil sample was selected. Randomly selected charcoal fragments were magnified 7 to 40x, cut transversely with a razor blade, and identified to the lowest possible taxonomic level. If a charcoal fragment was too small to cut with a razor blade and identify, it

was deemed “unidentifiable” and categorized as such. Charcoal mass for these fragments was tallied and separated by taxonomic category per study site.

Charcoal of many taxonomic groups was under-represented or not present in some 0–10 cm core increments. Therefore, taxonomic groups of surface-sample soil charcoal and forest mensuration data were consolidated in four major categories to ensure sufficient representation of taxa. The categories are mesic conifer, oak, other hardwood, and yellow pine. The mesic conifer category consists of eastern white pine with a minor eastern hemlock component. The oak category consists of both white and red oaks. The other hardwood category consists of all hardwoods other than oaks. I included American chestnut charcoal in this category (as opposed to creating a xeric to subxeric tree category for it) because American chestnut was such a significant component of multiple forest types, from cove hardwood to pitch pine, in the southern Appalachians (Woods and Shanks 1959). Also, in the drier portions of GRSM, blight-killed American chestnuts were rapidly replaced by red maple during the 20th century due to the abundant and widely dispersed seed supply of red maple and because of a lack of sufficient fire that would have curbed or excluded red maple at xeric sites (Woods and Shanks 1959).

Percentages of surface-sample charcoal mass and modern vegetation measurements for each of the four major taxonomic categories were entered into a modified *R*-value model (Davis 1963). This was repeated for each study site. Davis developed the *R*-value model to provide a past-vegetation correctional factor (*R*) based on the ratio of a taxon’s pollen percentage in a modern surface sample (P_m) to the percentage of that taxon in the surrounding present vegetation (V_m) (Davis 1963, Birks and Birks 1980). This is the first time the *R*-value model has been used for soil charcoal analysis. The *R*-value model is based on the assumptions that environmental proxy (*e.g.*, pollen) input is local and that input for the proxy deposited per unit time at a given

point is directly related to the abundance of the corresponding species in the surrounding vegetation (Davis 1963). For any taxon,

$$R = \frac{\text{modern charcoal percentage of taxon}}{\text{modern veg. percentage of taxon}} = \frac{C_m}{V_m}.$$

For this study, V_m is based on basal-area measurements, determined by LaForest (2012), of trees in the study sites. For outputs of the modified R -value model, an R -value of 1 indicates a proportional match between percentages of surface soil charcoal (C_m) and current forest vegetation (V_m). If a taxonomic group is over- or under-represented by soil charcoal, the R -value will be $<$ or $>$ 1, respectively. If the R -value has not changed through time, it may be possible to estimate past vegetation (V_p) based on past soil charcoal mass percentage (C_p) per site. For any taxon,

$$V_p = \frac{C_p}{R}.$$

A constraint of the predictive capabilities of Davis's R -value model is the potential error introduced by the contribution of pollen transported from long distances (Birks and Birks 1980). The use of soil charcoal (C_m) recovered from the 0–10 cm core increments instead of pollen (P_m) in the R -value model should alleviate this complication, because soil charcoal is not often transported far from its point of origin and, thus, is considered site-specific.

Chapter 5

Results

I recovered six soil cores from each of the eight sites, for a total of 48 cores. The 48 cores extracted from these sites yielded 315 individual, 10 cm core sections. The average depth of each core was approximately 65 cm, with some cores extending as deep as 100 cm. Macroscopic charcoal was present in all transects and cores, and occurred in 304 of the 315 core sections (97%) (Figures 14–21). A total of 83.41 g of charcoal was recovered from all sites (Figure 22).

Three of eight sites, Gold Mine Trail B, Rabbit Creek Trail C, and Pine Mountain C, exhibited significant differences in the distribution of macroscopic charcoal among replicate cores (Table 1). For these three sites, a Fisher's least significant difference test separated (*i.e.*, grouped) those cores with significantly different mean charcoal masses (Table 2). At Gold Mine Trail B and Pine Mountain C, the core with the greatest mean charcoal mass occurred at core position C (*i.e.*, the core position that was farthest downslope) of transect 1. At Gold Mine Trail B, the core with the least mean charcoal mass occurred at core position B of transect 1, while at Pine Mountain C, the core with the least mean charcoal mass occurred at core position C of transect 2. At Rabbit Creek Trail C, some cores differed significantly by mean charcoal mass, but there is no distinct pattern in the distribution of charcoal mass by core. Three of six transects at Gold Mine Trail B, Rabbit Creek Trail C, and Pine Mountain C exhibit an overall downslope increase in mean charcoal mass.

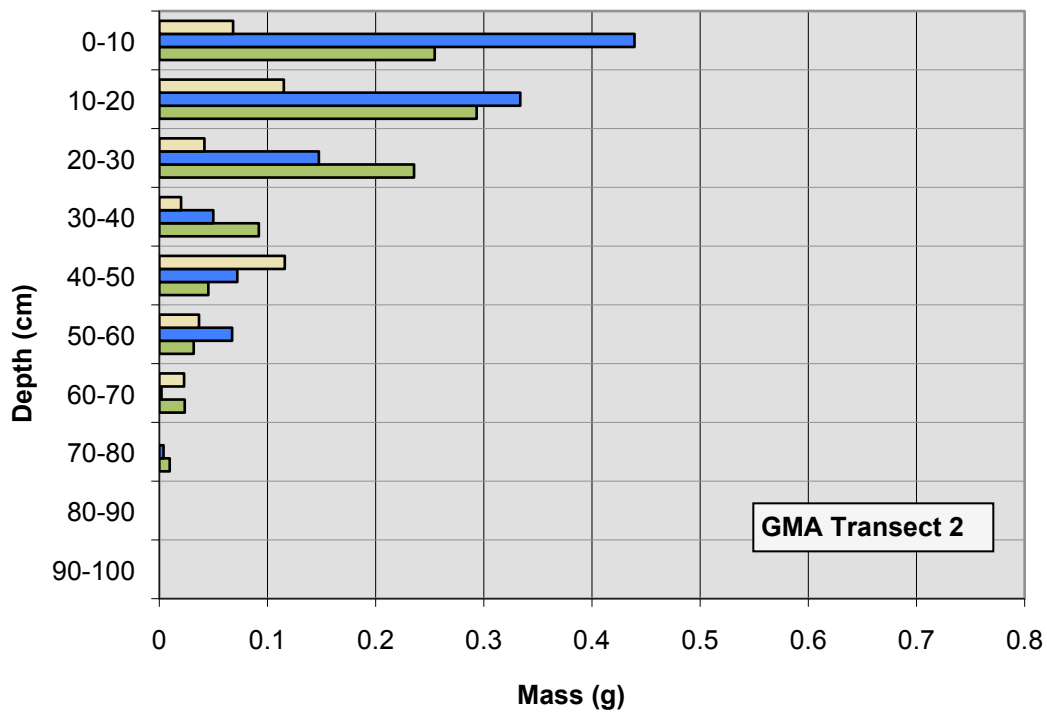
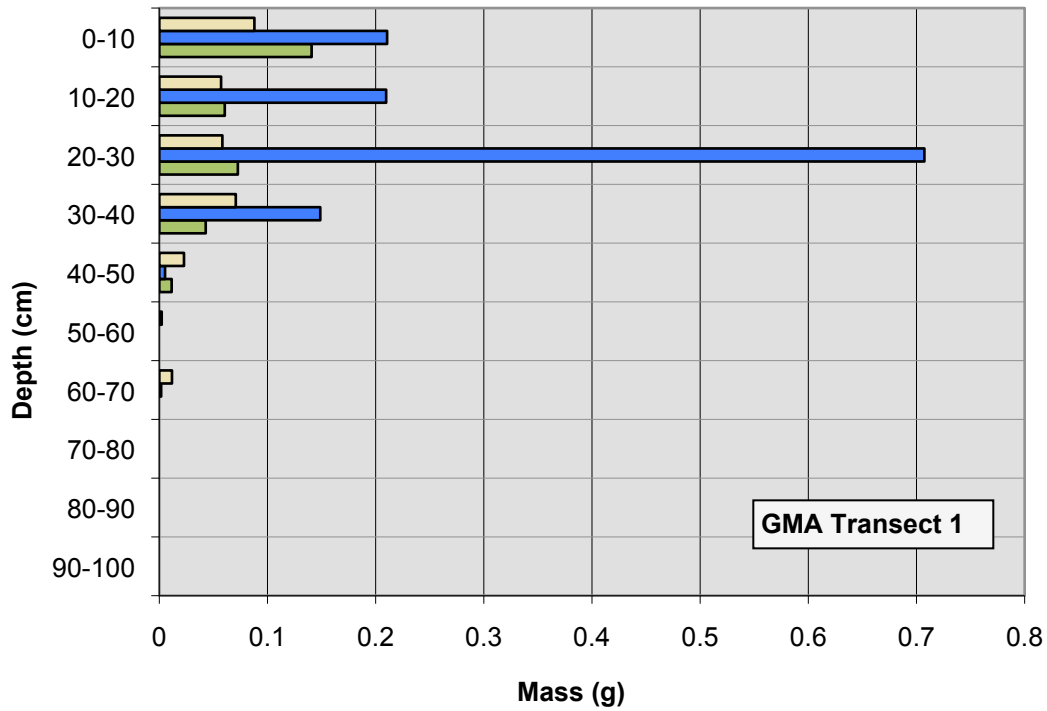


Figure 14. Total charcoal mass at Gold Mine Trail A, by transect and core. Core A is yellow, Core B is blue, and Core C is green.

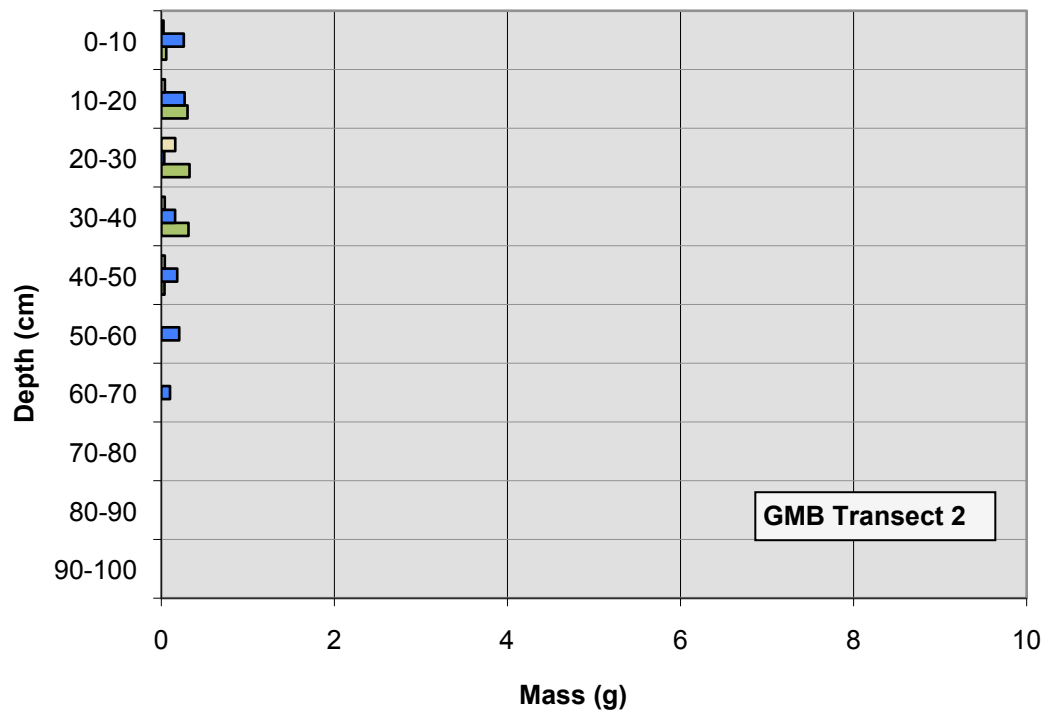
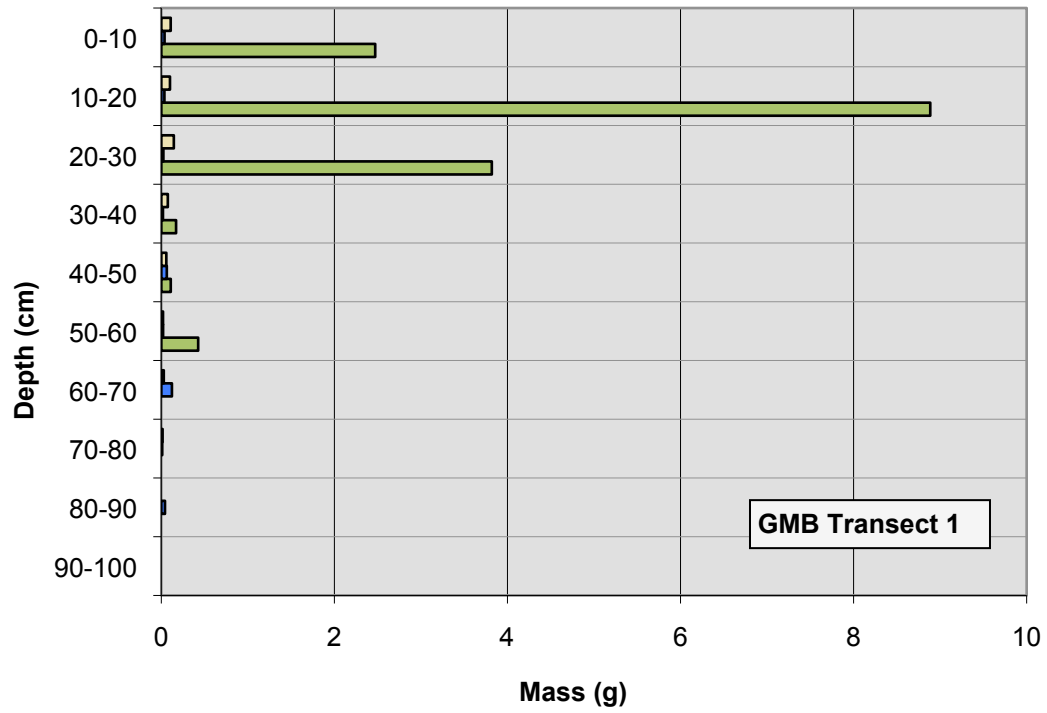


Figure 15. Total charcoal mass at Gold Mine Trail B, by transect and core. Core A is yellow, Core B is blue, and Core C is green.

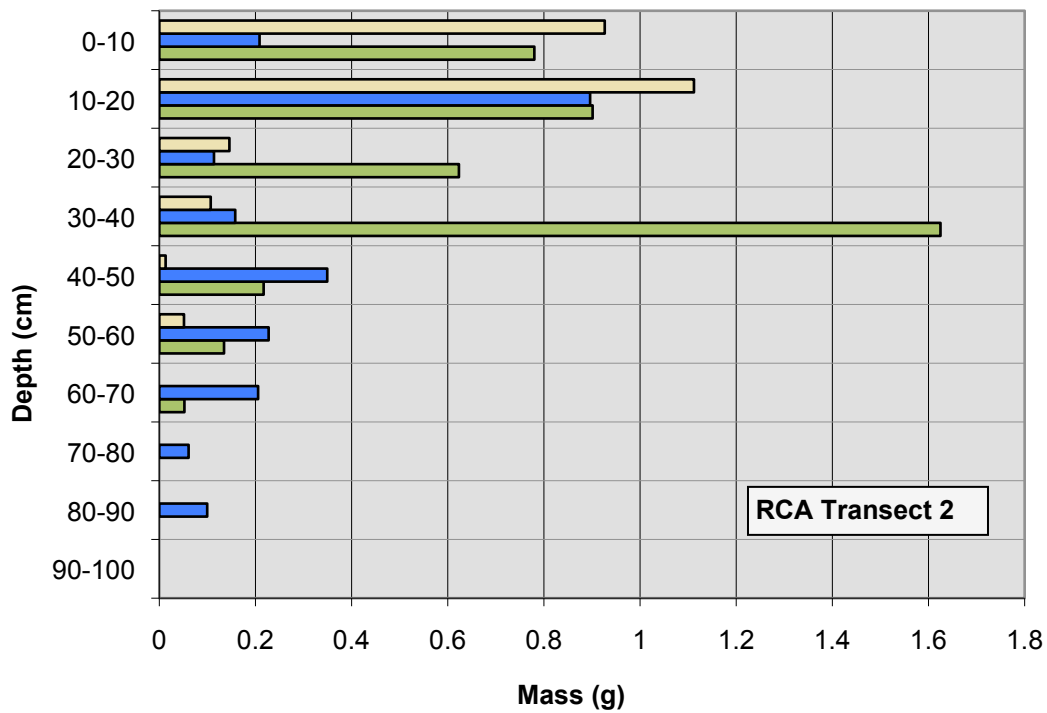
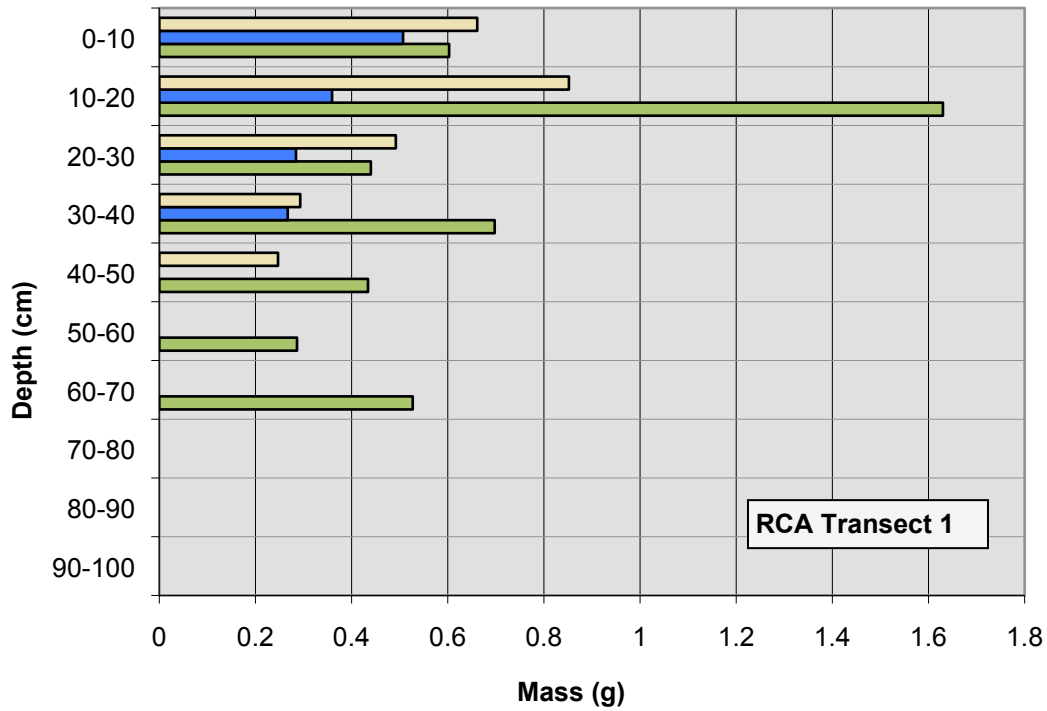


Figure 16. Total charcoal mass at Rabbit Creek Trail A, by transect and core. Core A is yellow, Core B is blue, and Core C is green.

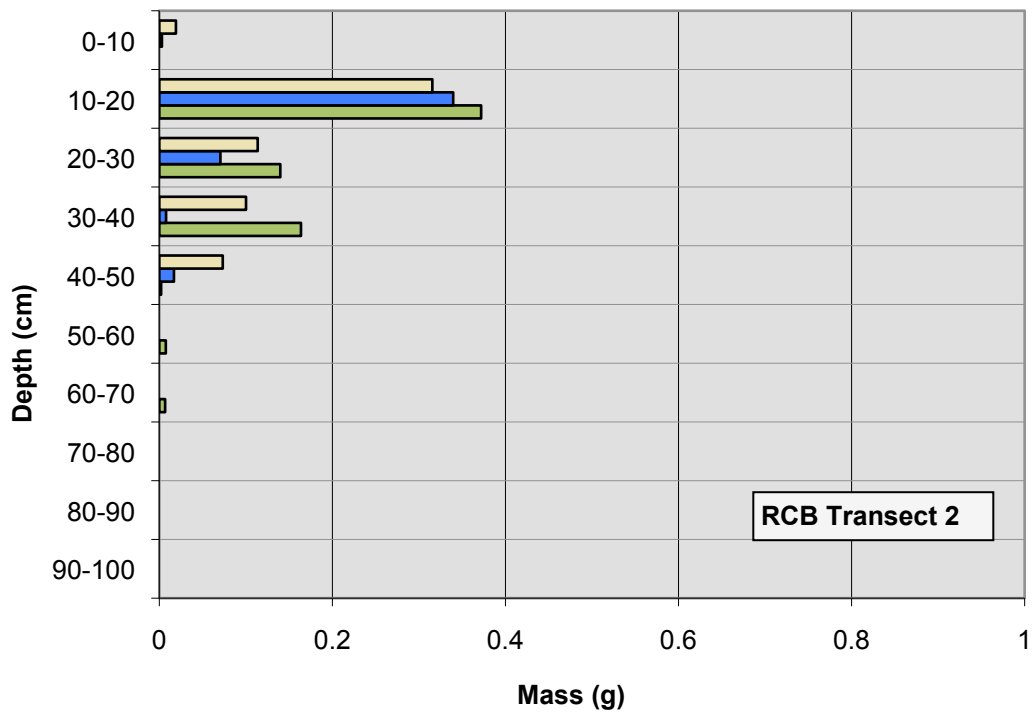
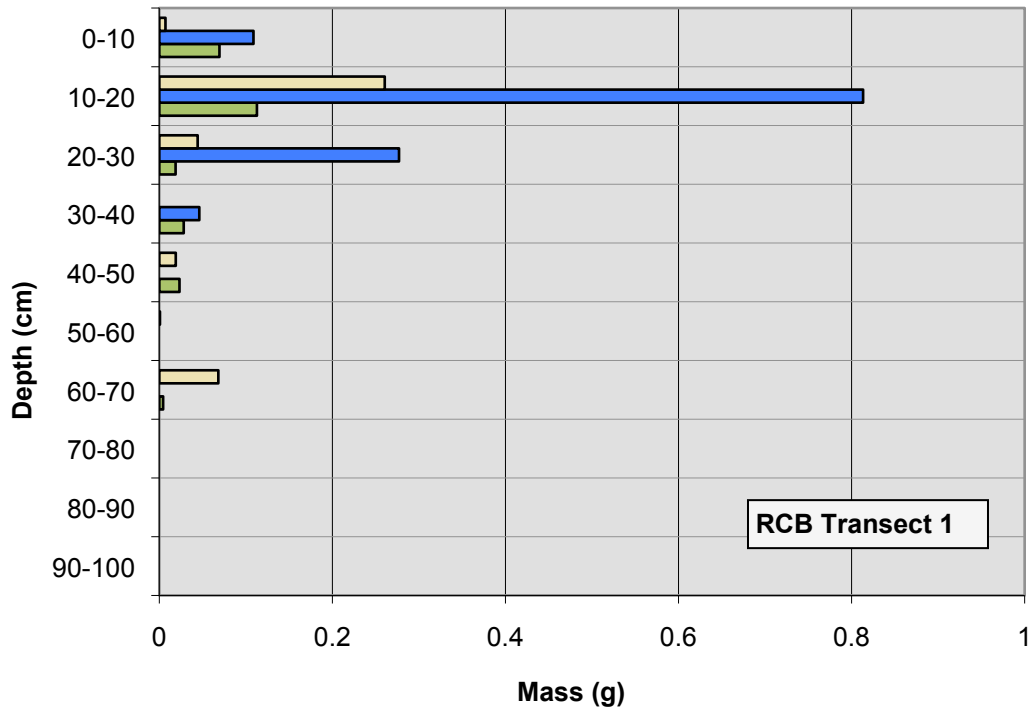


Figure 17. Total charcoal mass at Rabbit Creek Trail B, by transect and core. Core A is yellow, Core B is blue, and Core C is green.

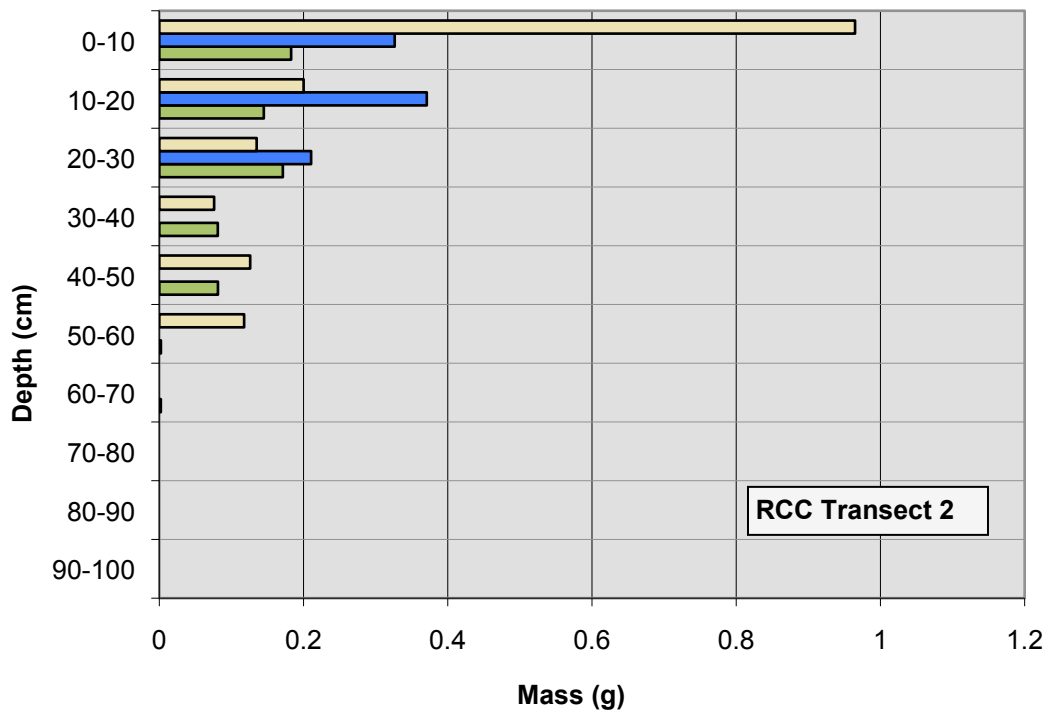
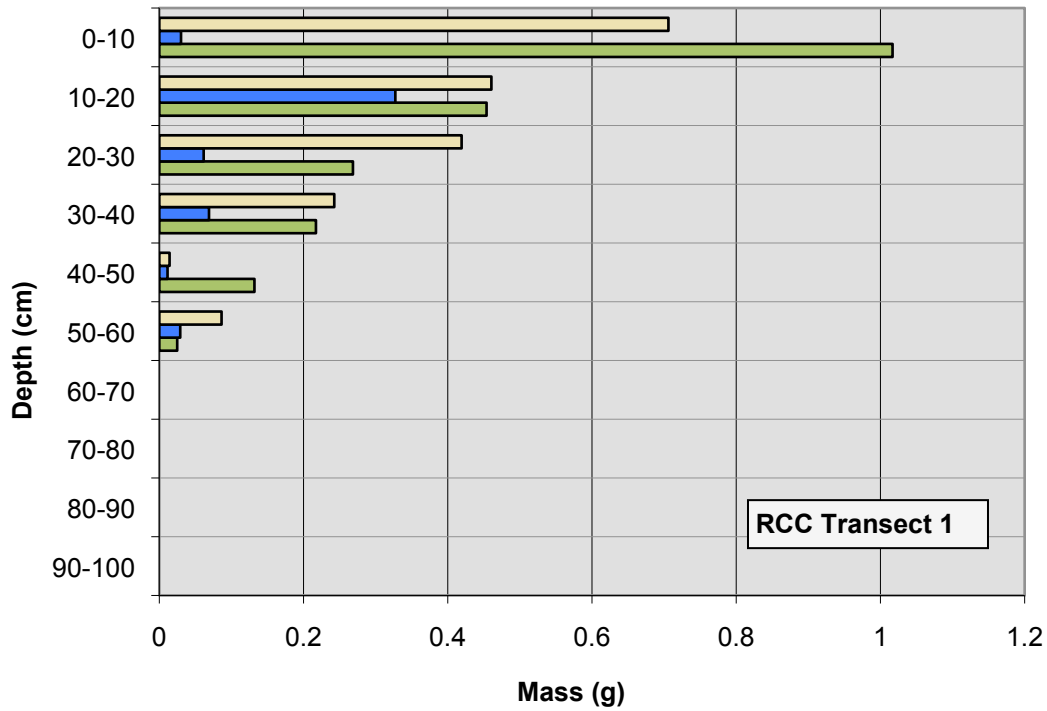


Figure 18. Total charcoal mass at Rabbit Creek Trail C, by transect and core. Core A is yellow, Core B is blue, and Core C is green.

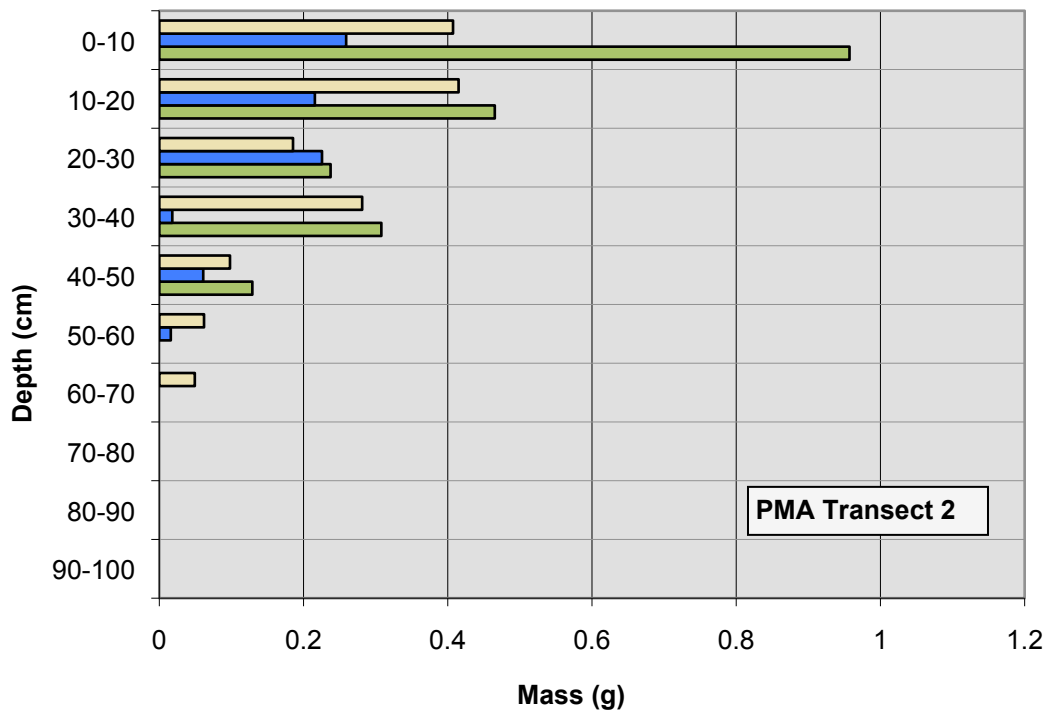
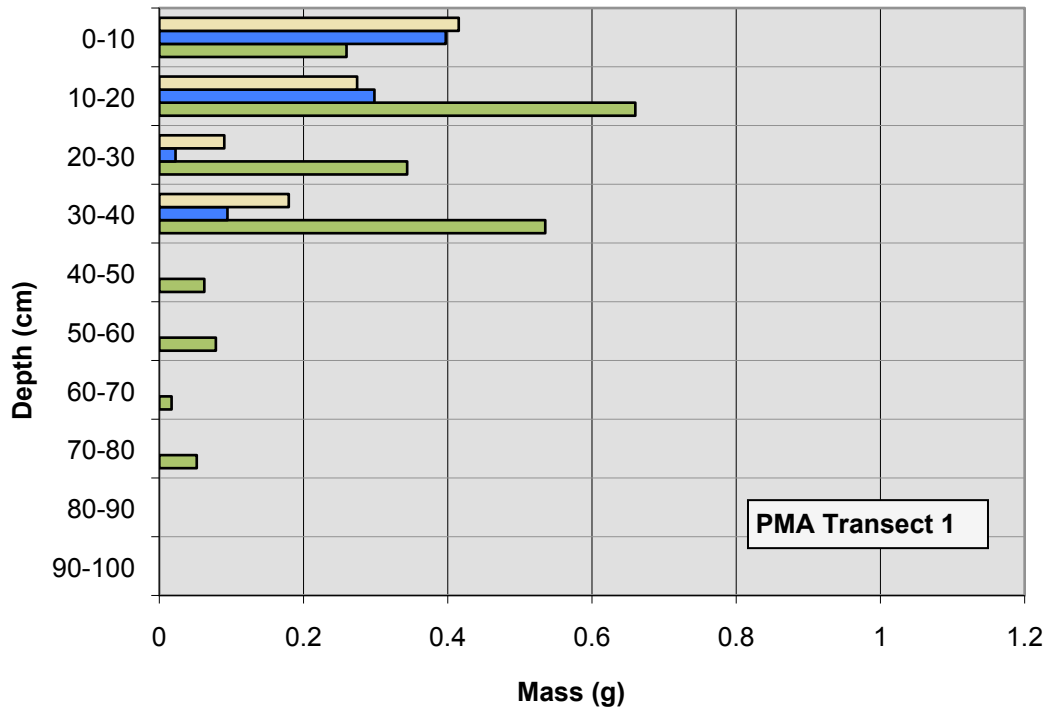


Figure 19. Total charcoal mass at Pine Mountain A, by transect and core. Core A is yellow, Core B is blue, and Core C is green.

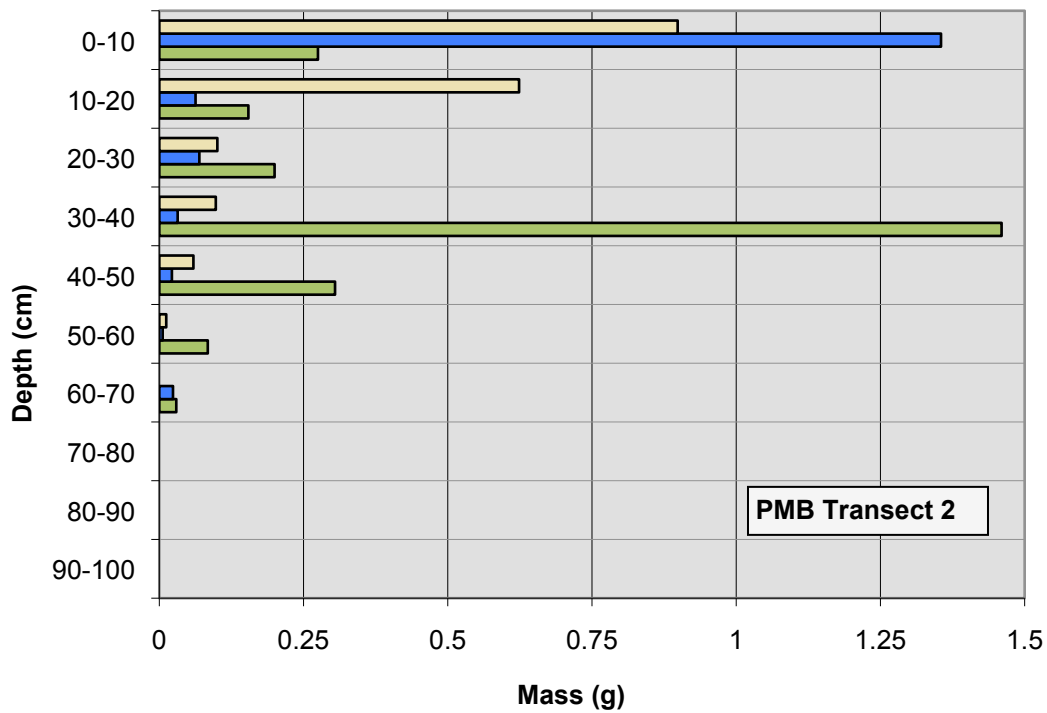
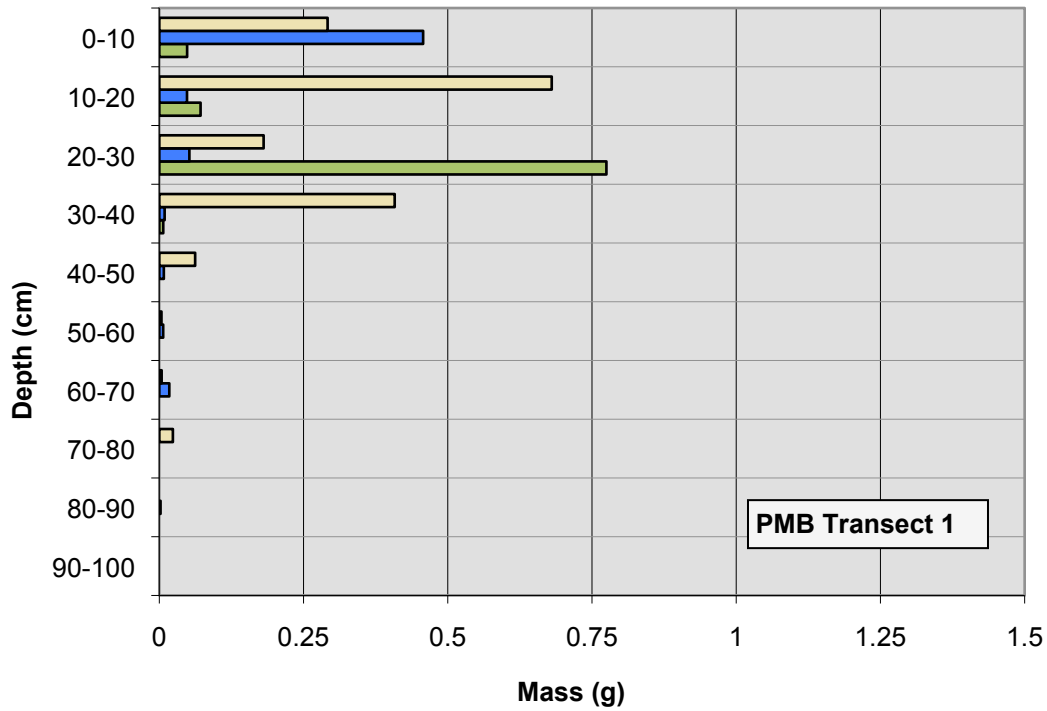


Figure 20. Total charcoal mass at Pine Mountain B, by transect and core. Core A is yellow, Core B is blue, and Core C is green.

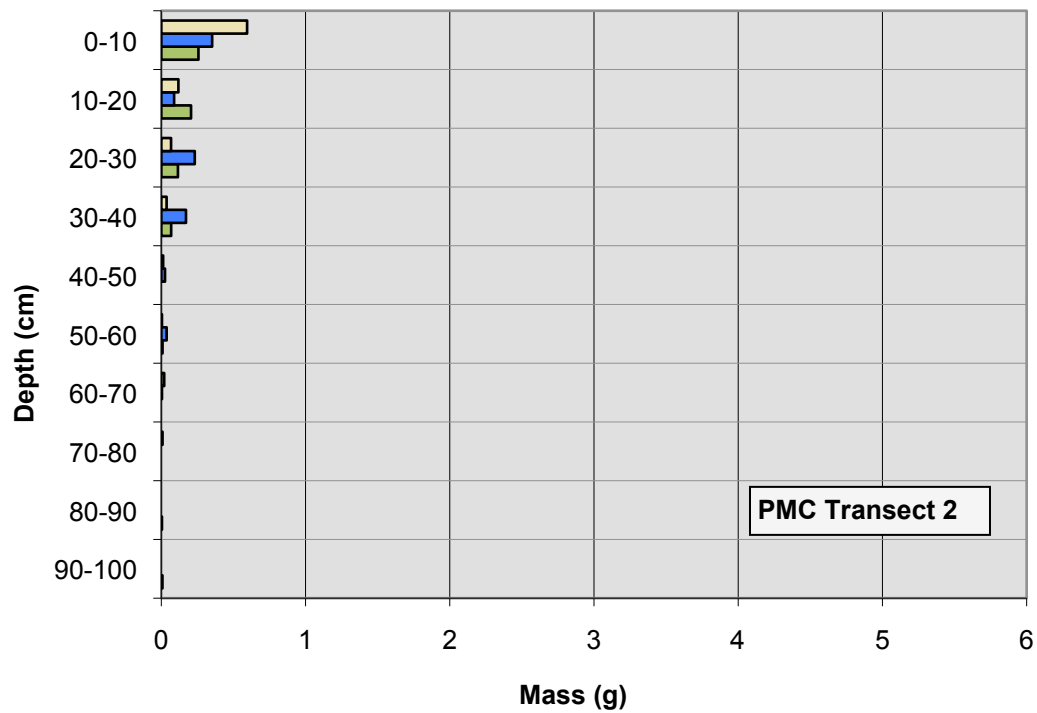
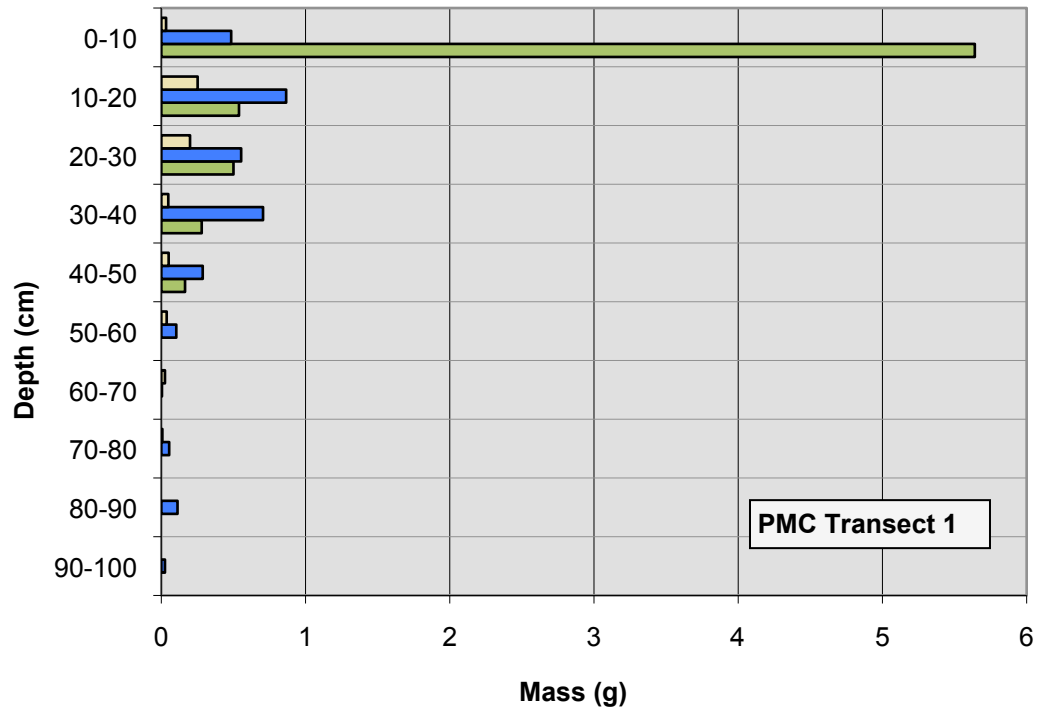


Figure 21. Total charcoal mass at Pine Mountain C, by transect and core. Core A is yellow, Core B is blue, and Core C is green.

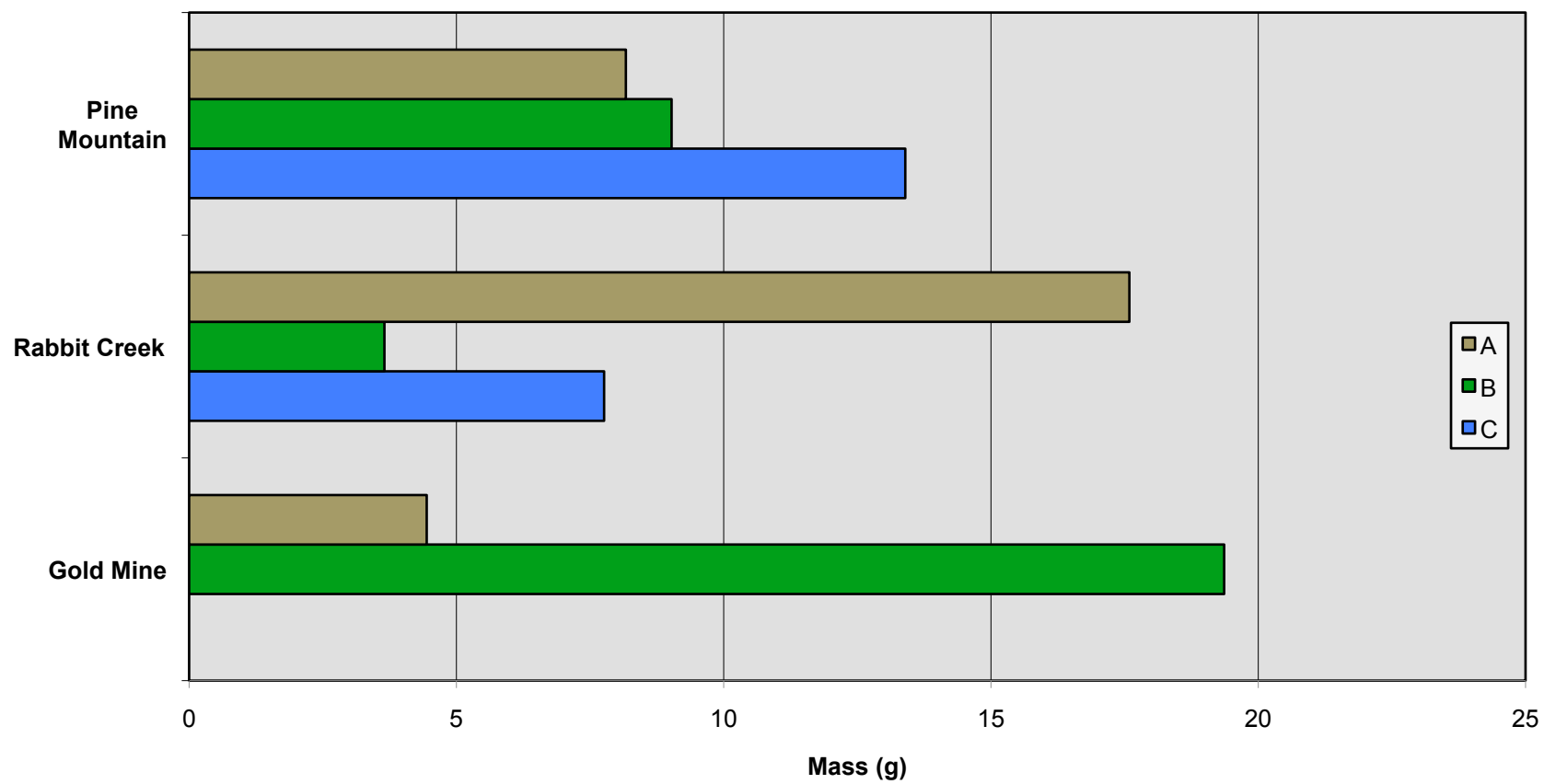


Figure 22. Total charcoal mass by study area and site (A–C).

Table 1. ANOVA results for variation in total charcoal mass by core for each site. A separate ANOVA was conducted for each site.

Site	numerator DF	denominator DF	<i>F</i> -value	<i>p</i> -value
Gold Mine Trail A [†]	5	38	1.16	0.3443
Gold Mine Trail B	5	34	9.42	< 0.0001 ^{***}
Rabbit Creek Trail A [†]	5	32	1.15	0.3545
Rabbit Creek Trail B	5	29	1.75	0.1550
Rabbit Creek Trail C	5	29	2.57	0.0485 [*]
Pine Mountain A [†]	5	28	1.13	0.3683
Pine Mountain B	5	35	1.38	0.2553
Pine Mountain C	5	42	4.78	0.0015 ^{**}

[†]Normally distributed data

^{*}Significant at $\alpha = 0.05$

^{**}Significant at $\alpha = 0.01$

^{***}Significant at $\alpha = 0.001$

Table 2. Least squares mean separation of charcoal mass by core. Mean groups were designated[†] by Fisher's least significant difference test. Only those sites that exhibited significant differences in total charcoal mass by core (Table 1) are included.

Site	Transect and core	<i>n</i> core sections	Back-transformed least squares mean mass (g)	Back-transformed standard error	Least squares mean group*	Observed mean mass (g) per core section	Observed σ
Gold Mine Trail B	1A	8	0.0603	0.0896	BC	0.07	0.05
	1B	9	0.0372	0.0751	C	0.04	0.03
	1C	6	1.0145	0.3214	A	2.65	3.40
	2A	5	0.0531	0.1096	BC	0.06	0.06
	2B	7	0.1560	0.1309	B	0.17	0.08
	2C	5	0.1640	0.1578	B	0.21	0.15
Rabbit Creek Trail C	1A	6	0.2282	0.1626	A	0.32	0.26
	1B	6	0.0617	0.1030	B	0.09	0.12
	1C	6	0.2422	0.1666	A	0.35	0.36
	2A	6	0.1864	0.1499	AB	0.27	0.34
	2B	3	0.2956	0.2563	A	0.30	0.08
	2C	8	0.0613	0.0891	B	0.08	0.08
Pine Mountain C	1A	8	0.0611	0.1015	BC	0.08	0.09
	1B	10	0.1941	0.1346	B	0.32	0.31
	1C	5	0.6154	0.3144	A	1.42	2.36
	2A	8	0.0552	0.0988	C	0.11	0.20
	2B	7	0.0934	0.1233	BC	0.13	0.13
	2C	10	0.0400	0.0817	C	0.07	0.10

$\alpha = 0.05$

[†]The letter "A" was assigned to the mean(s) with the highest value. Subsequent letters of the alphabet are assigned to groups with significantly smaller means. Means in the same letter group are not significantly different from each other.

Seven of eight individual sites and all sites combined exhibited significant and strong negative correlations between the distribution of macroscopic charcoal and depth in a soil core (Table 3). The Spearman's rank correlation coefficient implies a monotonic relationship in which the closer the coefficient is to ± 1 , the stronger the correlation, while the closer the coefficient is to 0, the weaker the correlation. A Spearman's rank correlation coefficient of ± 0.7 to ± 1 should be considered a strong association, while 0 to ± 0.40 should be considered a weak association (A. Reed, pers. communication).

Gold Mine Trail B produced the greatest total (19.36 g) and observed mean (3.23 g per core, $\sigma = 6.21$ g) charcoal mass of any site. However, 82% (15.88 g) of the charcoal from Gold Mine Trail B came from a single core (Gold Mine Trail B, transect 1, core C), and 46% (8.89 g) came from a single core section within that core (Gold Mine Trail B, transect 1, core C, 10–20 cm). Stratified-random selection of charcoal samples for radiocarbon dating produced eight charcoal samples from Gold Mine Trail B, transect 1, core C, ranging in depth from 20–60 cm. Weighted mean calibrated ages for these fragments range from 596 to 415 cal yr BP. All eight samples were identified as southern yellow pine. Therefore, this rather large spike in mass is likely the result of a large accumulation of charcoal from a single source such as a burned yellow pine tree limb that was subsequently buried within the soil profile. For Gold Mine Trail B, the extreme deviation in charcoal mass associated with this spike was reduced via a log transformation of the data. ANOVA results show that macroscopic charcoal mass varied significantly among study sites ($F = 2.36$; degrees of freedom = 7, 32; $p = 0.046$). Cores from Rabbit Creek Trail A contained the greatest mean charcoal mass, while cores from Rabbit Creek Trail B contained the least (Table 4).

Table 3. Spearman's rank correlation coefficient results for total charcoal mass vs. depth in core.

Site	<i>n</i> core sections	Spearman's <i>P</i>	<i>p</i> -value
Gold Mine Trail A	44	−0.791	< 0.001**
Gold Mine Trail B	40	−0.287	0.073
Rabbit Creek Trail A	38	−0.632	< 0.001**
Rabbit Creek Trail B	35	−0.380	0.025*
Rabbit Creek Trail C	35	−0.752	< 0.001**
Pine Mountain A	34	−0.745	< 0.001**
Pine Mountain B	41	−0.713	< 0.001**
Pine Mountain C	48	−0.742	< 0.001**
All sites combined	315	−0.595	< 0.001**

*Significant at $\alpha = 0.05$ (2-tailed)

**Significant at $\alpha = 0.01$ (2-tailed)

Table 4. Least squares mean separation of total charcoal mass by site. Mean groups were designated[†] by Fisher's least significant difference test.

Site	<i>n</i> cores	Back-transformed least squares mean mass (g)	Back-transformed standard error	Least squares mean group [*]	Observed mean (g) per core	Observed σ
Gold Mine Trail A	6	0.6351	0.2564	BC	0.7407	0.4365
Gold Mine Trail B	6	1.0709	0.3280	BC	3.2271	6.2105
Rabbit Creek Trail A	6	2.7122	0.5149	A	2.9315	1.2615
Rabbit Creek Trail B	6	0.5430	0.2386	C	0.6089	0.3490
Rabbit Creek Trail C	6	1.1395	0.3379	ABC	1.2938	0.6797
Pine Mountain A	6	1.2591	0.3545	ABC	1.3617	0.5936
Pine Mountain B	6	1.3656	0.3686	ABC	1.5042	0.6776
Pine Mountain C	6	1.4241	0.3761	AB	2.2347	2.5854

^{*} $\alpha = 0.05$

[†]The letter "A" was assigned to the mean(s) with the highest value. Subsequent letters of the alphabet are assigned to groups with significantly smaller means. Means in the same letter group are not significantly different from each other.

Uncalibrated radiocarbon dates for 122 randomly selected, individual charcoal fragments range from 8687 ± 49 to 60 ± 25 ^{14}C yr BP (Table 5). The weighted mean values of the 2- σ probability distributions for the calibrated ages range from 9649 to 107 cal yr BP. The older charcoal fragments (9649, 8099, and 8059 cal yr BP) provide evidence that fires occurred in the westernmost portion of GRSM during the early Holocene, and that charcoal from that period was preserved in soils.

Tests of association using the Pearson's product-moment correlation coefficient showed that a significant correlation between age of macroscopic charcoal fragments and depth in the soil column only exists for charcoal samples from Pine Mountain A (Table 6, Figures 23–25). The correlation is negative, meaning that age of charcoal decreases as depth increases. When all sites are combined, there is no statistically significant correlation between macroscopic charcoal age and depth (Table 6, Figure 26).

The charcoal dates indicate that fires occurred regularly at all study areas from ca. 4000 to 100 cal yr BP (Figure 27). Fesenmyer and Christensen (2010) proposed an inbuilt-error estimate of 50 to 100 years for southern Appalachian hardwood-pine forests. Therefore, the dates of fire events are possibly 50 to 100 years more recent than the weighted mean calibration age of some charcoal fragments. Radiocarbon-dated charcoal fragments that have calibrated age ranges ($\pm 2 \sigma$, 95% confidence interval) and inbuilt-age estimates that do not overlap with adjacent periods of fire activity constitute a distinct, coarse-resolution fire window. Eleven such windows occurred at Gold Mine Trail, 14 at Rabbit Creek Trail, and 11 at Pine Mountain (Figures 28–30), for a total of 36 fire windows. The use of a fire window to define the occurrence of a fire is a highly conservative approach, since charcoal fragments with overlapping calibrated age ranges and inbuilt-age estimates could also represent multiple fire events. Because of the degree of error

Table 5. Taxonomic identifications and AMS ^{14}C dates on randomly selected soil-charcoal samples from eight sites.

Lab number ^a	Site, core, and depth (cm)	Sample ID ^b	$\delta^{13}\text{C}$ (‰)	Uncalibrated ^{14}C age (^{14}C yr BP)	Calibrated age range (cal yr BP) $\pm 2 \sigma^c$	Relative area under prob. curve	Weighted mean calibration age (cal yr BP) ^d
AA91283	GMA 1B 20–30	<i>Pinus</i>	–26.4	1198 $\pm$ 31	1027–1010 1183–1054 1238–1205	0.021 0.916 0.063	1124
AA91284	GMA 1B 20–30	SYP	–25.3	533 $\pm$ 30	560–511 631–599	0.773 0.227	556
AA91285	GMA 1B 30–40	<i>Pinus</i>	–24.3	1231 $\pm$ 31	1190–1068 1262–1197	0.662 0.338	1166
AA91286	GMA 2A 40–50	SYP	–26.7	3417 $\pm$ 34	3728–3573 3765–3748 3823–3792	0.905 0.024 0.071	3673
AA91287	GMA 2A 40–50	SYP	–26.6	3452 $\pm$ 35	3830–3637	1.0	3728
AA91288	GMA 2C 20–30	<i>Pinus</i>	–27.5	3557 $\pm$ 35	3800–3721 3930–3810 3967–3944	0.243 0.715 0.042	3845
AA91289	GMB 1C 20–30	SYP	–26.1	588 $\pm$ 30	570–536 651–580	0.297 0.703	596
AA91290	GMB 1C 20–30	SYP	–26.7	371 $\pm$ 34	400–316 406–402 504–421	0.431 0.010 0.559	415
AA91291	GMB 1C 20–30	SYP	–26.7	397 $\pm$ 41	397–317 517–422	0.327 0.673	433
AA91292	GMB 1C 20–30	SYP	–27.0	500 $\pm$ 30	552–502 616–614	0.996 0.004	528
AA91293	GMB 1C 20–30	SYP	–26.7	371 $\pm$ 32	399–316 405–405 504–422	0.426 0.002 0.572	416
AA91294	GMB 1C 20–30	SYP	–27.2	448 $\pm$ 30	535–468	1.0	503
AA91295	GMB 1C 50–60	SYP	–25.9	508 $\pm$ 34	557–503 625–606	0.928 0.072	536

Table 5. (continued)

Lab number ^a	Site, core, and depth (cm)	Sample ID ^b	$\delta^{13}\text{C}$ (‰)	Uncalibrated ^{14}C age (^{14}C yr BP)	Calibrated age range (cal yr BP) $\pm 2 \sigma^c$	Relative area under prob. curve	Weighted mean calibration age (cal yr BP) ^d
AA91296	RCA 1A 20–30	<i>Pinus</i>	–25.8	477 ± 43	346–343 557–462 626–605	0.003 0.963 0.034	517
AA91297	RCA 1C 50–60	SYP	–26.1	951 ± 32	928–793	1.0	857
AA91298	RCA 1C 60–70	SYP	–26.3	789 ± 31	743–671 762–752	0.979 0.021	709
AA91299	RCA 2B 60–70	PIST	–27.8	3004 ± 47	3046–3041 3352–3063	0.003 0.997	3199
AA91300	PMA 1A 30–34	SYP	–27.4	170 ± 33	35 to –3* 118–69 230–131 248–244 293–250	0.192 0.102 0.517 0.003 0.185	157
AA91301	PMA 1B 20–30	SYP	–26.3	1278 ± 34	1105–1094 1161–1138 1291–1168	0.011 0.036 0.953	1219
AA91302	PMA 1B 30–40	SYP	–26.7	1782 ± 40	1580–1573 1820–1602	0.009 0.991	1705
AA91303	PMA 1C 30–40	SYP	–27.2	280 ± 31	166–155 334–284 439–349 455–444	0.025 0.396 0.563 0.016	357
AA91304	PMA 1C 50–60	SYP	–26.8	236 ± 40	23 to –2* 219–141 330–263 369–359 429–372	0.097 0.367 0.418 0.008 0.111	235
AA91305	PMA 2A 20–30	<i>Pinus</i>	–28.3	1742 ± 40	1739–1542 1778–1758	0.983 0.017	1652

Table 5. (continued)

Lab number ^a	Site, core, and depth (cm)	Sample ID ^b	$\delta^{13}\text{C}$ (‰)	Uncalibrated ^{14}C age (^{14}C yr BP)	Calibrated age range (cal yr BP) $\pm 2 \sigma^c$	Relative area under prob. curve	Weighted mean calibration age (cal yr BP) ^d
AA91306	PMA 2A 30–40	SYP	–28.7	278 ± 33	167–154	0.036	353
					334–283	0.398	
					440–349	0.544	
					456–441	0.023	
AA91307	PMA 2A 30–40	SYP	–27.8	220 ± 33	23 to –2 [*]	0.133	197
					219–142	0.485	
					311–264	0.381	
AA91308	PMA 2B 20–30	SYP	–26.6	3098 ± 45	3405–3209	0.989	3312
					3440–3429	0.011	
AA91309	PMA 2C 20–30	<i>Pinus</i>	–27.2	2323 ± 33	2236–2183	0.085	2335
					2368–2305	0.860	
					2402–2388	0.012	
					2439–2408	0.036	
					2454–2446	0.007	
AA91310	PMB 1A 40–50	CADN	–25.8	3399 ± 37	3516–3514	0.001	3648
					3726–3558	0.957	
					3762–3750	0.009	
					3821–3793	0.033	
AA91311	PMB 1B 20–30	QU ERYTHRO	–25.8	2549 ± 33	2598–2495	0.355	2643
					2639–2611	0.174	
					2750–2684	0.471	
AA91312	PMB 1B 60–70	CADN	–26.9	234 ± 40	24 to –2 [*]	0.102	230
					220–141	0.383	
					328–261	0.412	
					368–359	0.006	
					429–374	0.097	
AA91313	PMB 1C 20–30	PIST	–26.1	2109 ± 31	2152–1995	0.992	2083
					2285–2280	0.008	

Table 5. (continued)

Lab number ^a	Site, core, and depth (cm)	Sample ID ^b	$\delta^{13}\text{C}$ (‰)	Uncalibrated ^{14}C age (^{14}C yr BP)	Calibrated age range (cal yr BP) $\pm 2 \sigma^c$	Relative area under prob. curve	Weighted mean calibration age (cal yr BP) ^d
AA91314	PMB 2A 20–30	<i>Pinus</i>	–27.5	130 ± 30	0* to –3* 45–9 151–57 275–172	0.004 0.157 0.442 0.397	139
AA91315	PMB 2B 20–30	<i>Pinus</i>	–25.9	6122 ± 43	7158–6899	1.0	7024
AA91316	PMB 2C 30–40	QU LEUCO	–27.1	1874 ± 36	1885–1717	1.0	1809
AA91317	PMC 1A 20–30	SYP	–25.9	7231 ± 46	8162–7968	1.0	8059
AA91318	PMC 1A 40–50	SYP	–25.4	332 ± 34	479–307	1.0	392
AA91319	PMC 1B 40–50	PIST	–27.2	2174 ± 36	2087–2062	0.039	2206
AA91320	PMC 1C 20–30	<i>Pinus</i>	–26.3	1783 ± 46	1585–1569 1822–1592	0.023 0.977	1706
AA91321	PMC 1C 30–40	SYP	–27.1	241 ± 35	19 to –1* 215–145 322–267 428–377	0.076 0.328 0.485 0.111	246
AA91322	PMC 1C 40–48	<i>cf.</i> CADN	–26.8	3335 ± 39	3643–3468 3684–3662	0.959 0.041	3565
AA91323	PMC 2A 30–40	SYP	–27.2	304 ± 35	467–295	1.0	379
AA91324	PMC 2B 30–40	SYP	–26.0	157 ± 35	40 to –3* 119–60 158–122 233–164 285–241	0.187 0.176 0.123 0.339 0.175	151
AA91325	RCB 1A 60–68	SYP	–26.5	214 ± 35	30 to –2* 222–139 311–258	0.151 0.509 0.340	189

Table 5. (continued)

Lab number ^a	Site, core, and depth (cm)	Sample ID ^b	$\delta^{13}\text{C}$ (‰)	Uncalibrated ^{14}C age (^{14}C yr BP)	Calibrated age range (cal yr BP) $\pm 2 \sigma^c$	Relative area under prob. curve	Weighted mean calibration age (cal yr BP) ^d
AA91326	RCB 1B 20–30	SYP	–26.7	422 $\pm$ 35	359–330 373–369 530–429	0.104 0.005 0.891	468
AA91327	RCB 1B 30–36	SYP	–27.3	141 $\pm$ 35	0* to –3* 43–3 153–58 282–169	0.006 0.163 0.375 0.456	144
AA91328	RCB 1B 30–36	SYP	–26.9	143 $\pm$ 35	0* to –3* 42–2 153–59 282–169	0.007 0.166 0.365 0.462	145
AA91329	RCB 1C 40–50	PIST cf.	–26.5	201 $\pm$ 36	32 to –2* 76–75 97–83 112–108 224–137 307–255	0.175 0.001 0.013 0.004 0.532 0.275	175
AA91330	RCB 2A 20–30	SYP	–25.0	1207 $\pm$ 42	1028–1009 1263–1053	0.030 0.970	1136
AA91331	RCB 2A 30–40	PIST	–26.1	1230 $\pm$ 36	1263–1066	1.0	1164
AA91332	RCB 2C 20–30	<i>Pinus</i>	–26.7	1866 $\pm$ 64	1670–1624 1947–1689	0.049 0.951	1798
AA91333	RCB 2C 30–40	PIST	–26.5	683 $\pm$ 35	600–559 685–630	0.370 0.630	629
AA91334	RCC 1A 20–30	PIST	–27.5	5846 $\pm$ 44	6512–6508 6752–6533 6777–6764	0.003 0.982 0.015	6657
AA91335	RCC 1A 20–30	PIST	–27.0	5822 $\pm$ 44	6524–6503 6733–6526	0.044 0.956	6623

Table 5. (continued)

Lab number ^a	Site, core, and depth (cm)	Sample ID ^b	$\delta^{13}\text{C}$ (‰)	Uncalibrated ^{14}C age (^{14}C yr BP)	Calibrated age range (cal yr BP) $\pm 2 \sigma^c$	Relative area under prob. curve	Weighted mean calibration age (cal yr BP) ^d
AA91336	RCC 1B 30–40	PIST	–26.3	319 ± 35	474–303	1.0	387
AA91337	RCC 1C 30–40	CADN	–26.3	4185 ± 40	4582–4602 4769–4607 4841–4781	0.034 0.725 0.241	4719
AA91338	RCC 2A 20–30	SYP	–26.1	263 ± 35	9 to –1* 173–151 181–180 334–274 439–349 455–443	0.018 0.111 0.002 0.476 0.382 0.011	317
AA91339	RCC 2A 40–50	PIST	–26.5	707 ± 35	594–562 699–636 710–704 721–719	0.184 0.805 0.009 0.001	652
AA91340	RCC 2A 50–60	PIST	–26.5	362 ± 35	410–316 501–421	0.501 0.499	408
AA91341	RCC 2A 50–60	SYP	–26.0	186 ± 35	33 to –2* 115–73 225–136 302–254	0.188 0.055 0.534 0.223	165
AA91342	RCC 2B 20–30	CADN	–27.6	2505 ± 38	2387–2369 2741–2458	0.013 0.987	2588
AA91343	RCC 2C 20–30	<i>Pinus</i>	–25.8	3666 ± 40	3881–3880 4093–3885 4143–4126	0.001 0.977 0.023	3999

Table 5. (continued)

Lab number ^a	Site, core, and depth (cm)	Sample ID ^b	$\delta^{13}\text{C}$ (‰)	Uncalibrated ^{14}C age (^{14}C yr BP)	Calibrated age range (cal yr BP) $\pm 2 \sigma^c$	Relative area under prob. curve	Weighted mean calibration age (cal yr BP) ^d
AA91344	RCC 2C 40–50	SYP	–26.7	6302 ± 46	7041–7029	0.005	7227
					7076–7070	0.003	
					7094–7087	0.003	
					7109–7103	0.003	
					7327–7156	0.974	
					7366–7360	0.003	
					7412–7396	0.009	
AA93006	GMA 1A 30–40	PIST	–28.2	1497 ± 39	1421–1305	0.856	1388
					1441–1433	0.012	
					1515–1460	0.131	
AA93007	GMA 1A 40–50	PIST	–26.2	2100 ± 42	1963–1949	0.015	2078
					2156–1967	0.945	
					2296–2267	0.040	
AA93008	GMA 2B 30–40	<i>cf.</i> CADN	–29.0	2397 ± 43	2520–2340	0.801	2467
					2541–2525	0.015	
					2615–2591	0.040	
					2698–2636	0.145	
AA93009	GMA 2B 40–50	QU ERYTHRO	–26.1	3865 ± 55	4117–4098	0.019	4287
					4423–4146	0.981	
AA93010	GMB 1A 20–30	PIST	–27.0	3246 ± 43	3567–3381	1.0	3473
AA93011	GMB 1A 30–40	PIST	–26.7	2027 ± 41	2068–1889	0.930	1986
					2112–2079	0.070	
AA93012	GMB 2A 20–30	ULAM	–25.6	5760 ± 51	6671–6438	1.0	6560
AA93013	GMB 2B 30–40	CADN	–26.1	2171 ± 36	2089–2061	0.050	2202
					2314–2097	0.950	
AA93014	GMB 2B 40–50	<i>Pinus</i>	–27.7	1202 ± 34	1026–1012	0.019	1129
					1185–1054	0.872	
					1244–1202	0.097	
					1257–1246	0.012	

Table 5. (continued)

Lab number ^a	Site, core, and depth (cm)	Sample ID ^b	$\delta^{13}\text{C}$ (‰)	Uncalibrated ^{14}C age (^{14}C yr BP)	Calibrated age range (cal yr BP) $\pm 2 \sigma^c$	Relative area under prob. curve	Weighted mean calibration age (cal yr BP) ^d
AA93015	GMB 2B 50–60	<i>Pinus</i>	–26.0	2103 $\pm$ 35	2153–1990 2292–2274	0.980 0.020	2078
AA93016	GMB 2B 60–65	PIST	–26.7	1698 $\pm$ 35	1695–1535	1.0	1611
AA93017	GMB 2C 20–30	PIST	–27.4	354 $\pm$ 33	413–315 496–419	0.544 0.456	403
AA93018	GMB 2C 30–40	PIST	–27.5	411 $\pm$ 33	362–325 376–366 521–428	0.142 0.015 0.843	458
AA93019	RCA 1A 30–40	<i>Pinus</i>	–26.6	3119 $\pm$ 37	3409–3249 3441–3425	0.973 0.027	3338
AA93020	RCA 1A 40–50	TSCA	–26.6	377 $\pm$ 34	398–317 506–422	0.400 0.600	420
AA93021	RCA 1B 20–30	PIST	–27.6	4538 $\pm$ 40	5200–5047 5316–5211	0.629 0.371	5179
AA93022	RCA 1B 30–40	<i>Pinus</i>	–26.6	8687 $\pm$ 49	9786–9539 9864–9849 9885–9877	0.984 0.010 0.006	9649
AA93023	RCA 1C 20–30	SYP	–26.3	1653 $\pm$ 33	1467–1418 1502–1487 1626–1507 1690–1668	0.097 0.015 0.844 0.044	1554
AA93024	RCA 1C 30–40	PIST	–27.6	97 $\pm$ 33	–1* to –4* 147–14 193–189 268–213	0.012 0.703 0.006 0.279	128
AA93025	RCA 1C 60–70	SYP	–26.7	695 $\pm$ 32	593–562 688–637	0.254 0.746	641
AA93026	RCA 2B 40–50	PIST	–26.4	387 $\pm$ 34	393–318 509–425	0.336 0.664	430

Table 5. (continued)

Lab number ^a	Site, core, and depth (cm)	Sample ID ^b	$\delta^{13}\text{C}$ (‰)	Uncalibrated ^{14}C age (^{14}C yr BP)	Calibrated age range (cal yr BP) $\pm 2 \sigma^c$	Relative area under prob. curve	Weighted mean calibration age (cal yr BP) ^d
AA93027	RCA 2C 30–40	QU LEUCO	–26.9	1828 ± 32	1645–1637	0.009	1766
					1831–1695	0.951	
					1864–1841	0.040	
AA93028	RCA 2C 30–40	QU LEUCO	–26.9	1842 ± 32	1865–1710	1.0	1778
AA93029	PMA 1A 20–30	PIST	–25.5	1012 ± 34	815–798	0.040	923
					868–823	0.130	
					981–899	0.815	
					1047–1036	0.015	
AA93030	PMA 1C 30–40	SYP	–26.7	154 ± 33	40 to –3 [*]	0.188	150
					119–60	0.184	
					155–122	0.120	
					233–166	0.336	
					284–241	0.173	
AA93031	PMA 2B 20–30	PIST	–26.7	701 ± 32	591–563	0.204	648
					690–639	0.796	
AA93032	PMA 2C 20–30	PIST	–27.0	2057 ± 32	1939–1933	0.010	2026
					2119–1945	0.990	
AA93033	PMA 2C 40–42	PIST	–27.8	195 ± 33	32 to –2 [*]	0.180	171
					88–84	0.004	
					96–92	0.004	
					111–109	0.003	
					223–137	0.554	
					304–256	0.256	
AA93034	PMB 1A 20–30	CADN	–25.7	3457 ± 33	3784–3640	0.744	3734
					3829–3785	0.256	
AA93035	PMB 1A 30–40	CADN	–27.1	3423 ± 34	3578–3730	0.864	3683
					3746–3769	0.041	
					3791–3825	0.095	

Table 5. (continued)

Lab number ^a	Site, core, and depth (cm)	Sample ID ^b	$\delta^{13}\text{C}$ (‰)	Uncalibrated ^{14}C age (^{14}C yr BP)	Calibrated age range (cal yr BP) $\pm 2 \sigma^c$	Relative area under prob. curve	Weighted mean calibration age (cal yr BP) ^d
AA93036	PMB 1A 30–40	CADN	–26.2	3337 ± 39	3643–3470	0.952	3567
AA93037	PMB 1C 20–30	PIST	–26.2	2188 ± 37	2075–2074 2330–2114	0.002 0.998	2219
AA93038	PMB 2A 40–50	<i>cf. Pinus</i>	–27.0	2034 ± 37	2068–1897 2112–2079	0.921 0.079	1994
AA93039	PMB 2B 30–40	<i>Pinus</i>	–26.5	4512 ± 41	4990–4989 5311–5039	0.001 0.999	5165
AA93040	PMB 2C 30–40	QU ERYTHRO	–25.9	1805 ± 37	1675–1616 1825–1686 1858–1852	0.148 0.846 0.006	1739
AA93041	PMC 1A 30–40	SYP	–26.6	7291 ± 47	8184–8007	1.0	8099
AA93042	PMC 1B 20–30	CADN	–26.0	1834 ± 37	1644–1638 1870–1695	0.008 0.992	1770
AA93043	RCB 1A 20–30	TSCA	–26.7	124 ± 35	0* to –3* 49–9 151–52 179–173 274–181	0.009 0.159 0.456 0.016 0.361	137
AA93044	RCC 1C 20–30	PIST	–28.0	1249 ± 36	1273–1079	1.0	1188
AA93045	RCC 2A 30–40	SYP	–26.8	274 ± 36	3–0* 169–153 337–282 459–348	0.005 0.056 0.403 0.535	344
B247697	GMA 1A 60–70	<i>Pinus</i>	–29.0	110 ± 40	–1* to –4* 150–10 178–174 273–185	0.008 0.651 0.007 0.334	134
B247698	GMB 1C 50–60	SYP	–31.5	540 ± 40	564–509 642–588	0.614 0.386	568

Table 5. (continued)

Lab number ^a	Site, core, and depth (cm)	Sample ID ^b	$\delta^{13}\text{C}$ (‰)	Uncalibrated ^{14}C age (^{14}C yr BP)	Calibrated age range (cal yr BP) $\pm 2 \sigma^c$	Relative area under prob. curve	Weighted mean calibration age (cal yr BP) ^d
B247701	PMC 1B 70–80	SYP	–26.0	190 ± 40	35 to –3* 117–70 229–132 305–251	0.179 0.072 0.513 0.236	167
B247702	PMC 1B 80–90	PIST	–26.2	2200 ± 40	2331–2123	1.0	2225
B247703	RCA 2B 60–70	SYP	–26.4	2860 ± 40	3080–2862 3109–3093 3140–3127	0.970 0.016 0.014	2984
B247704	RCC 2C 30–40	QU ERYTHRO	–26.1	2360 ± 40	2322–2492 2601–2608 2641–2679	0.944 0.006 0.050	2412
B251145	PMB 2A 40–50	CADN	–26.4	101 ± 0	43–33 73–58 105–99 136–114 253–225	0.126 0.204 0.031 0.266 0.374	141
B251146	PMC 2A 60–70	SYP	–25.5	160 ± 40	40 to –3* 119–60 233–122 287–241	0.182 0.176 0.465 0.176	151
B251147	RCB 2C 30–40	<i>cf.</i> CADN	–27.4	350 ± 40	495–313	1.0	401
UGA8440	GMA 2B 20–30	<i>Pinus</i>	–26.3	250 ± 25	7 to –1* 171–151 318–280 424–394	0.019 0.206 0.697 0.078	272
UGA8441	GMA 2C 30–40	CADN	–27.2	750 ± 25	725–666	1.0	688
UGA8442	GMA 2C 40–50	SYP	–26.0	5810 ± 30	6675–6501 6713–6707	0.993 0.007	6611

Table 5. (continued)

Lab number ^a	Site, core, and depth (cm)	Sample ID ^b	$\delta^{13}\text{C}$ (‰)	Uncalibrated ^{14}C age (^{14}C yr BP)	Calibrated age range (cal yr BP) $\pm 2 \sigma^c$	Relative area under prob. curve	Weighted mean calibration age (cal yr BP) ^d
UGA8443	GMB 1A 30–40	PIST	–28.4	60 ± 25	–2* to –4*	0.023	107
					83–32	0.542	
					90–90	0.002	
					109–96	0.036	
					137–111	0.166	
					255–223	0.231	
UGA8444	PMC 1B 30–40	PIST	–26.5	2180 ± 25	2210–2120	0.413	2224
					2309–2223	0.587	
UGA8445	PMC 2C 30–40	SYP	–27.8	1500 ± 25	1416–1314	0.979	1381
					1484–1468	0.021	
UGA8446	RCB 1A 60–68	SYP	–27.0	70 ± 25	–2* to –4*	0.019	115
					84–31	0.486	
					93–87	0.015	
					138–96	0.234	
					256–223	0.246	
UGA8447	RCB 2A 20–30	PIST	–26.1	1180 ± 25	1028–1008	0.046	1106
					1175–1053	0.954	
UGA8448	RCB 2A 40–48	<i>Pinus</i>	–27.5	1170 ± 25	990–990	0.002	1093
					1032–998	0.120	
					1173–1051	0.879	
UGA8449	RCB 2C 20–30	<i>Pinus</i>	–27.0	1740 ± 25	1587–1569	0.065	1649
					1710–1591	0.935	
UGA8450	RCC 1C 40–50	CADN	–27.5	4150 ± 25	4581–4604	0.062	4700
					4606–4769	0.742	
					4781–4823	0.196	

^aAnalyses were performed by the National Science Foundation-University of Arizona Accelerator Mass Spectrometry Laboratory (AA), Beta Analytic, Inc. (B), and the Center for Applied Isotope Studies at the University of Georgia (UGA). Each sample consisted of a single fragment of charred wood or cone.

Table 5. (continued)

^bSYP refers to southern yellow pines. PIST refers to eastern white pine (*Pinus strobus* L.). Charred pine materials that could not be further identified are listed as *Pinus*. QU LEUCO refers to white oak sp., while QU ERYTHRO refers to red oak sp. CADN refers to American chestnut (*Castanea dentata* (Marsh.) Borkh). TSCA refers to eastern hemlock (*Tsuga canadensis* (L.) Carr.). ULAM refers to American elm (*Ulmus americana* L.). Sample IDs with the *cf.* abbreviation were not precisely identified to an exact taxonomic group, but strongly compare with other samples from that group.

^cCalibrations were calculated using CALIB 6.0.2 (Stuiver and Reimer 1993) and the dataset of Reimer *et al.* (2004).

^dWeighted mean of the 2- σ calibration probability distribution

*Indicates a date after AD 1950

Table 6. Pearson's product-moment correlation coefficient results for ^{14}C dates on randomly selected charcoal fragments vs. depth in core at which the fragment was collected.

Site	n ^{14}C dates	Pearson's r	p -value
Gold Mine Trail A	14	0.208	0.476
Gold Mine Trail B	18	-0.068	0.789
Rabbit Creek Trail A	15	-0.199	0.478
Rabbit Creek Trail B	15	-0.480	0.070
Rabbit Creek Trail C	15	-0.260	0.350
Pine Mountain A	15	-0.583	0.023*
Pine Mountain B	15	-0.377	0.166
Pine Mountain C	15	-0.293	0.289
All sites combined	122	-0.147	0.105

*Significant at $\alpha = 0.05$ (2-tailed)

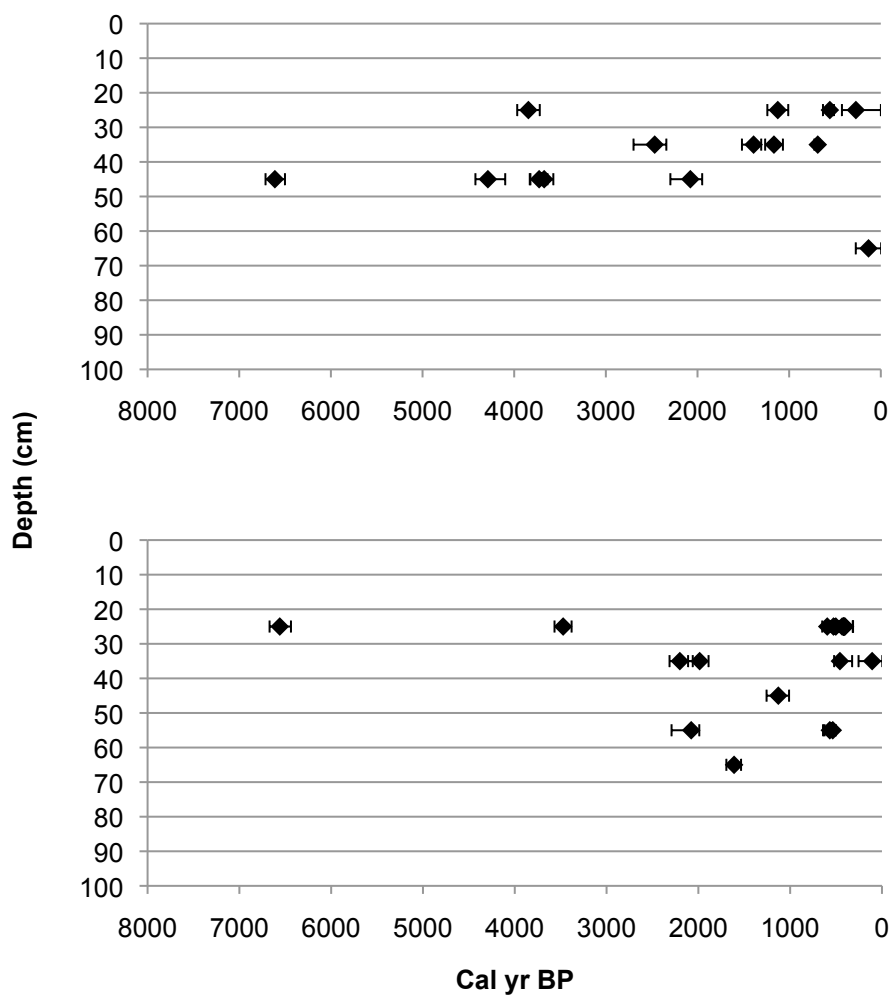


Figure 23. Weighted mean calibration age (cal yr BP) of charcoal fragments compared to depth in the soil at which the charcoal fragment was collected at Gold Mine Trail A (top) and B (bottom). No dates were obtained from the uppermost 20 cm. Error bars indicate the $\pm 2\sigma$ calibration error range.

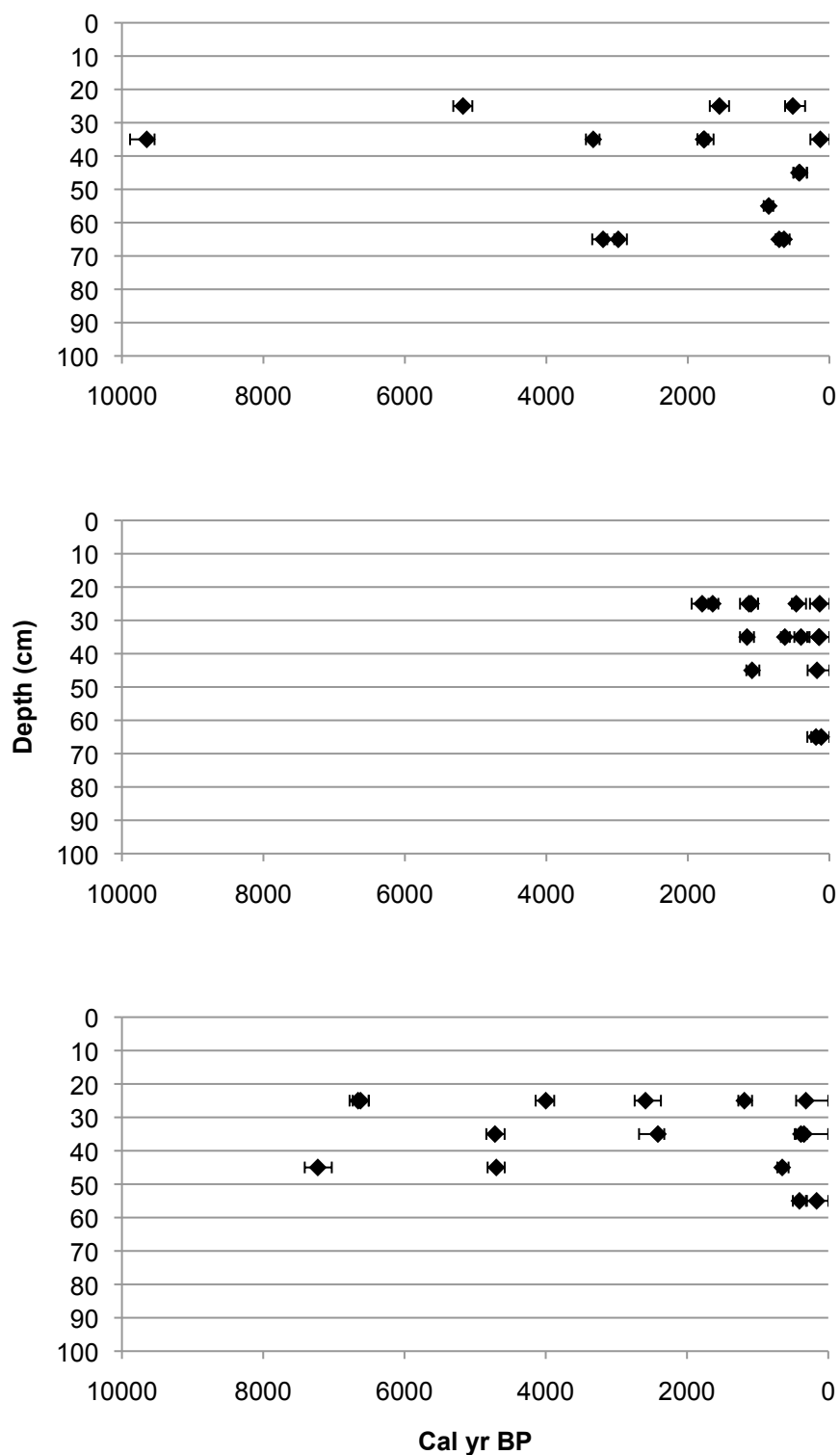


Figure 24. Weighted mean calibration age (cal yr BP) of charcoal fragments compared to depth in the soil at which the charcoal fragment was collected at Rabbit Creek Trail A (top), B (middle), and C (bottom). No dates were obtained from the uppermost 20 cm. Error bars indicate the $\pm 2\text{-}\sigma$ calibration error range.

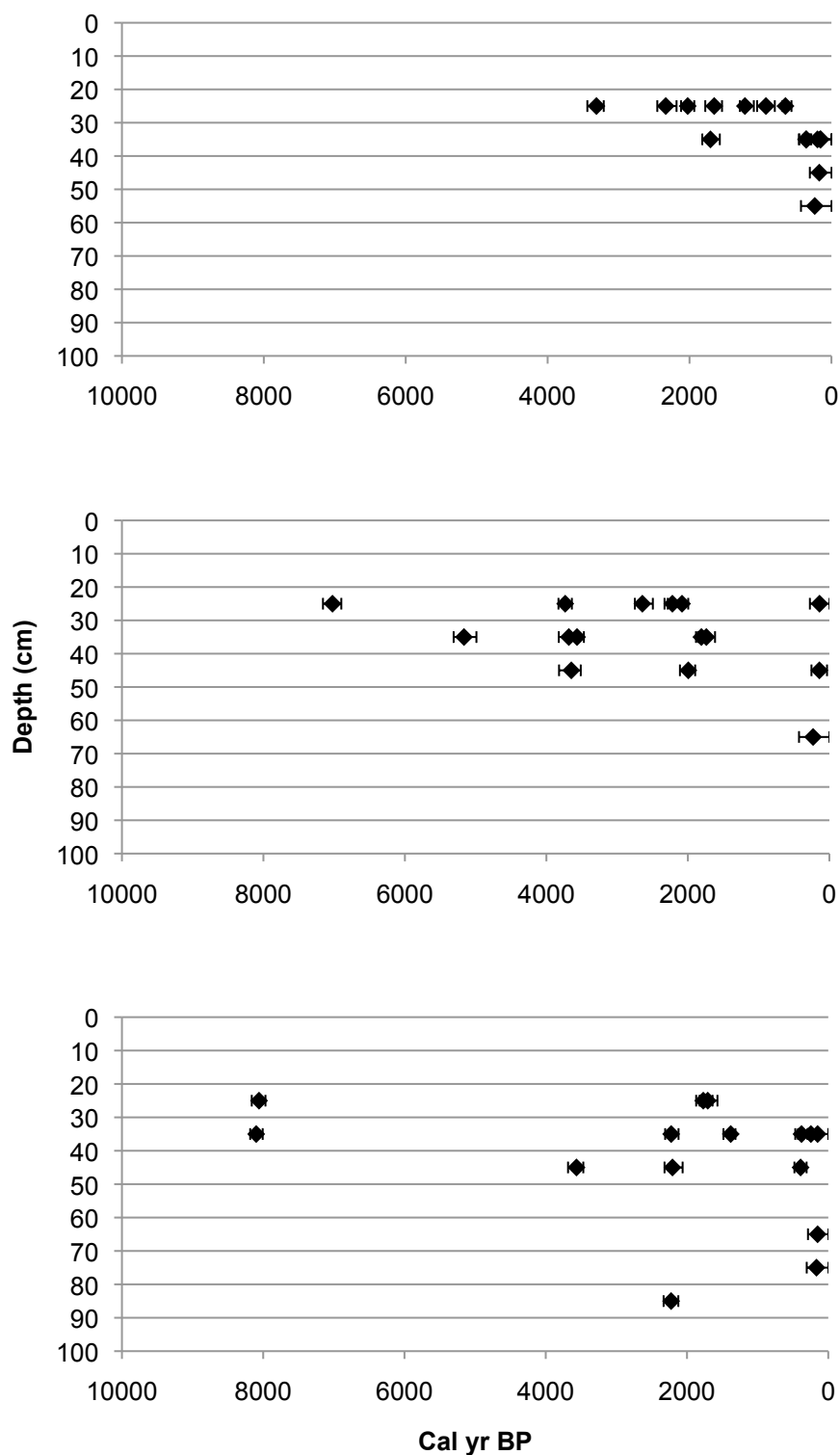


Figure 25. Weighted mean calibration age (cal yr BP) of charcoal fragments compared to depth in the soil at which the charcoal fragment was collected at Pine Mountain A (top), B (middle), and C (bottom). No dates were obtained from the uppermost 20 cm. Error bars indicate the $\pm 2\text{-}\sigma$ calibration error range.

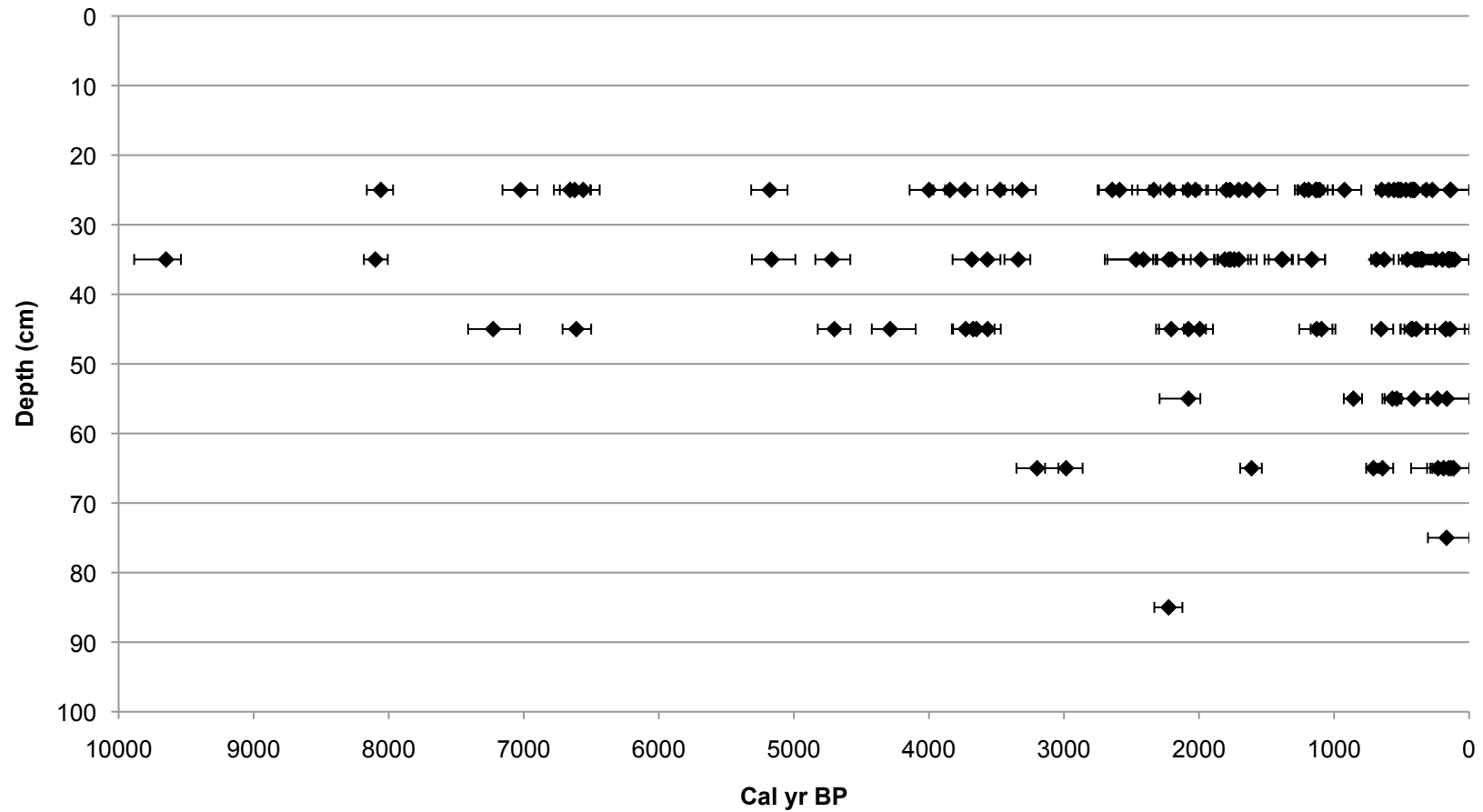


Figure 26. Weighted mean calibration age (cal yr BP) of charcoal fragments compared to depth in the soil at which the charcoal fragment was collected for all sites combined. No dates were obtained from the uppermost 20 cm. Error bars indicate the $\pm 2\sigma$ calibration error range.

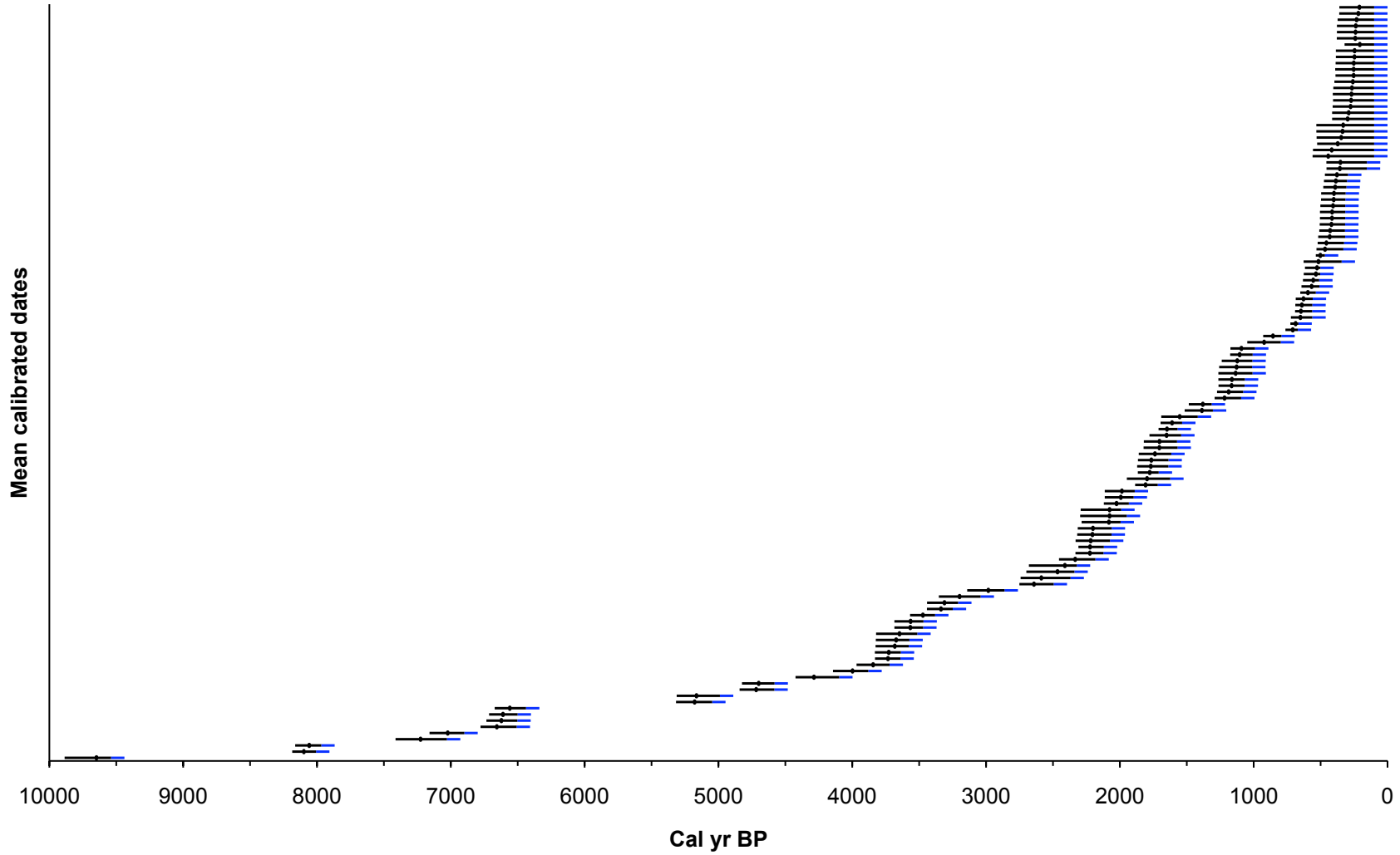


Figure 27. Fire history for all study areas. The 122 randomly selected charcoal fragments are arrayed by the weighted mean probability of the calibrated age with 2- σ error bars (black). The 100-year inbuilt-age estimate is shown in blue. Figures 27–31, 33, 35, and 37 are modeled after a similar diagram in Fesenmyer and Christensen (2010).

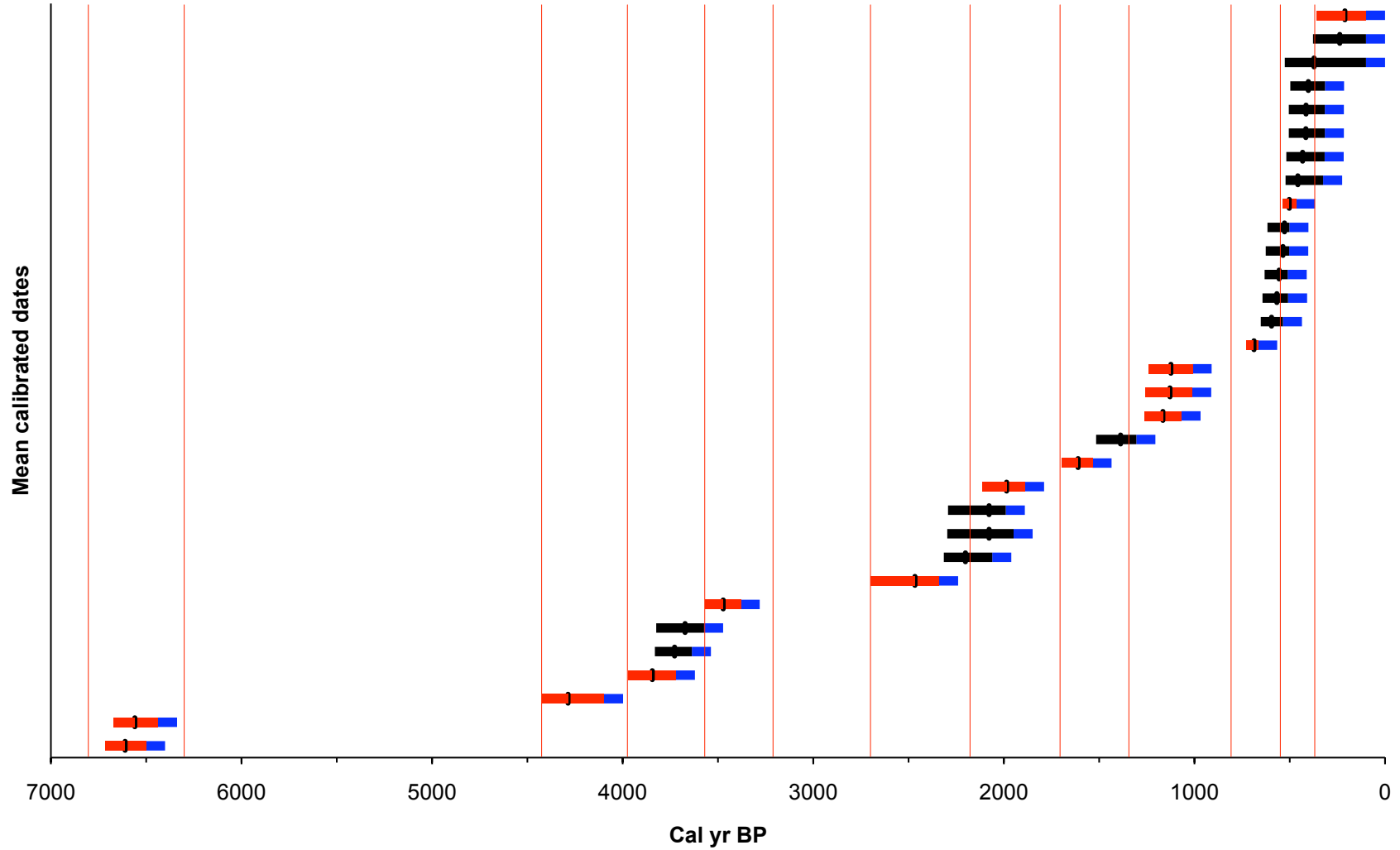


Figure 28. Fire history of the Gold Mine Trail study area. The 32 randomly selected charcoal fragments are arrayed by the weighted mean probability of the calibrated age with 2- σ error bars (black). The 100-year inbuilt-age estimate is shown in blue. Vertical red lines separate distinct windows for which total age ranges for dated samples (calibrated age and inbuilt error) do not overlap with adjacent periods of fire activity. Error bars for charcoal fragments that belong to a distinct fire window are red.

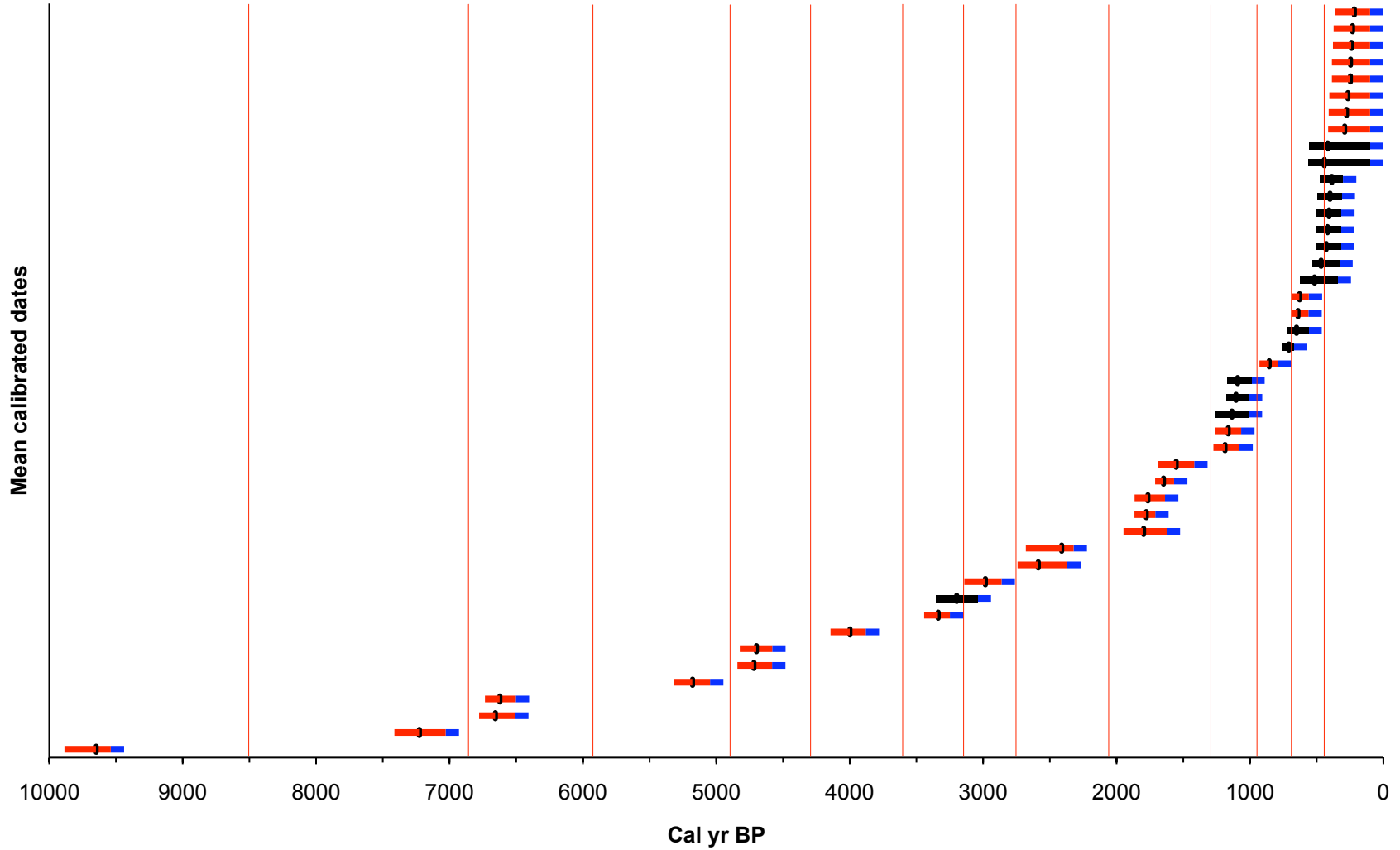


Figure 29. Fire history of the Rabbit Creek Trail study area. The 45 randomly selected charcoal fragments are arrayed by the weighted mean probability of the calibrated age with 2- σ error bars (black). The 100-year inbuilt-age estimate is shown in blue. Vertical red lines separate distinct windows for which total age ranges for dated samples (calibrated age and inbuilt error) do not overlap with adjacent periods of fire activity. Error bars for charcoal fragments that belong to a distinct fire window are red.

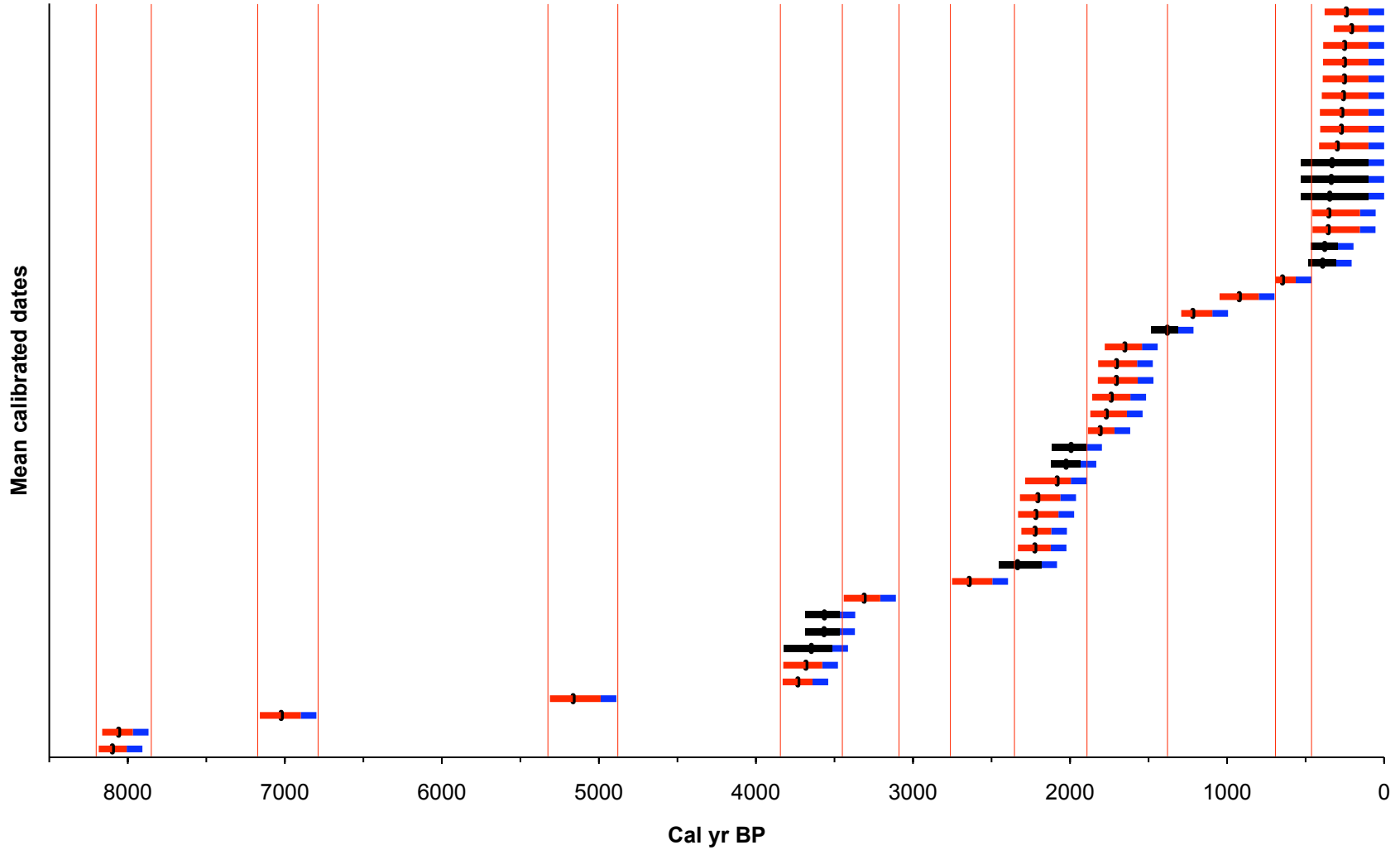


Figure 30. Fire history of the Pine Mountain study area. The 45 randomly selected charcoal fragments are arrayed by the weighted mean probability of the calibrated age with 2- σ error bars (black). The 100-year inbuilt-age estimate is shown in blue. Vertical red lines separate distinct windows for which total age ranges for dated samples (calibrated age and inbuilt error) do not overlap with adjacent periods of fire activity. Error bars for charcoal fragments that belong to a distinct fire window are red.

that is innately involved with soil-charcoal reconstructions of past environments, a conservative approach is prudent and prevents an overstatement of past fire activity.

Results from the fixed-factor ANOVA showed that all sites differ significantly by age of radiocarbon dates ($F = 2.70$; degrees of freedom = 7, 114; $p = 0.013$). Pine Mountain B, Rabbit Creek Trail C, and Gold Mine Trail A produced the oldest ranked-mean radiocarbon dates, while Rabbit Creek Trail B produced the youngest (Table 7).

Charcoal, from among all charcoal fragments in core increments deeper than 20 cm, was randomly selected, identified, and dated. Six tree categories are represented by the taxonomically identified and dated samples: southern yellow pine, mesic conifer (*i.e.*, eastern white pine and eastern hemlock), undifferentiated pine, chestnut, oak, and elm. Sample depth of identified and dated charcoal fragments is greatest ca. 4000 to 107 cal yr BP. Mesic conifer and southern yellow pine were the dominant categories at the Gold Mine Trail and Rabbit Creek Trail study areas (Figures 31–34). Southern yellow pine was the dominant category for the Pine Mountain study area (Figures 35 and 36). For all combined sites, southern yellow pine was the dominant category, followed by mesic conifer, undifferentiated pine, chestnut, oak, and elm (Figures 37 and 38). The distribution of charcoal taxa among study areas suggests a relationship between soil moisture and tree type (Table 8). The stratified-random selection of charcoal fragments for identification and radiocarbon dating did not produce any samples from diffuse-porous species (*e.g.*, red maple). The absence of charcoal from such species suggests that past fire regimes in these forests prevented the common occurrence of diffuse-porous mesophytes such as red maple and black gum.

The greatest amount of randomly selected, taxonomically identified, and dated macroscopic charcoal at the Gold Mine Trail and Rabbit Creek Trail study areas was produced

Table 7. Least squares mean separation of radiocarbon dates by site. Mean groups were designated[†] by Fisher's least significant difference test.

Site	n ¹⁴ C dates	Ranked-date mean ^a	Ranked-date standard error	Ranked-date mean group [*]	Observed mean (cal yr BP)	Observed σ
Gold Mine Trail A	14	73.11	9.02	A	2287	1899
Gold Mine Trail B	18	54.81	7.95	ABC	1333	1581
Rabbit Creek Trail A	15	67.67	8.71	AB	2210	2506
Rabbit Creek Trail B	15	37.20	8.71	C	690	585
Rabbit Creek Trail C	15	73.60	8.71	A	2826	2617
Pine Mountain A	15	47.33	8.71	BC	1029	980
Pine Mountain B	15	78.13	8.71	A	2655	1899
Pine Mountain C	15	62.27	8.71	AB	2181	2605

^aRank-transformed mean dates from the fixed-factor ANOVA output

^{*} $\alpha = 0.05$

[†]The letter "A" was assigned to the mean(s) with the highest value. Subsequent letters of the alphabet are assigned to groups with significantly smaller means. Means in the same letter group are not significantly different from each other.

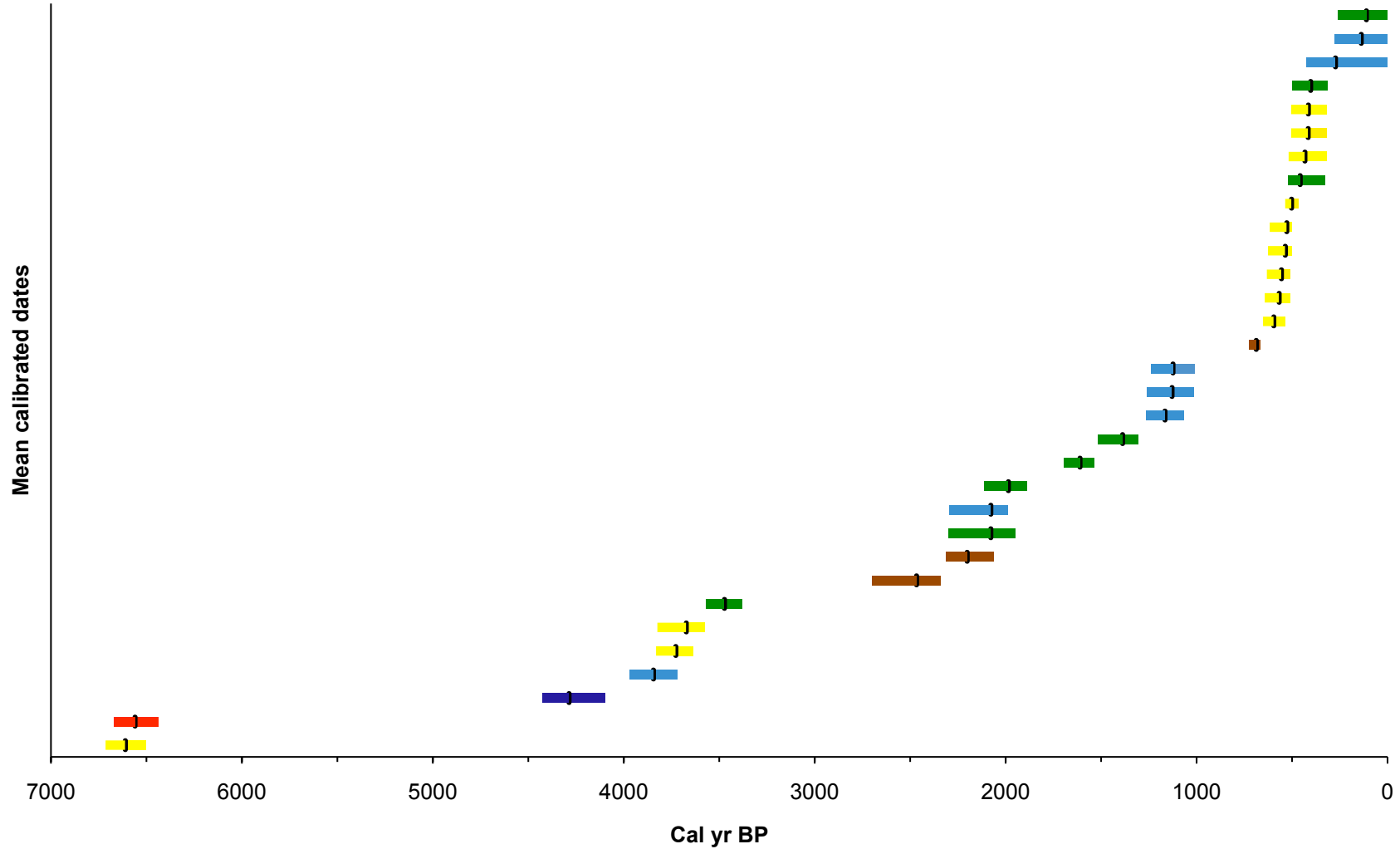


Figure 31. Taxonomic categorization of charcoal fragments for the Gold Mine Trail study area. The 32 randomly selected charcoal fragments are arrayed by weighted mean probability of the calibrated age with 2- σ error bars. Type of tree is indicated by color: mesic conifer (green), undifferentiated pine (lt. blue), southern yellow pine (yellow), American chestnut (brown), oak sp. (dk. blue), and American elm (red).

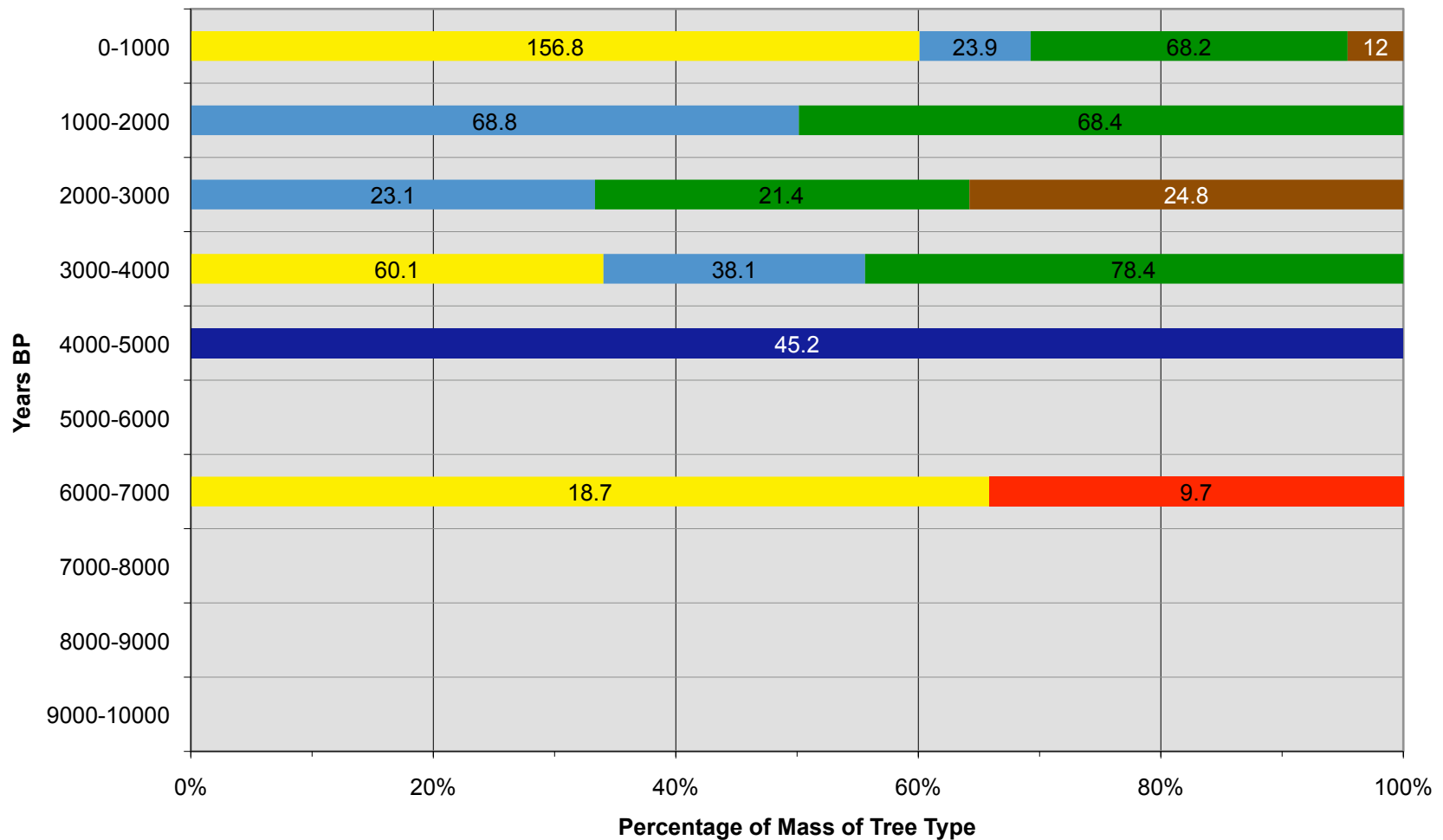


Figure 32. Percent radiocarbon-dated charcoal mass by tree type for the Gold Mine Trail study area. Values on bars are combined masses (mg) for tree type per 1000-yr period. Type of tree is indicated by color: mesic conifer (green), undifferentiated pine (lt. blue), southern yellow pine (yellow), American chestnut (brown), oak sp. (dk. blue), and American elm (red).

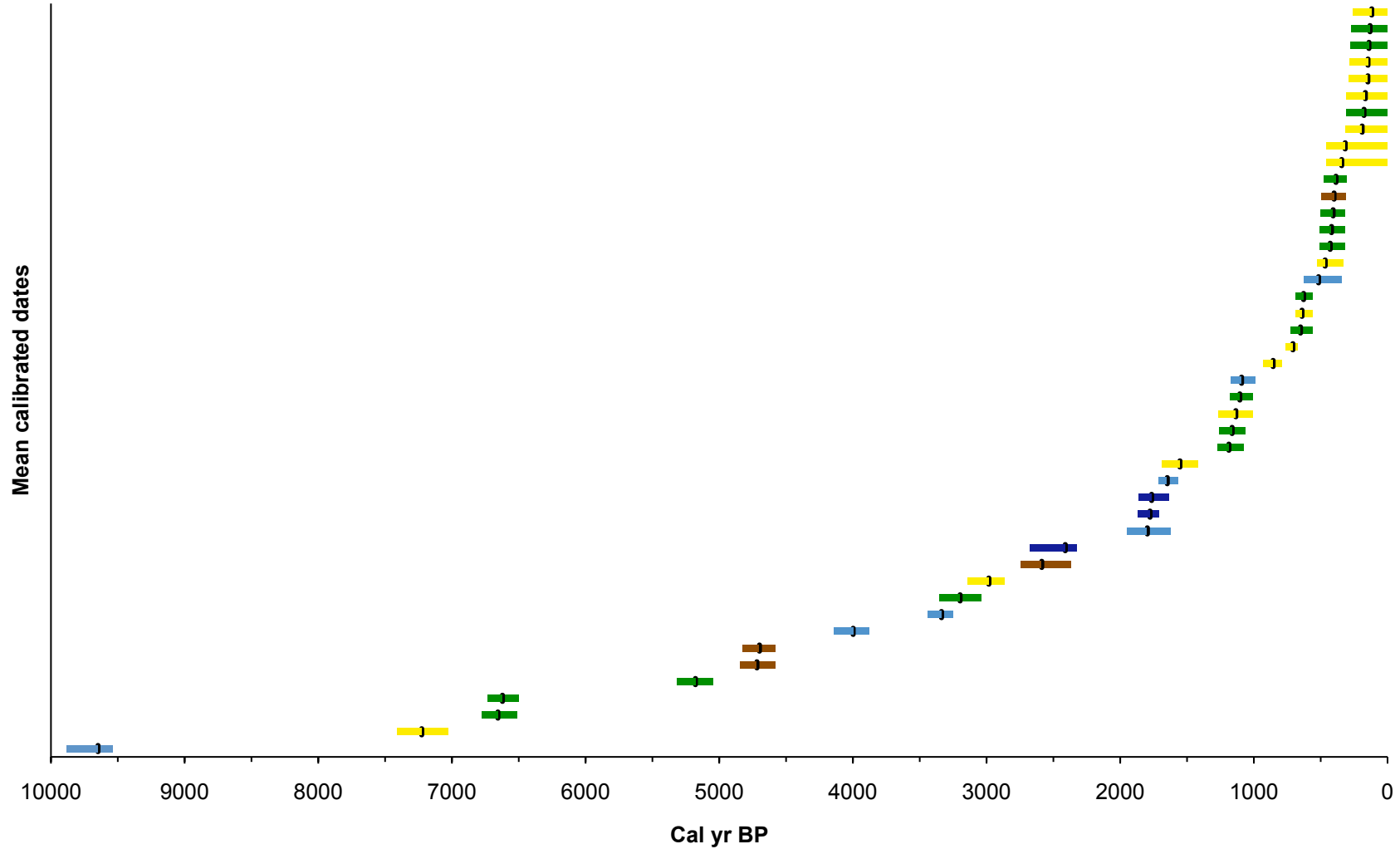


Figure 33. Taxonomic categorization of charcoal fragments for the Rabbit Creek Trail study area. The 45 randomly selected charcoal fragments are arrayed by weighted mean probability of the calibrated age with 2- σ error bars. Type of tree is indicated by color: mesic conifer (green), undifferentiated pine (lt. blue), southern yellow pine (yellow), American chestnut (brown), and oak spp. (dk. blue).

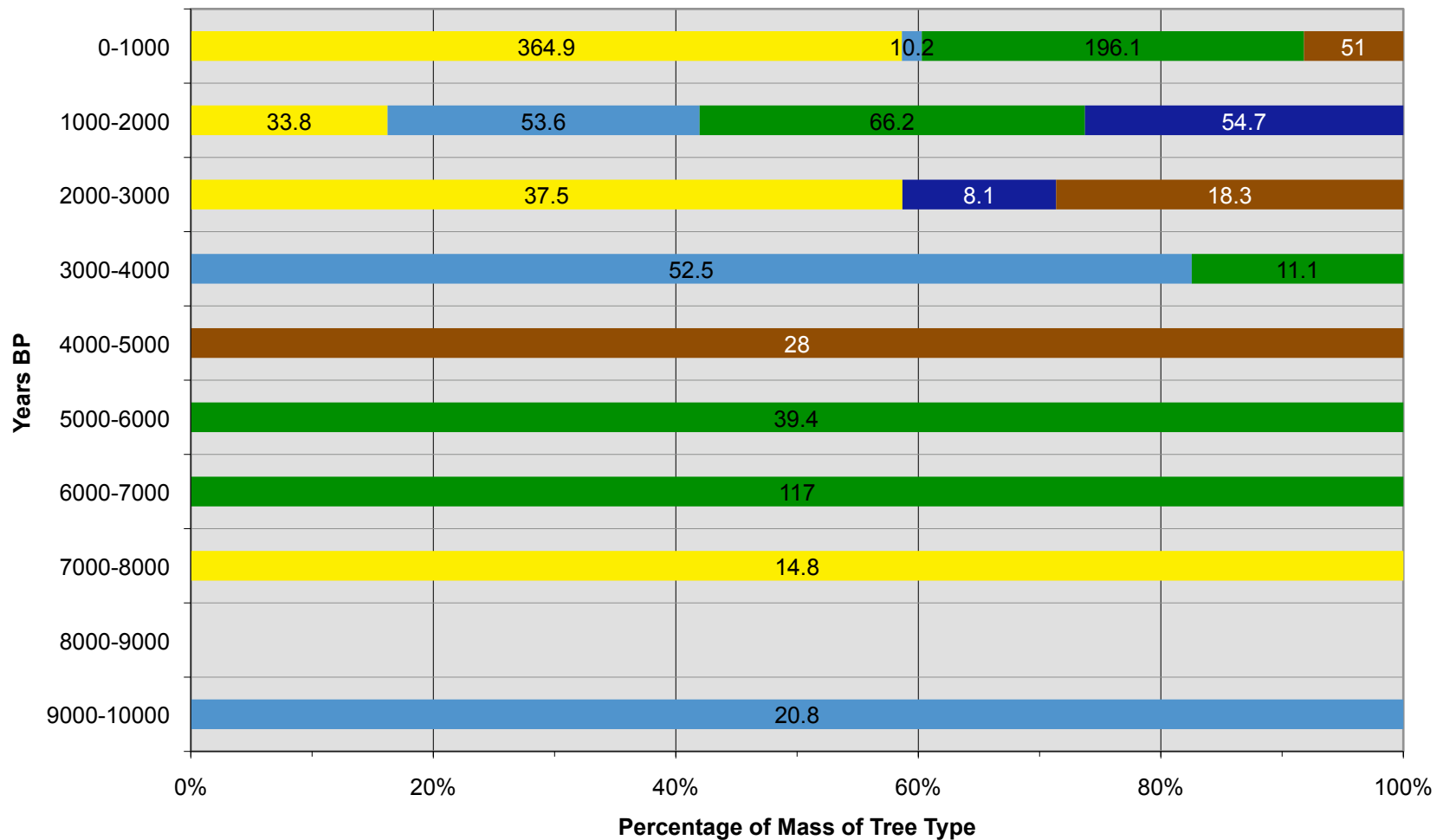


Figure 34. Percent radiocarbon-dated charcoal mass by tree type for the Rabbit Creek Trail study area. Values on bars are combined masses (mg) for tree type per 1000-yr period. Type of tree is indicated by color: mesic conifer (green), undifferentiated pine (lt. blue), southern yellow pine (yellow), American chestnut (brown), and oak spp. (dk. blue).

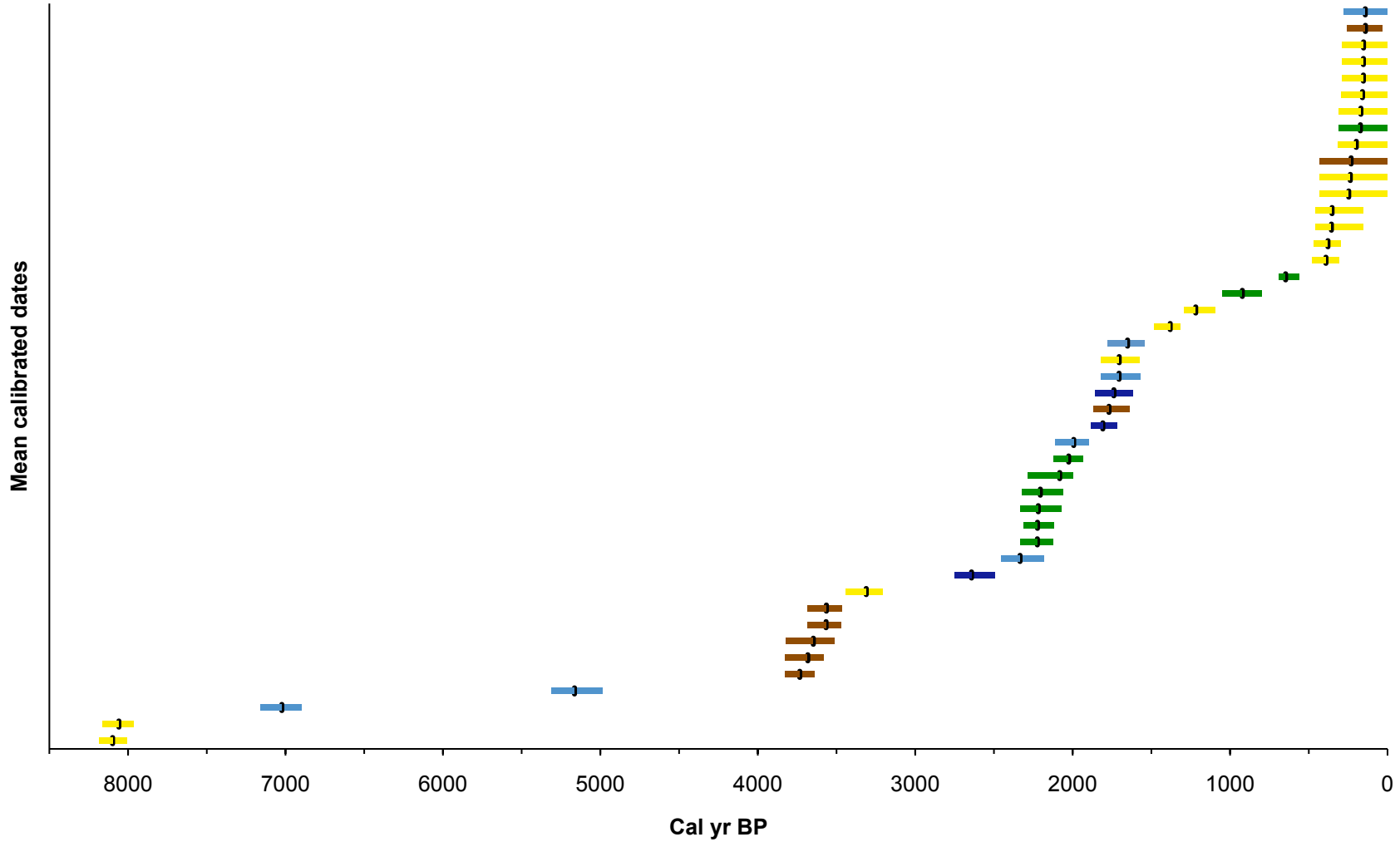


Figure 35. Taxonomic categorization of charcoal fragments for the Pine Mountain study area. The 45 randomly selected charcoal fragments are arrayed by weighted mean probability of the calibrated age with 2- σ error bars. Type of tree is indicated by color: mesic conifer (green), undifferentiated pine (lt. blue), southern yellow pine (yellow), American chestnut (brown), and oak spp. (dk. blue).

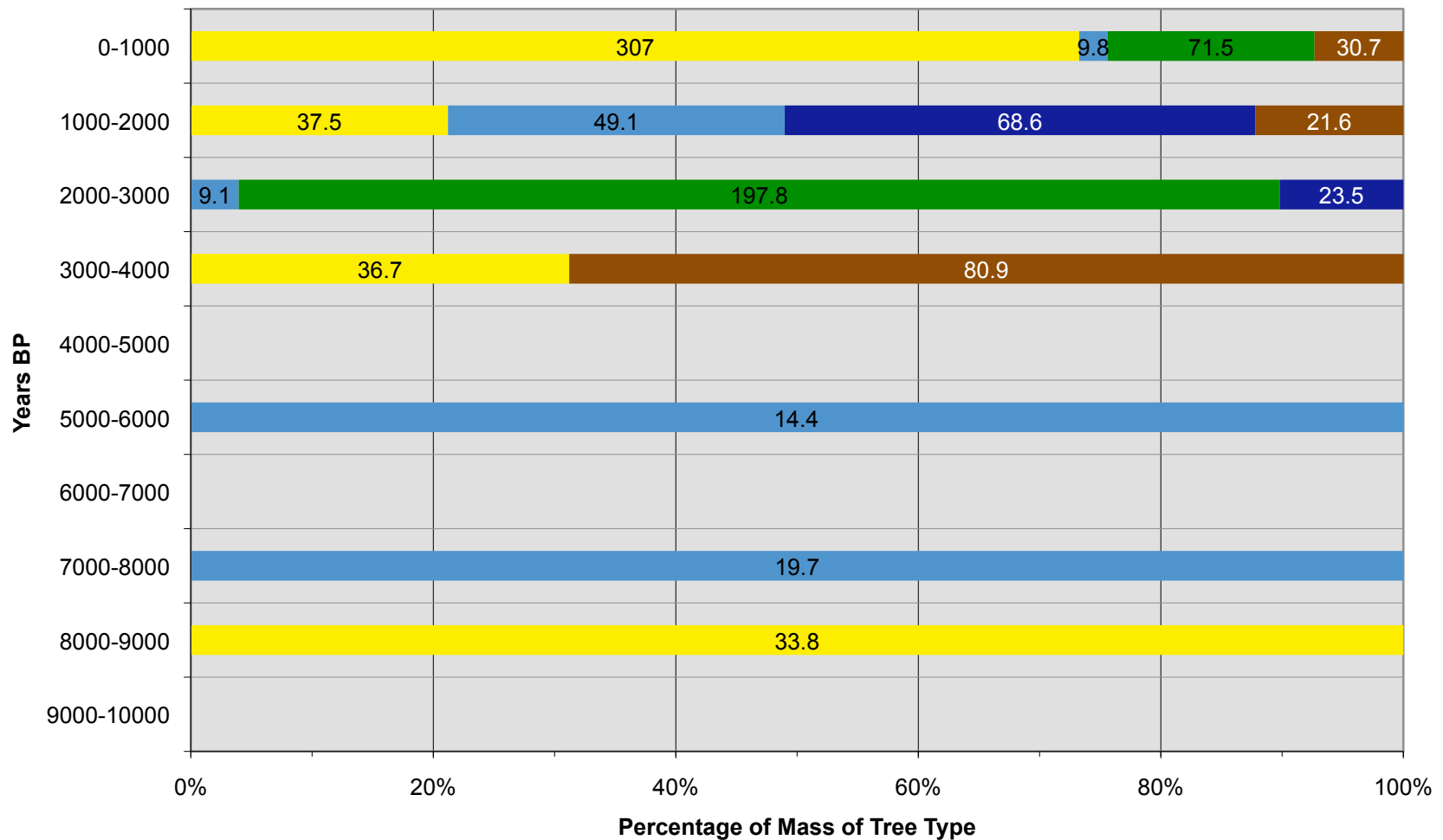


Figure 36. Percent radiocarbon-dated charcoal mass by tree type for the Pine Mountain study area. Values on bars are combined masses (mg) for tree type per 1000-yr period. Type of tree is indicated by color: mesic conifer (green), undifferentiated pine (lt. blue), southern yellow pine (yellow), American chestnut (brown), and oak spp. (dk. blue).

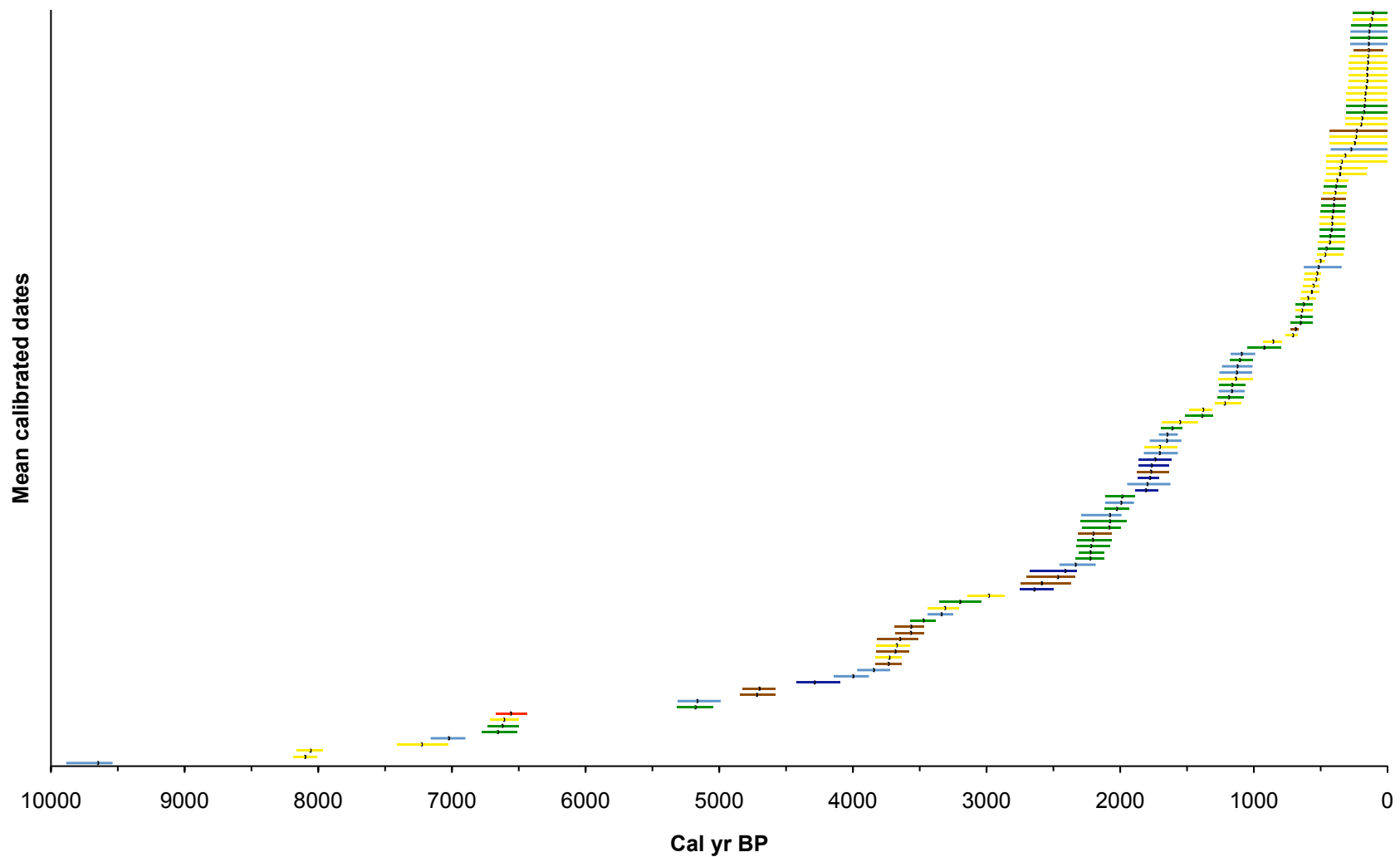


Figure 37. Taxonomic categorization of charcoal fragments for all study areas. The 122 randomly selected charcoal fragments are arrayed by weighted mean probability of the calibrated age with 2- σ error bars. Type of tree is indicated by color: mesic conifer (green), undifferentiated pine (lt. blue), southern yellow pine (yellow), American chestnut (brown), oak spp. (dk. blue), and American elm (red).

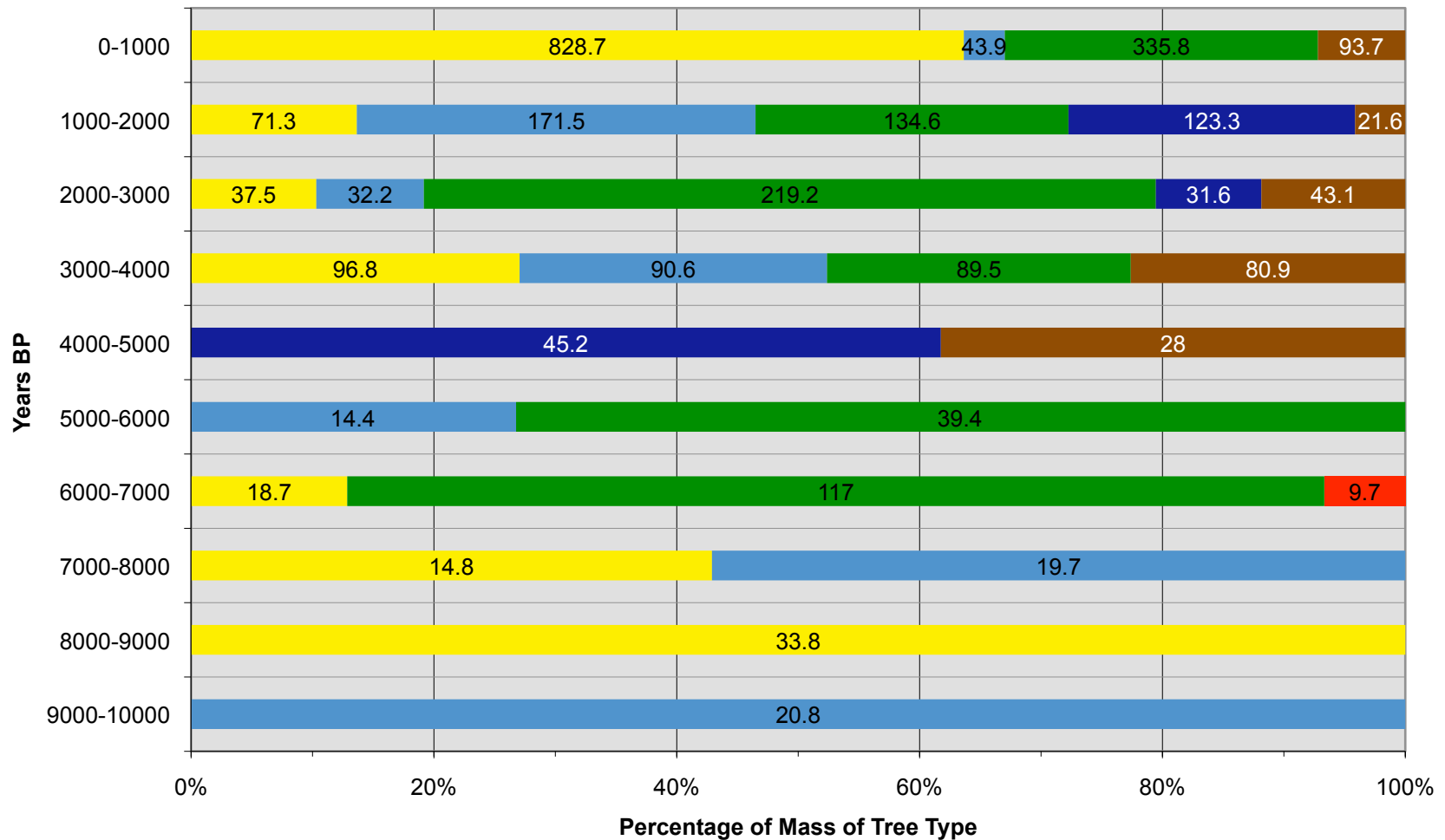


Figure 38. Percent radiocarbon-dated charcoal mass by tree type for all study areas. Values on bars are combined masses (mg) for tree type per 1000-yr period. Type of tree is indicated by color: mesic conifer (green), undifferentiated pine (lt. blue), southern yellow pine (yellow), American chestnut (brown), oak spp. (dk. blue), and American elm (red).

Table 8. Percentage of tree category by study area for the period 9649 to 107 cal yr BP. Study areas are ordered, left to right, from most mesic to most xeric.*

Tree category	Gold Mine Trail %	Rabbit Creek Trail %	Pine Mountain %	All sites %
Southern yellow pine	33	38	41	38
Mesic conifer	33	36	27	32
Undifferentiated pine	21	12	10	14
American chestnut	5	8	13	9
Oak spp.	6	5	9	7
American elm	1	0	0	0

*These categorizations are based on mean percent slope and slope aspect of individual study sites within the study areas.

during the Mississippian period, while the greatest amount of charcoal at the Pine Mountain study area was produced during the Woodland period. For all study areas, charcoal abundance was greatest during the Woodland and Mississippian periods, with an abrupt decrease during the Historic period (Table 9).

To enable comparison of modern forest composition and charcoal assemblages at each study site, basal area (m^2/ha) measurements of mature trees (> 5 cm DBH) (LaForest 2012) were used to create pie charts of current forest composition (Figures 39–41). The relatively mesic Gold Mine Trail study area currently supports the lowest relative basal area (7%) of yellow pines. The more xeric Rabbit Creek Trail study area supports a higher yellow pine basal area (18%) than the Gold Mine Trail study area; nevertheless, the majority of the Rabbit Creek Trail basal area is composed of mesophytes (*e.g.*, eastern white pine). The Pine Mountain study area, which is the most xeric of the three study areas, supports the highest relative basal area (32%) of yellow pine trees and also supports the highest combined relative basal area (72%) of yellow pines and oaks.

The modified R -value model was used to compare species composition of macroscopic soil charcoal in surface samples (0–10 cm) (Figures 42–44) and current forest composition. These data were used to calculate R -values for each of the taxonomic groups at each study site. An R -value of 1 indicates a proportional match between abundance of surface soil charcoal (C_m) and current forest vegetation (V_m). If a taxonomic group is over- or under-represented by soil charcoal, the R -value will be $<$ or $>$ 1, respectively. Calculation of R -values, and, consequently, V_p , was not possible for the “other” category, because there were no unidentified modern forest trees at any of the study sites.

Table 9. Mass (mg) and percent of radiocarbon-dated charcoal by site, study area, and cultural period.

Site	Early and Middle Archaic (10,000– 5000 yr BP)	Late Archaic (5000– 3000 yr BP)	Woodland (3000– 950 yr BP)	Mississippian (950–350 yr BP)	Historic (350 yr BP– Present)	Total per site and study area
	Hunter/Gatherer Societies		Horticultural Societies		Agricultural Societies	
Gold Mine Trail A	9.0 (3%)	143.4 (48%)	90.8 (30%)	32.8 (11%)	23.9 (8%)	299.9
Gold Mine Trail B	9.7 (2%)	78.4 (19%)	115.7 (28%)	190.2 (47%)	14.0 (3%)	408.0
Gold Mine Trail total	18.7 (3%)	221.8 (31%)	206.5 (29%)	223.0 (32%)	37.9 (5%)	707.9
Rabbit Creek Trail A	60.2 (16%)	69.8 (19%)	72.3 (20%)	124.1 (34%)	39.2 (11%)	365.6
Rabbit Creek Trail B	0 (0%)	0 (0%)	116.3 (25%)	234.6 (51%)	109.6 (24%)	460.5
Rabbit Creek Trail C	131.8 (37%)	59.3 (17%)	46.1 (13%)	69.1 (20%)	45.6 (13%)	351.9
Rabbit Creek Trail total	192.0 (16%)	129.1 (11%)	234.7 (20%)	427.8 (36%)	194.4 (17%)	1178.0
Pine Mountain A	0 (0%)	36.7 (9%)	76.2 (19%)	133.7 (33%)	158.6 (39%)	405.2
Pine Mountain B	34.1 (11%)	56.4 (18%)	175.9 (57%)	0 (0%)	40.5 (13%)	306.9
Pine Mountain C	33.8 (11%)	24.5 (8%)	155.1 (52%)	26.4 (9%)	59.8 (20%)	299.6
Pine Mountain total	67.9 (7%)	117.6 (12%)	407.2 (40%)	160.1 (16%)	258.9 (26%)	1011.7
Total per cultural period	278.6 (10%)	468.5 (16%)	848.4 (29%)	810.9 (28%)	491.2 (17%)	

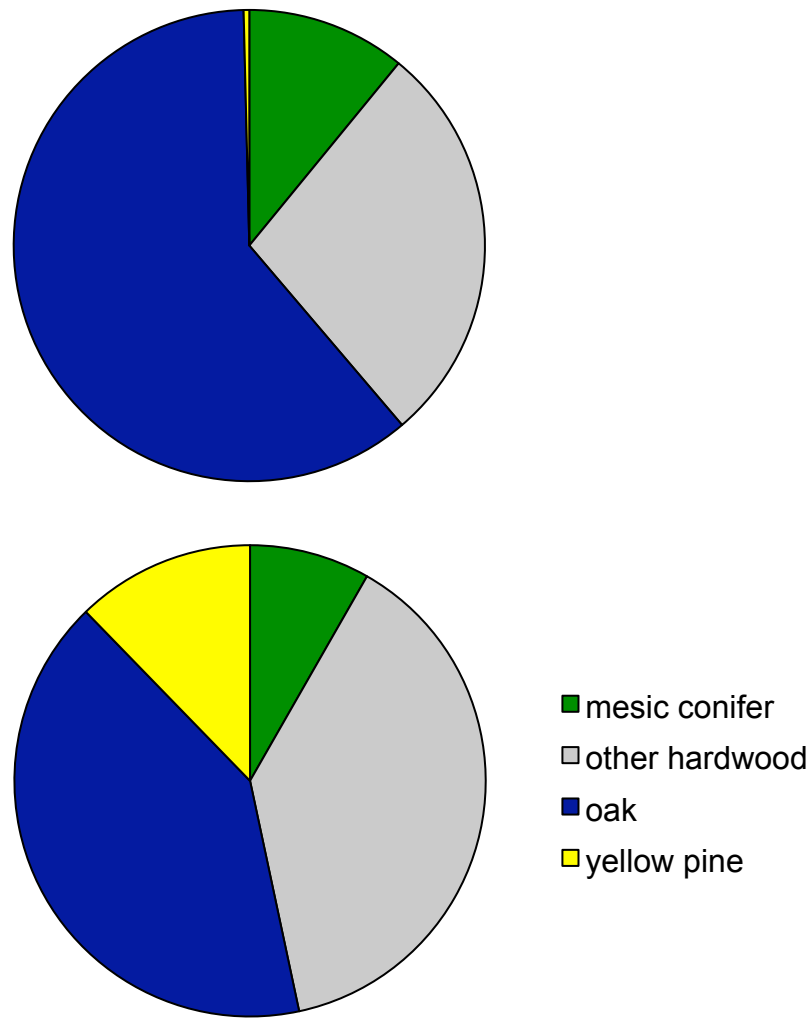


Figure 39. Modern forest composition at Gold Mine Trail A (top) and B (bottom). Percentages show relative basal area of mature trees (> 5 cm DBH).

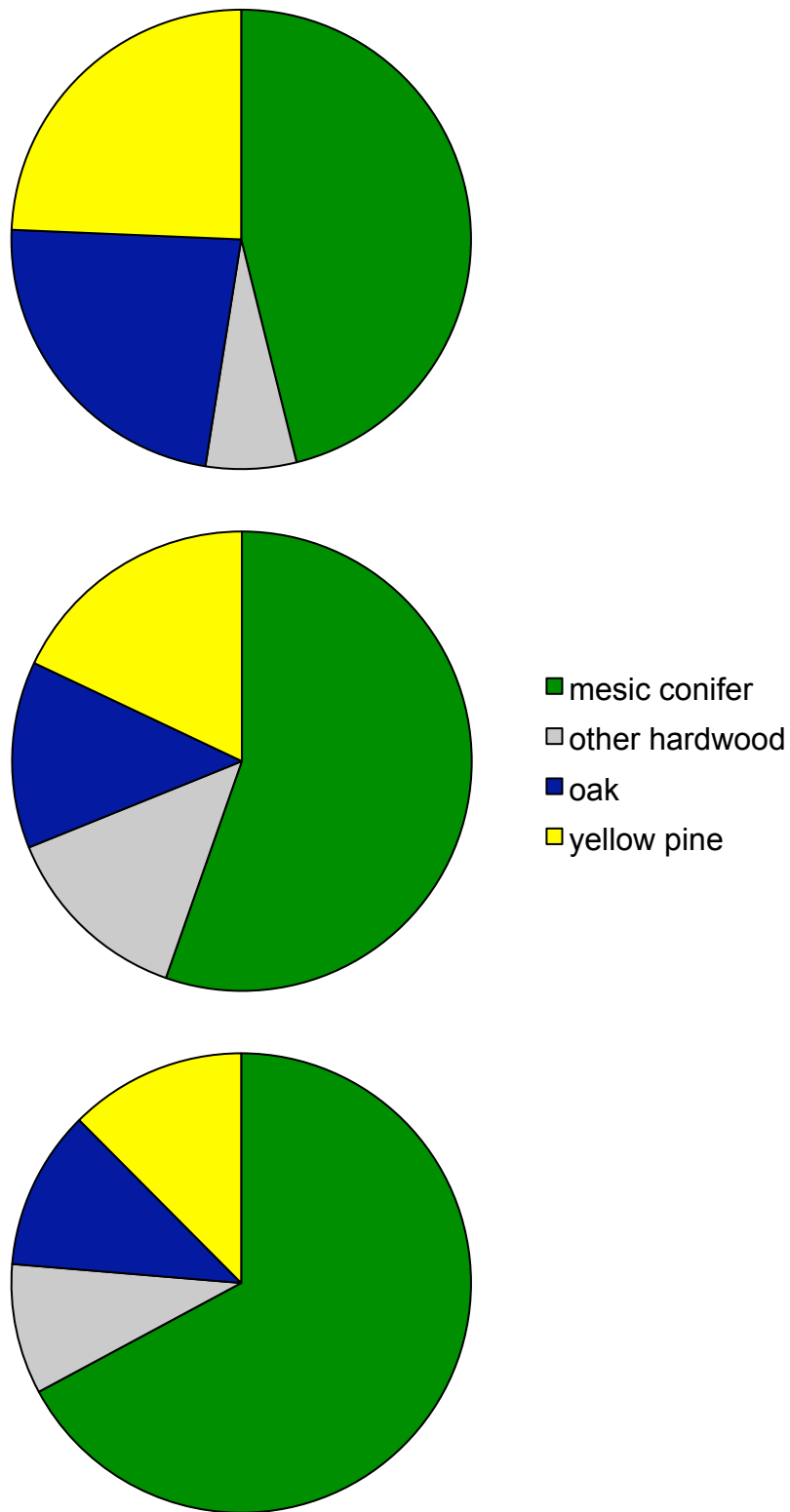


Figure 40. Modern forest composition at Rabbit Creek Trail A (top), B (middle), and C (bottom). Percentages show relative basal area of mature trees (> 5 cm DBH).

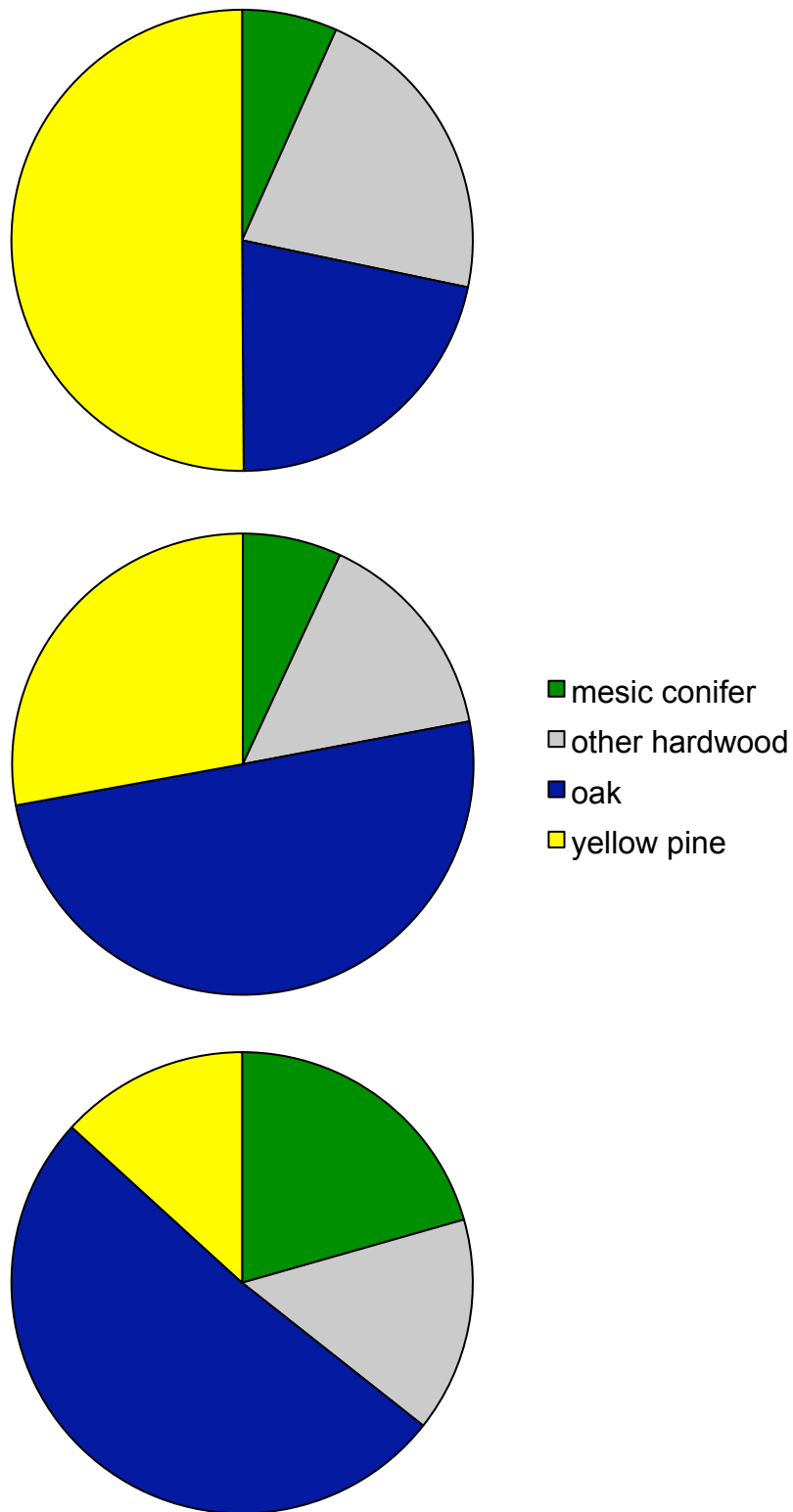


Figure 41. Modern forest composition at Pine Mountain A (top), B (middle), and C (bottom). Percentages show relative basal area of mature trees (> 5 cm DBH).

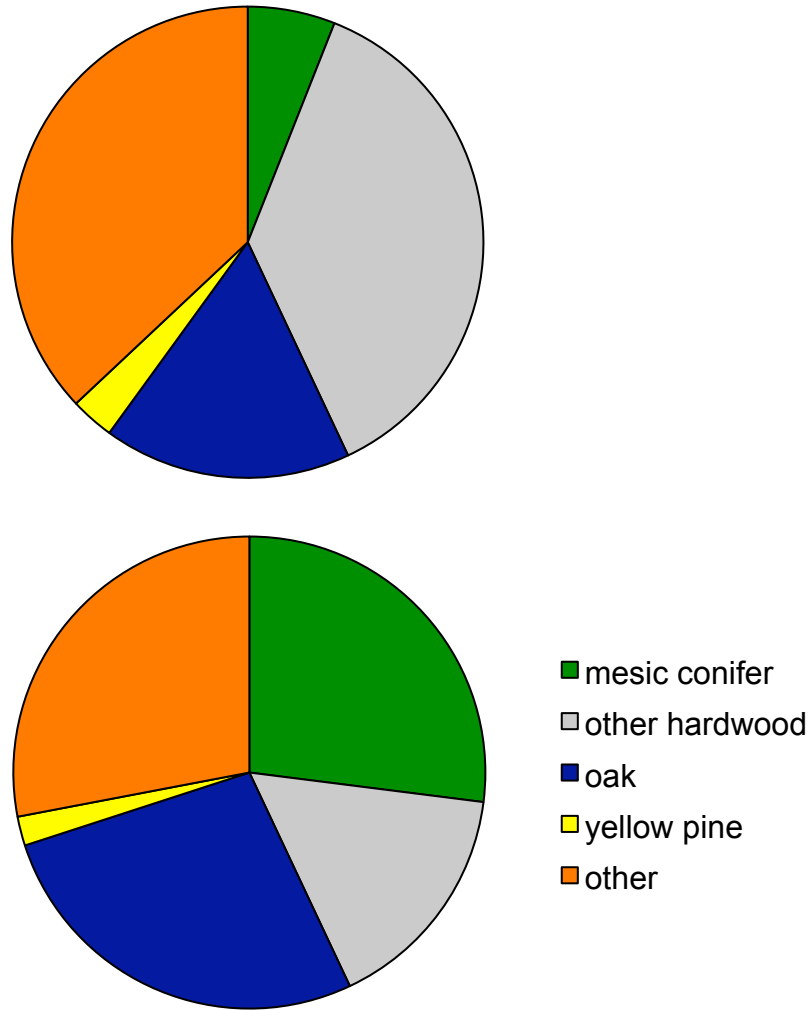


Figure 42. Surface charcoal mass by tree type at Gold Mine Trail A (top) and B (bottom). Surface charcoal was extracted from the uppermost 10 cm of soil in 12 soil cores.

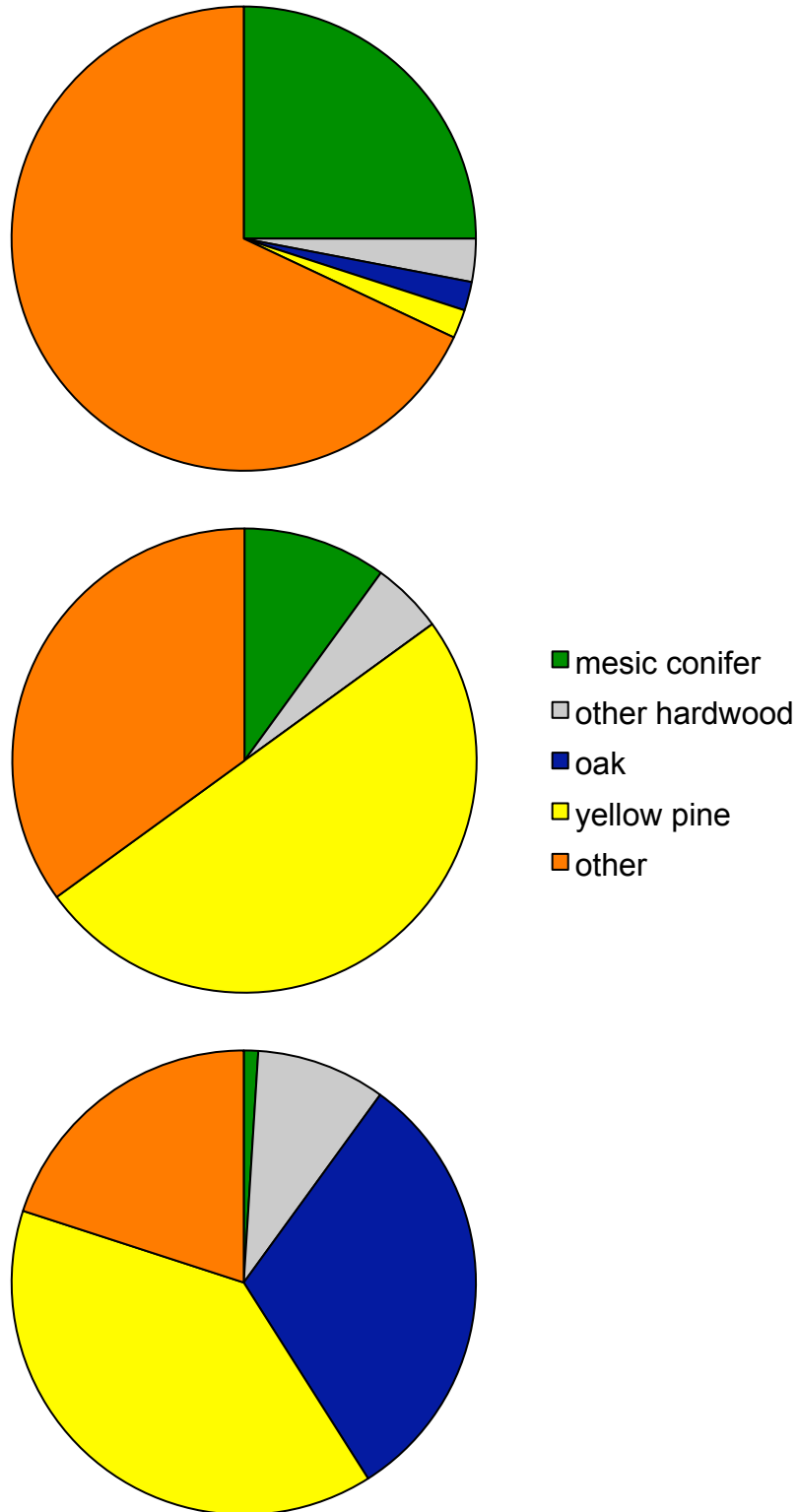


Figure 43. Surface charcoal mass by tree type at Rabbit Creek Trail A (top), B (middle), and C (bottom). Surface charcoal was extracted from the uppermost 10 cm of soil in 18 soil cores.

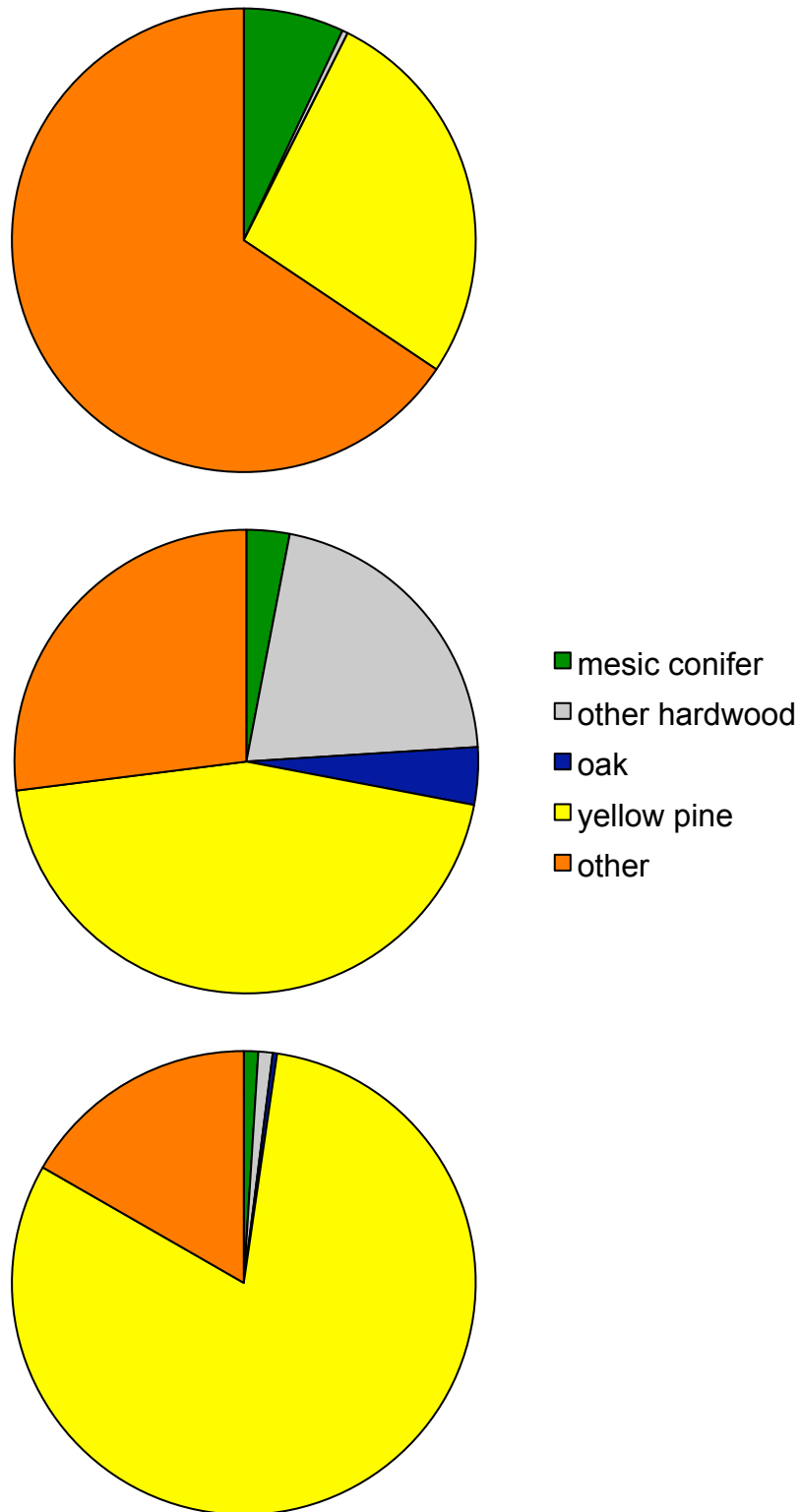


Figure 44. Surface charcoal mass by tree type at Pine Mountain A (top), B (middle), and C (bottom). Surface charcoal was extracted from the uppermost 10 cm of soil in 18 soil cores.

The R -value model produced equivocal results for percent V_p of many of the taxonomic groups (Table 10). In an example from Gold Mine Trail A, although yellow pine is the most dominant C_p type, aside from the “other” category, the dominant V_p types are oak and mesic conifer. Yellow pine was the least abundant V_p type, as it is today at some of the study sites. The results suggest that the high amount of past yellow pine charcoal did not, in this case, result from an abundance of yellow pine trees, but rather from other taxonomic groups at Gold Mine Trail A with comparatively low R -values (Davis 1963). Similar departures between C_p and V_p values occur with other taxonomic groups at other study sites.

Table 10. Estimation of past vegetation (9649 to 107 cal yr BP) after correction for differences in representation.

Site	Taxonomic group	V_m^a	C_m^b	R^c	C_p^d	V_p^e	% V_p^f
Gold Mine Trail A	mesic conifer	11	6	0.5	28	56	23.7
	other hardwood	28	37	1.3	23.1	17.8	7.5
	oak	61	17	0.3	45.2	150.7	63.7
	yellow pine	0.4	3	7.5	89.9	12	5.1
	others	0	37	--	101.2	--	--
Gold Mine Trail B	mesic conifer	8	27	3.4	195.9	57.6	34.5
	other hardwood	38	16	0.4	23.4	58.5	35.0
	oak	41	27	0.7	0	0	0
	yellow pine	12	2	0.2	10.2	51	30.5
	others	0	28	--	52.7	--	--
Rabbit Creek Trail A	mesic conifer	46	25	0.5	126.3	252.6	11.9
	other hardwood	6	3	0.5	0	0	0
	oak	23	2	0.1	54.7	547	25.8
	yellow pine	24	2	0.1	132.4	1324	62.3
	others	0	32	--	52.2	--	--
Rabbit Creek Trail B	mesic conifer	55	10	0.2	97.7	488.5	69.0
	other hardwood	14	5	0.4	51	127.5	18.0
	oak	13	0	0.0	0	--	--
	yellow pine	18	50	2.8	258.2	92.2	13.0
	others	0	35	--	53.6	--	--
Rabbit Creek Trail C	mesic conifer	67	1	0.01	205.8	20580	99.7
	other hardwood	9	9	1.0	46.3	46.3	0.2
	oak	11	31	2.8	8.1	2.9	0.01
	yellow pine	12	39	3.3	60.4	18.3	0.09
	others	0	20	--	31.3	--	--

Table 10. (Continued)

Site	Taxonomic group	V_m^a	C_m^b	R^c	C_p^d	V_p^e	% V_p^f
Pine Mountain A	mesic conifer	7	7	1.0	81.7	81.7	12.5
	other hardwood	22	0.4	0.02	0	0	0
	oak	22	0	0.0	0	--	--
	yellow pine	50	27	0.5	287	574.0	87.5
	others*	0	66	--	36.5	--	--
Pine Mountain B	mesic conifer	7	3	0.4	72.1	180.3	15.5
	other hardwood	15	21	1.4	87.1	62.2	5.3
	oak	50	4	0.1	92.1	921.0	79.2
	yellow pine	28	45	1.6	0	0	0
	others	0	27	--	55.6	--	--
Pine Mountain C	mesic conifer	21	1	0.05	115.5	2310.0	82.7
	other hardwood	15	1	0.1	46.1	461.0	16.5
	oak	51	0.3	0.006	0	0	0
	yellow pine	13	81	6.2	128	20.6	0.7
	others	0	17	--	10	--	--

^aModern forest composition, based on percentages of basal area (LaForest 2012)

^bModern charcoal, based on percentages of randomly sampled wood charcoal from 0–10 cm core increments

^cPast-vegetation correctional factor (C_m/V_m)

^dRandomly sampled radiocarbon-dated charcoal (mg) from core increments deeper than 20 cm; these values represent past forest composition

^eCorrected past forest composition (C_p/R)

^fCorrected percentage of past forest composition ($V_p/\text{total } V_p$ for that study site)

*Unidentified charcoal; this category does not apply to V_m data since all trees at all study sites were identified

Chapter 6

Discussion

Soil charcoal was ubiquitous in all cores, transects, and sites, indicating that fire has affected all of these yellow pine and mixed hardwood-pine forests in the past. This is the only study to date that has used soil charcoal as the primary proxy for reconstructions of fire *and* forest history, based on taxonomically identified soil charcoal fragments, in southern yellow pine and mixed hardwood-pine forests in the southern Appalachians. This study addressed multiple research questions, which are revisited in this chapter.

Does the distribution of macroscopic charcoal vary among replicate cores in a study site?

Three of eight sites (Gold Mine Trail B, Rabbit Creek Trail C, and Pine Mountain Trail C) produced cores that exhibited statistically significant differences in charcoal mass, demonstrating the importance of collecting multiple cores at each site. At two of the three sites, the core with the greatest mean charcoal mass occurred at the lowest position along its respective transect, suggesting a possible downslope-accumulation of charcoal. However, significant differences in mean charcoal mass distribution within a site may also be explained by patchiness of fire (in space or intensity), bioturbation, and the distribution of charred woody debris after a fire. Large woody debris from the same source (*e.g.*, a large tree branch) could burn during a fire and intersect two or more coring locations, thus providing a source of increased charcoal for more than one core.

Does the distribution of macroscopic charcoal vary by depth in a soil core?

All sites except Gold Mine Trail B exhibited a significant and strong negative correlation between charcoal mass and depth within cores; that is to say, charcoal mass is greatest in shallow core increments and least in deep core increments. Gold Mine Trail B is located within an ephemeral stream valley, and disturbance of soil accumulation by seasonal and episodic water flow may be responsible for the lack of correlation of macroscopic charcoal and soil depth at this site. The fact that shallow core increments contain more macroscopic soil charcoal than deeper ones is most likely related to the taphonomic breakdown of macroscopic soil charcoal within the soil profile, rather than a significant increase in fires that resulted in an influx of charcoal to the shallow core increments. Charcoal is stored indefinitely in soils, but freeze-thaw action, drought, root penetration (Carcaillet and Talon 1996), and earthworm ingestion (Topoliantz and Ponge 2003, 2005; Eckmeier *et al.* 2007) cause fragmentation of charcoal particles that can break charcoal into sizes too small to be retained on a 2 mm sieve.

Does macroscopic charcoal mass differ among sites?

Topography, slope aspect, and microclimates can affect forest types, likelihood of fire, and soil charcoal occurrence and distribution. Rabbit Creek Trail A produced the greatest mean charcoal mass. Rabbit Creek Trail A has the steepest slope (57%) of all the sites, suggesting that a steep slope angle does not necessarily equate with downslope loss of charcoal. Scales (2011) reported similar findings in his study of modern charcoal deposition following controlled burns in western Virginia. At his sites, slope was positively correlated with charcoal abundance. Rabbit Creek Trail A may have yielded the greatest amount of soil charcoal of all my sites *because* of its steep slope. Fires typically burn more rapidly on steep slopes because fuels on the slope above a

fire are more easily ignited by upward-moving flames. Convection currents and radiant heat also move upslope and dry fuels during a fire. Because of its steep slope, Rabbit Creek Trail A may be more susceptible to fire than any of the other study sites. Further research could clarify the effects of slope and fire intensity on soil charcoal abundance in GRSM, and whether areas such as Rabbit Creek Trail A are indeed more fire-prone than others.

The moisture level at the eight study sites appears to be somewhat related to mean charcoal mass and, thus, to the occurrence of fire at these sites. Locations with western and southern exposures and steep slopes tend to be drier than those with eastern and northern exposures and shallow slopes. Study areas ranked in descending order of moisture are Gold Mine Trail, Rabbit Creek Trail, and Pine Mountain. These categorizations are based on mean percent slope and slope aspect of individual study sites. Gold Mine Trail also has a higher concentration of creeks than the Rabbit Creek Trail and Pine Mountain study areas (LaForest 2012). Furthermore, LaForest (2012) determined that yellow pines growing at the Rabbit Creek Trail study area were more responsive to the Palmer Drought Severity Index (*i.e.*, more sensitive to drought) than pines in the other study areas, suggesting that Rabbit Creek Trail is relatively drought-prone. Mean charcoal mass at the relatively mesic Gold Mine Trail sites is consistently low. Core sites at the relatively xeric Rabbit Creek Trail study area had the greatest and least mean charcoal masses, suggesting a pattern of patchy fire occurrence. At the relatively xeric Pine Mountain study area, core sites consistently produced moderate to high amounts of charcoal.

Forest composition itself can also affect the spatial distribution of charcoal. Certain types of trees, such as yellow pines, are prone to being more affected by fire than other tree types. Pine needles and self-pruned branches contribute to surface fuels, while highly flammable resinous compounds produced by pines can promote fire. In his study in the Virginia highlands, Scales

(2011) determined that average char heights were 1 to 3 m for all trees other than pines, for which char height was 7.3 m. He also found a weak, but positive correlation between char height and the production of soil charcoal, leading him to suggest that fire intensity was likely higher in pine stands (Scales 2011). The Rabbit Creek Trail and Pine Mountain study areas produced a higher percentage of yellow pine charcoal than the Gold Mine Trail study area. Yellow pine was the most common charcoal type at the Rabbit Creek Trail and Pine Mountain study areas, and these two locations currently support higher percentages of yellow pine trees than the Gold Mine Trail study area. These findings, and the fact that two sites from these study areas, Rabbit Creek Trail A and Pine Mountain C, produced the greatest mean charcoal mass in this study, are probably related. Forests dominated by yellow pines are more fire-prone and should produce the greatest amounts of soil charcoal.

Does the age of charcoal fragments vary by depth in the soil column?

The lack of a chronological relationship between charcoal age and depth is consistent with previous studies (*e.g.*, Carcaillet 2001a, b) and underscores the need in soil-charcoal studies to obtain large numbers of radiocarbon dates. Only Pine Mountain A exhibited a significant correlation between charcoal age and depth. However, this is a negative correlation, meaning that age of charcoal decreases as depth increases. This finding may be explained by the high degree of bioturbation and colluvial soil movement in the southern Appalachians. The decision to randomly select charcoal fragments for dating from core sections ≥ 20 cm in depth may have affected the lack of correlation between age and depth, because soil charcoal with the youngest calibrated ages stands the highest chance of being present in the shallowest core sections. When all sites are combined, there is no statistically significant correlation between calibrated age and

depth. These findings are different from those of Fesenmyer and Christensen (2010), in which seven of their sites in western North Carolina showed no pattern between soil-charcoal calibrated ages and depth, one site showed a decreasing age/depth relationship, and 10 sites showed an increasing age/depth relationship. However, Fesenmyer and Christensen (2010) selected charcoal for dating from throughout entire soil cores (*i.e.*, including the 0–20 cm portion of cores). This could be a reason some of their sites showed an increasing age/depth relationship, whereas none of my sites did.

Does the mean age of charcoal fragments vary by site?

Pine Mountain B, Rabbit Creek Trail C, and Gold Mine Trail A produced the oldest mean calibrated ages, while Rabbit Creek Trail B produced the youngest. The distribution and, in some cases, clustering of mean calibrated ages may be related to Native American activity at the study sites and areas. For example, Gold Mine Trail A has a relatively high concentration of natural water sources in comparison to the other sites. Native Americans may have been attracted to the easily accessible water in the Gold Mine Trail A area, which in turn could have led to an increase in anthropogenic fires at this site.

The spike in radiocarbon dates ca. 3500 cal yr BP, apparent at all study areas, corresponds with increased cultivation practices of native plants, such as squash (*Cucurbita pepo* L.), lambsquarters (*Chenopodium berlandieri* Moq.), and little barley (*Hordeum pusillum* Nutt.), in the Eastern Agricultural Complex during the end of the Late Archaic period (Delcourt *et al.* 1998, Scarry 2003, Smith and Cowan 2003). This was an important period of change for Native Americans in the southern Appalachians, as many groups were transitioning from hunter/gatherer to horticultural societies. Also during this time Native American occupation of

Tuckaleechee Cove increased. Tuckaleechee Cove, adjacent to GRSM, consists of flat bottomlands and terraces that were permanently occupied and farmed by Native Americans for thousands of years. Another spike in charcoal occurred ca. 1000 cal yr BP at the beginning of the Mississippian period. Widespread farming of corn began ca. 1000 yr BP and continued into the Mississippian and Historic periods (Scarry 2003). Forest clearing associated with agricultural societies could be largely responsible for the spike in charcoal production ca. 1000 cal yr BP.

Any patterns in spatial and temporal distributions of soil charcoal could also be related to issues of preservation of charcoal in soils. However, the charcoal spike ca. 3500 cal yr BP involves multiple old charcoal fragments from different taxa, suggesting that factors other than coincidence were involved in producing this spike.

Were southern yellow pine and mixed hardwood-pine forests maintained by lightning-ignited and Native American-set fires before the arrival of Euro-American settlers? Were mesophytic taxa also present during this period?

Because forest soils do not typically preserve stratigraphically ordered charcoal fragments, soil-charcoal reconstructions of fire history must be based on multiple radiocarbon dates. Radiocarbon-dated charcoal fragments in this study range in age from 9649 to 107 cal yr BP. The distribution of charcoal ages demonstrates that fires have been prevalent in the western portion of GRSM during much of the Holocene, especially from ca. 4000 to 100 cal yr BP. The older charcoal fragments, although not as abundant as the younger ones, provide evidence that fires occurred at the study sites during the early Holocene. Approximately 80% of the 2- σ calibrated age ranges of radiocarbon-dated charcoal in this study predate two major 20th-century anthropogenically induced forest disturbances: the period of active fire suppression and the

initial outbreak of chestnut blight that was introduced by Europeans. Thus, the fire and forest history provided by this study is one for which most fires were caused by Native Americans or natural processes.

At least 36 distinct, coarse-resolution fire windows are apparent. Fire windows are represented by groups of radiocarbon-dated charcoal fragments for which the calibrated age ranges ($\pm 2 \sigma$, 95% confidence interval) plus the inbuilt-age estimates (100 years) of the samples do not overlap with adjacent periods of fire activity. Distinct fire windows determined from radiocarbon dates are representative of the *minimum* number of fires that occurred. For example, the high-resolution tree-ring record (AD 1684–2007) of fire for the Gold Mine Trail study area indicate 10 fires during the pre-Euro-American settlement period, 52 during the settlement period, and six during the period of active fire suppression (LaForest 2012). All of these fires would most likely produce overlapping radiocarbon ages, and would fall within one distinct fire window.

Interpretation of fire history based on radiocarbon-dated soil charcoal is complicated by the fact that the number of charcoal fragments decreases with increasing charcoal age in this study, as Fesenmyer and Christensen (2010) also found in their study of mixed hardwood and oak-pine forests in western North Carolina. Of 122 weighted-mean calibrated ages, 40 are 499 to 107 cal yr BP, 15 are 999 to 500 cal yr BP, 25 are 1999 to 1000 cal yr BP, 15 are 2999 to 2000 cal yr BP, 13 are 3999 to 3000 cal yr BP, 3 are 4999 to 4000 cal yr BP, 2 are 5999 to 5000 cal yr BP, 4 are 6999 to 6000 cal yr BP, 2 are 7999 to 7000 cal yr BP, 2 are 8999 to 8000 cal yr BP, and 1 is > 9000 cal yr BP. The pattern of decreasing sample depth with increasing age is characteristic of virtually all historical data sets (Egan and Howell 2001).

Radiocarbon dates on taxonomically identified charcoal fragments show that southern yellow pine, mesic conifer (*i.e.*, eastern white pine and eastern hemlock), undifferentiated pine, chestnut, and oak are well-represented in this study and were present during most of the Holocene. Southern yellow pine charcoal was dominant or co-dominant through the Holocene at each study area and for a combination of all study areas. This is especially important given that yellow pines simply are not presently regenerating to maturity in the western portion of GRSM, a consequence of nearly a century of fire exclusion. The lack of frequent burning, demonstrated at these study sites by LaForest (2012), has allowed fire-intolerant species to encroach upon historic yellow pine habitats and successfully supplant yellow pines as the dominant tree type.

Soil moisture for individual study sites may, at least partially, explain the higher soil-charcoal percentages of the mesic conifer category at Gold Mine Trail and Rabbit Creek Trail, and southern yellow pine, oak, and chestnut categories at Pine Mountain. Even though some of these study sites are more mesic compared to each other, and all support more mesophytes now than in the past because of fire suppression (LaForest 2012), all sites were selected for this study because they traditionally supported xeric and fire-associated forests with a high component of southern yellow pine, oak, and chestnut trees. In comparison with other areas in GRSM, my study sites are all relatively xeric.

Nonetheless, the abundance of charcoal from the mesic conifer category cannot be denied. There is a lack of yellow pine charcoal ca. 3500 to 500 cal yr BP at Gold Mine Trail, ca. 6500 to 3000 cal yr BP and ca. 2500 to 1500 cal yr BP at Rabbit Creek Trail, and ca. 3000 to 1750 cal yr BP at Pine Mountain. The charcoal record suggests that mesophytic species, especially eastern white pine, were dominant at Pine Mountain, the most xeric area in this study, from ca. 3000 to 1750 cal yr BP. This suggests that periods of “mesophication,” are not

necessarily novel in this ecosystem, and that changes in precipitation or other factors besides fire suppression may have caused increases in mesic conifers in the past in this area. There is the possibility, however, that charcoal from certain species could be preferentially produced during or preserved after a fire. If so, the abundance of charcoal from mesic conifers or yellow pines could lead to an overestimation of the past occurrence of these trees.

I also compared the soil-charcoal records of fire and forest composition from this study with fire- and forest-history reconstructions from previous regional studies (Tables 11 and 12). During selection of soil charcoal for radiocarbon dating, I purposely excluded the upper 20 cm of soil cores from the selection pool. This was to avoid potential overlap with previously established dendrochronological records of fire history in and near the study areas, because the youngest charcoal fragments (*i.e.*, ones that would overlap with tree-ring records of fire) have a greater chance of occurring in shallow core increments. This reasoning is based on data from Fesenmyer and Christensen (2010), in which 10 of 18 of their core sites showed an increasing age/depth relationship, and nine of these ten sites produced profiles in which the youngest dates occurred in the top 10 cm of the soil horizon. This approach worked, because few dated soil-charcoal fragments overlap in age with the dendrochronological records of fire. The minimal occurrence of radiocarbon dates from the last 150 years could also be attributed to the diminished role of fire on this landscape during the 20th century and the probability that very little charcoal was created since the establishment of GRSM in 1934. However, radiometric errors are generally high for samples younger than 400 yr BP (Fesenmyer and Christensen 2010), and the low number of calibrated ages during the last 150 years could also reflect this aspect of the radiocarbon method.

Table 11. Comparison of results with previous studies of fire history in the southern Appalachians. The bold dividing lines separate dendrochronological studies (top), sediment studies (middle), and soil-charcoal studies (bottom).

Study	Region	Findings	Period	This study, in comparison
Harmon 1980, 1982	western GRSM	fire-return interval of 12.7 years	1855–1940	[*] <i>n</i> = 25 491.2 mg charcoal
Armbrister 2002	north-central GRSM	fire-return interval of 6.8 years	[†] pre-park establishment	not enough data from Armbrister for comparison
Brose and Waldrop 2006	uplands of TN, SC, and GA	2 to 6 fires per site	1900–1949	<i>n</i> = 25 491.2 mg charcoal
Feathers 2010	Cades Cove area of GRSM	fire-return interval of 5 years	1720–1818	<i>n</i> = 27; 587.5 mg charcoal
		fire-return interval of 2.5 years	1819–1934	<i>n</i> = 25 491.2 mg charcoal
LaForest 2012	western GRSM	fire-return interval of 6 to 12 years	1700–1834	<i>n</i> = 27; 587.5 mg charcoal
		fire-return interval of 1.7 to 2.3 years	1834–1934	<i>n</i> = 25 491.2 mg charcoal
		fire-return interval of 6.5 to 8.8 years	after 1934	<i>n</i> = 25 491.2 mg charcoal
Delcourt and Delcourt 1997	western NC highlands	charcoal increase	Early Woodland	[§] (+)
		charcoal accumulation peaked	Mississippian	(–) peak occurred during Woodland
		charcoal decline	Mississippian until 1830	(+)
		charcoal increase	1830–1900	(+)

Table 11. (continued)

Study	Region	Findings	Period	Comparison with this study
Delcourt <i>et al.</i> 1998	northern Cumberland Plateau	charcoal increase	Late Archaic–Woodland	(+)
Hass 2008	Cades Cove area of GRSM	charcoal increase	early 1800s–1950s	(+)
Hart <i>et al.</i> 2008	Cumberland Plateau	five distinct fires	6735–174 cal yr BP	11 distinct fire windows at Gold Mine Trail, 12 at Rabbit Creek Trail, and 9 at Pine Mountain
		steady record of fire	4000–1000 cal yr BP	(+)
Fesenmyer and Christensen 2010	western NC	charcoal increase	1000 cal yr BP	(+)
		charcoal decline	250 cal yr BP	(+)

* n is the number of radiocarbon dates obtained in this study

† Armbrister could not establish an exact date, because 9 of his 18 Table Mountain Pine samples did not crossdate.

§ The (+) or (–) symbols indicate similar or dissimilar results in comparison with this study.

Table 12. Comparison of results with previous studies of forest history in the southern Appalachians.

Study	Region	Findings	Period	This study, in comparison
Delcourt 1979	Highland Rim, TN	cool, wet climate	> 8000 yr BP	insufficient overlap
		warmer, drier climate; increase in oak pollen	8000–5000 yr BP	* (+) oak spike, ca. 5000 to 4000 cal yr BP
Delcourt <i>et al.</i> 1986	Little Tennessee River Valley	(Black Pond) minimal forest clearing (high ratio of oak and pine pollen)	3000–400 yr BP	(+) high ratio of pine charcoal, with some oak
		upland pollen dominated by oak and pine; hickory and chestnut subdominant	Late Holocene	(+)
		(Tuskegee Pond) clearing indicated by <i>Ambrosia</i> pollen	by 1500 yr BP	n/a; did not analyze non-arboreal charcoal
		charcoal from fire pits indicates dominance of oak, hickory, and chestnut	Early–Middle Archaic	(–) oak and chestnut appeared in Late Archaic
		increase in pine charcoal (concurrent with human disturbance)	Late Archaic	(+)
		further increase in pine charcoal; decrease in oak, hickory, and <i>Juglans</i>	Woodland	(–) <i>Pinus</i> and hardwood charcoal relatively steady
Delcourt and Delcourt 1997	western NC highlands	pollen dominated by oak and chestnut	ca. 4000–100 years ago	(–) <i>Pinus</i> dominant
		chestnut pollen declined to 10%, pine increased to 15% of all pollen	past 100 years	chestnut 6% of all charcoal, pine 85% of all charcoal

Table 12. (continued)

Study	Region	Findings	Period	This study, in comparison
Delcourt <i>et al.</i> 1998	northern Cumberland Plateau	increased pine, oak, and chestnut pollen (coeval with anthropogenic fires)	3000 yr BP	(+) ca. 3500 cal yr BP

*The (+) or (–) symbols indicate similar or dissimilar results in comparison with this study.

Is there a relationship between species composition of macroscopic soil charcoal in surface samples and current forest community composition?

The study of surface samples of pollen grains has been used for decades (*e.g.*, Janssen 1967) to estimate past vegetation from fossil pollen assemblages (Moore *et al.* 1991). In this study, I explored the possibility of making inferences about past vegetation using similar methods to compare modern vegetation and near-surface charcoal assemblages. However, I found the variability of tree-species composition during the past 70+ years in forests in the western portion of GRSM, the lack of stratigraphic integrity of soil charcoal, and the high percentage of imprecisely identified (*i.e.*, “other” category) surface-soil charcoal to impose restrictions on the use of the *R*-value model to reconstruct past vegetation percentages from past charcoal assemblages.

Forest fire suppression has resulted in a major species shift in which pines and oaks are being replaced by fire-intolerant species (LaForest 2012). Chestnut blight also contributed to significant changes in forest composition during the past century. Taphonomic processes are simply too complicated in these soils to confidently assume that surface soil samples contain primarily modern charcoal (Phillips and Marion 2006). The only statistically significant stratigraphy from this study (Pine Mountain A) exhibits a negative correlation between depth and soil-charcoal age. Because these forests have not burned regularly since the establishment of GRSM, the absolute latest soil charcoal will not correspond with current forest composition.

The accuracy of *R*-values depends on the accurate determination of the composition of modern forests and proxy assemblages (Davis 1963). High percentages of imprecisely identified surface charcoal at all study sites limited the power of the *R*-value model because it is impossible to compare data from this category with any modern tree category. Another potential issue is that

charcoal from certain genera or species of trees could be preferentially produced during or preserved after a fire. If so, the abundance of charcoal in soil samples for those genera or species could lead to an overestimation of past occurrences of that genera or species. In an ideal case, the *R*-value model might correct this issue, but the abundance of charcoal in surface samples that was not identified to a specific taxonomic category could complicate the work of the model.

Chapter 7

Conclusions and Suggestions for Further Research

7.1 Conclusions

The purpose of this study was to reconstruct a site-specific, long-term fire and forest history of yellow pine and mixed hardwood-pine forests in the western portion of GRSM. This study is the first of its kind to use taxonomically identified soil charcoal to reconstruct forest composition history in the southern Appalachians. In this region with sparse natural wetlands suitable for sediment-based reconstructions of vegetation and fire, soil-charcoal analysis can help fill a void in our knowledge of long-term vegetation and fire history.

Soil charcoal in GRSM provided evidence of fire and forest history during most of the Holocene. This research showed that fires have burned on this landscape for millennia. Taxonomic identification of charcoal showed the forests that burned were mostly composed of southern yellow pine, eastern white pine, American chestnut, and oak.

Protection of natural resources is a primary goal for those who study and manage forests. Forest managers of the early-20th century had this in mind when they enacted broad-scale fire suppression policies. Ironically, fire suppression has resulted in the decline of many yellow pine and mixed hardwood-pine communities (Harmon 1982) and an increase in fire-sensitive species and fuel loads (Lafon *et al.* 2005, LaForest 2012) in the southern Appalachians. This study demonstrates the importance of southern yellow pines in the western portion of GRSM through the Holocene. Southern yellow pine charcoal was either dominant or co-dominant at every study area, and it was the most dominant charcoal category for all study areas combined through the Holocene. This demonstrates a long-standing association between yellow pine species, fire, and

xeric landscapes in GRSM. Pines often serve as pioneer species in disturbed areas where they improve site characteristics (*e.g.*, erosion control) (Auten 1945, Hosner and Graney 1970, LaForest 2012) and provide food and habitat for wildlife (Van Dersal 1938, Harlow and Doyle 1990). Nonetheless, eastern white pine is also well represented in this charcoal record, suggesting that the current period of “mesophication” may not be unique in this ecosystem. Mesic and xeric conifers have coexisted in these forests for millennia, and the dynamics that may lead to the dominance of one group over the other are likely more complex than originally believed.

Yellow pines and oaks are poorly represented in contemporary seedling and sapling cohorts at the eight study sites (LaForest 2012). Yellow pines in particular are not reproducing in a way that will allow these species to maintain or regain dominance under the present fire regime in the southern Appalachians. If a management goal is to encourage and nurture yellow pine and mixed hardwood-pine forest growth, then these forests must burn at a higher frequency. Lack of sufficient action will most certainly lead to further degradation of yellow pine and mixed-hardwood-pine forests in the southern Appalachians.

With increasing numbers of fire-intolerant trees and the fuels that have been accumulating for almost a century at some sites in the western portion of GRSM, a single prescribed fire is not likely to replicate the effects of pre-suppression fires (Harrod *et al.* 1998, Nowacki and Abrams 2008, Fesenmyer and Christensen 2010). Insufficient or improperly applied prescribed burning can even encourage resprouting of fire-sensitive species such as red maple (Kuddes-Fischer and Arthur 2002). Thus, management practices sufficient to restore the importance of yellow pine and mixed hardwood-pine forests in the southern Appalachian

Mountains may require a multifaceted approach that includes not only prescribed fire, but also mechanical removal of competitive, fire-sensitive species (LaForest 2012).

My research results and interpretations will be shared with forest managers in GRSM and throughout the southern Appalachians to assist them in making decisions regarding forest and fire management. Information about past forest-fire trends and the departure of current fire trends from past conditions is important for guiding and justifying forest management practices, including prescribed burning. Restoring natural conditions (*e.g.*, high-frequency, low-intensity fires) in these forests is important not only to the health and conservation of the species that live therein, but also to the protection and preservation of human life and property along the expanding wildland-urban interface of GRSM.

7.2 Suggestions for Further Research

The Blue Ridge Mountains, and specifically GRSM, is one of the most diverse ecoregions in the western hemisphere, yet its history of forest succession and disturbance by fire through the Holocene remains poorly known (Fesenmyer and Christensen 2010). Strong evidence for a high-frequency, low-intensity fire regime exists here in the fact that during the period of 20th-century fire suppression, yellow pine and mixed hardwood-pine forests have been invaded by fire-sensitive species (Abrams 2002). This research shows that fire by natural or anthropogenic ignitions has occurred in xeric forests of GRSM throughout the Holocene, yet long-term fire history information is needed in other areas of the southern Appalachian Mountains to help fully construct conservation plans and to inform wildlife and land management decisions.

The pool of proxy records of fire and forest history for this region is dwindling. Old-growth forests are no longer abundant because much of the area was heavily logged during the 19th and 20th centuries. Many of the oldest trees that could provide dendrochronological records of fire history are reaching a point of natural mortality or are being stressed to the point of decline by a multitude of factors such as competition with encroaching species, pollution, and insect outbreaks (LaForest 2012). These trees should be sampled before their records are forever lost. Further soil-charcoal analyses would be especially informative in other areas of the central and southern Appalachians where recent fire history has been reconstructed from dendrochronological analyses (*e.g.*, DeWeese 2007, Feathers 2010, Aldrich 2011). This would extend records of fire history from tree rings at these sites and help build a network of soil charcoal-based Holocene fire and forest history data.

Further attempts at hindcasting past vegetation based on known modern soil-charcoal data (*i.e.*, charcoal collected immediately following a fire) would be beneficial. Also, more sophisticated models that integrate statistical analyses perhaps could be applied to these data to reconstruct past forest composition.

Research on the potential movement and loss of macroscopic soil charcoal in the western portion of GRSM, similar to the work performed by Scales (2011) in western Virginia, would be beneficial. Permanent study plots, installed and monitored repeatedly following a fire, could provide important information on natural processes that affect production, preservation, movement, and subsequent burial of charcoal in the western portion of GRSM. This could answer questions regarding whether charcoal from certain species is preferentially produced or preserved. It would be beneficial to conduct these studies after the occurrence of fires of different intensities and on varying degrees of slope. This would help hone the spatial resolution of soil

charcoal as a proxy to reconstruct forest history and past occurrences of fire at locations where other proxies are sparse or not viable.

Although not a focus of this research, soil charcoal stored in a terrestrial ecosystem acts as an important carbon sink and deserves further study. Charcoal accumulates in soils after a fire and does not readily decompose. Thus, the fires that occurred at these sites during the Holocene play a role in long-term carbon sequestration and in the global carbon budget (Carcaillet and Talon 2001). Soil-charcoal sequestration is more significant in biomes that are fire prone, and soil-carbon content should be high in forests with high woody biomass productivity and fire frequency (Carcaillet and Talon 2001). Under an unimpeded fire regime, the xeric yellow pine and mixed hardwood-pine forests of the southern Appalachians fit this description. The mean soil charcoal concentration for this study, based on the total charcoal extracted from 315 core increments, is 0.053 g per 100 cc of soil. On a mass per area basis, this mean charcoal amount corresponds to 347.54 g/m².

During a forest fire, large amounts of carbon dioxide can be released into the atmosphere, but after the initial pulse of carbon dioxide is released via smoke, carbonized wood becomes a highly effective terrestrial carbon sink that can be sequestered for millennia (Licata and Sanford 2010a, b). In the absence of fire in GRSM, this highly effective method of carbon sequestration is going unused. In a world of increased atmospheric greenhouse gas concentrations that exacerbate global warming, the study of terrestrial carbon sequestration has grown increasingly important, and research into carbon sequestration via soil charcoal in GRSM would be worthwhile. Licata and Sanford (2010) demonstrated that soil charcoal accumulates in different quantities in different fire-associated forest types in the Colorado Front Range. They proposed that high elevation, high biomass, slow decomposition rates, and less frequent mean fire return

intervals create conditions for net soil charcoal accumulation, and thus provide an environment for a more effective carbon sink (Licata and Sanford 2010). Similar research to determine the spatial variability of charcoal storage in relation to terrain, forest type, and fire regime would be beneficial to determining the effectiveness of soil charcoal as a carbon sink in GRSM.

References

- Abrams, M.D. 1992. Fire and the development of oak forests. *BioScience* 42: 346–353.
- Abrams, M.D. 2002. The postglacial history of oak forests in eastern North America. Pp. 34–45 in McShea, W.J., and Healy, W.M., eds., *Oak Forest Ecosystems: Ecology and Management for Wildlife*. The Johns Hopkins University Press, Baltimore, Maryland.
- Abrams, M.D. 2003. Where has all the white oak gone? *BioScience* 53: 927–939.
- Abrams, M.D., and Downs, J.A. 1990. Successional replacement of old-growth white oak by mixed mesophytic hardwoods in southwestern Pennsylvania. *Canadian Journal of Forest Research* 20: 1864–1870.
- Abrams, M.D., and Nowacki, G.J. 2008. Native Americans as active and passive promoters of mast and fruit trees in the eastern USA. *The Holocene* 18(7): 1123–1137.
- Agee, J.K. 1998. Fire and pine ecosystems. Pp. 320–350 in Richardson, D.M., ed., *Ecology and Biogeography of Pinus*. Cambridge University Press, Cambridge, U.K.
- Aitken, M.J. 1990. *Science-Based Dating in Archaeology*. Longman Group U.K., London, U.K., 296 pp.
- Aldrich, S.R. 2011. Fire regimes and successional dynamics of pine and oak forests in the central Appalachian Mountains. Ph.D. dissertation, Texas A&M University, 141 pp.
- Aldrich, S.R., Lafon, C.W., Grissino-Mayer, H.D., DeWeese, G.G., and Hoss, J.A. 2009. Three centuries of fire in montane pine-oak stands on a temperate forest landscape. *Applied Vegetation Science* 13: 36–46.
- Anagnostakis, S.L. 1987. Chestnut blight: the classical problem of an introduced pathogen. *Mycologia* 79(1): 23–37.
- Armbrister, M.R. 2002. Changes in fire regimes and the successional status of Table Mountain pine (*Pinus pungens* Lamb.) in the Southern Appalachians, USA. M.S. thesis, University of Tennessee, Knoxville, 151 pp.
- Augspurger, M.K., Van Lear, D.H., Cox, S.K., and Phillips, D.R. 1987. Regeneration of hardwood coppice following clearcutting with and without prescribed fire. Pp. 89–92 in Phillips, D.R., ed., *Proceedings of the Fourth Biennial Southern Silvicultural Research Conference*. General Technical Report SE-42. U.S. Department of Agriculture, Forest Service, Southern Research Station, Asheville, North Carolina.
- Auten, J.T. 1945. Relative influence of sassafras, black locust, and pines upon old-field soils. *Journal of Forestry* 43: 441–496.

- Ayres, H. B. and Ashe, W. W. 1905 The southern Appalachian Forests, *USDI Geological Survey Professional Paper 37*. Government Printing Office, Washington, D.C.
- Barden, L.S., and Woods, F.W. 1973. Characteristics of lightning fires in southern Appalachian forests. *Proceeding of the Annual Tall Timbers Fire Ecology Conference* 13: 345–361.
- Barden, L.S., and Woods, F.W. 1976. Effects of fire on pine and pine-hardwood forests in the southern Appalachians. *Forest Science* 22: 399–403.
- Beatty, S.W., and Stone, E.L. 1986. The variety of soil microsites created by tree falls. *Canadian Journal of Forest Research* 16: 539–548.
- Birks, H.J.B., and Birks, H.H. 1980. *Quaternary Palaeoecology*. Edward Arnold Limited, London, U.K., 298 pp.
- Blackford, J. J. 2000. Charcoal fragments in surface samples following a fire and the implications for interpretation of subfossil charcoal data. *Palaeogeography, Palaeoclimatology, Palaeoecology* 164: 33–42.
- Blankenship, B., and Arthur, M. 2006. Stand structure over 9 years in burned and fire-excluded oak stands on the Cumberland Plateau, Kentucky. *Forest Ecology and Management* 225(1–3): 134–145.
- Bormann, B.T., Spaltenstein, H., McClellan, M.H., Ugolini, F.C., Cromack, K., and Nay, S.M. 1995. Rapid soil development after windthrow disturbance in pristine forests. *Journal of Ecology* 83: 747–757.
- Bramble, W.C., and Goddard, M.K. 1942. Effect of animal coaction and seedbed condition on regeneration of pitch pine in the barrens of central Pennsylvania. *Ecology* 29: 330–335.
- Braun, E.L. 1950. *Deciduous Forests of Eastern North America*. McGraw-Hill Book Company, New York, New York, 596 pp.
- Brose, P., Schuler, T., Van Lear, D., and Berst, J. 2001. Bringing fire back: the changing regimes of the Appalachian mixed-oak forests. *Journal of Forestry* 99(11): 30–35.
- Brose, P.H., and Waldrop, T.A.. 2006. Changes in the disturbance regime of upland yellow pine stands in the southern Appalachian Mountains during the 20th century. Pp. 467–470 in Conner, K.F., ed., *Proceedings of the 13th Biennial Southern Silvicultural Research Conference*. General Technical Report SRS-92, U.S. Department of Agriculture, Forest Service, Southern Research Station, Asheville, North Carolina.
- Brown, H.P., and Panshin, A.J. 1934. *Identification of the Commercial Timbers of the United States*. McGraw-Hill, New York, New York, 223 pp.

- Brown, M.L. 2002. *Wild East: A Biography of the Great Smoky Mountains*. University Press, Tallahassee, Florida, 457 pp.
- Bryson, R.A., Irving, W.N., and Larsen, J.A. 1965. Radiocarbon and soil evidence of former forest in the southern Canadian tundra. *Science* 147: 46–48.
- Carcaillet, C. 1998. A spatially precise study of fires, climate and human impacts within the Maurienne valley, North French Alps. *Journal of Ecology* 86: 384–396.
- Carcaillet, C. 2001a. Are Holocene wood-charcoal fragments stratified in alpine and subalpine soils? Evidence from the Alps based on AMS ^{14}C dates. *The Holocene* 11: 231–242.
- Carcaillet, C. 2001b. Soil particles reworking evidences by AMS ^{14}C dating of charcoal. *Earth and Planetary Sciences* 332: 21–28.
- Carcaillet, C., Almquist, H., Asnong, H., Bradshaw, R.H.W., Carrión, J.S., Gaillard, M.-J., Gajewski, K., Haas, J.N., Haberle, S.G., Hadorn, P., Müller, S.D., Richard, P.J.H., Richoz, I., Rösch, M., Sánchez Goñi, M.F., von Stedingk, H., Stevenson, A.C., Talon, B., Tardy, C., Tinner, W., Tryterud, E., Wick, L., and Willis, K.J. 2002. Holocene biomass burning and global dynamics of the carbon cycle. *Chemosphere* 49: 845–863.
- Carcaillet, C., and Talon, B. 1996. Stratigraphie et datations de charbons de bois dans les Alpes: quelques aspects taphonomiques. *Géographie Physique et Quaternaire* 50: 233–244.
- Carcaillet, C., and Talon, B. 2001. Soil carbon sequestration by Holocene fires inferred from soil charcoal in the dry French Alps. *Arctic, Antarctic, and Alpine Research* 33(3): 282–288.
- Carlquist, S.J. 1988. *Comparative Wood Anatomy: Systematic, Ecological, and Evolutionary Aspects of Dicotyledon Wood*. Springer-Verlag, New York, New York, 436 pp.
- Carter, K.K., and Snow, Jr., A.G. 1990. *Pinus virginiana* Mill. Pp. 513–519 in Burns, R.M., and Honkala, B.H., technical coordinators, *Silvics of North America: Volume 1, Conifers*. Agriculture Handbook 654. U.S. Department of Agriculture, Forest Service, Washington, D.C.
- Chandler, C.C., Cheney, P., Thomas, P., Traubad, L., and Williams, D. 1983. *Fire in Forestry, Volume 1, Forest Fire Behavior and Effects*. John Wiley and Sons, New York, New York, 450 pp.
- Chapman, J., Delcourt, P.A., Cridlebaugh, P.A., Shea, A.B., and Delcourt, H.R. 1982. Man-land interaction: 10,000 years of American Indian impact on native ecosystems in the lower Tennessee River Valley, eastern Tennessee. *Southeastern Archaeology* 1: 115–121.

- Clark, J.S., and Patterson, III, W.A. 1997. Background and local charcoal in sediments: scales of fire evidence in the paleorecord. Pp. 23–48 in Clark, J.S., Cachier, H., Goldammer, J.G., and Stocks, B., eds., *Sediment Records of Biomass Burning and Global Change*. Springer-Verlag, Berlin, Germany.
- Cohen, D., Dellinger, B., Klein, R., and Buchanan, B. 2007. Patterns in lightning-caused fires at Great Smoky Mountains National Park. *Fire Ecology Special Issue* 3(2): 68–82.
- Copenheaver, C.A., Matthews, J.M., Showalter, J.M., and Auch, W.E. 2006. Forest stand development patterns in the southern Appalachians. *Northeastern Naturalist* 13(4): 477–494.
- Core, H.A., Côté, W.A., and Day, A.C. 1979. *Wood Structure and Identification*, 2nd Ed. Syracuse University Press, Syracuse, New York, 182 pp.
- Cronan, W. 1983. *Changes in the Land: Indians, Colonists, and the Ecology of New England*. Hill and Wang, New York, New York, 242 pp.
- Crow, T.R. 1988. Reproductive mode and mechanism for self-replacement of northern red oak (*Quercus rubra*): a review. *Forest Science* 34: 19–40.
- Davis, M.B. 1963. On the theory of pollen analysis. *American Journal of Science* 261: 897–912.
- Davis, M. B. 1981. Outbreaks of forest pathogens in Quaternary history. Pp. 216–227 in *Proceedings of the IV International Palynological Conference* (vol. 3), Lucknow, India.
- Davis, Jr., R.P.S. 1986. Stability and change in aboriginal settlement within the lower Little Tennessee River Valley. Ph.D. dissertation, University of Tennessee, Knoxville, 465 pp.
- DeFoe, D., Giddens, B, Kemp, S, and Cave, K., eds. 2003. *Hiking Trails of the Smokies*. Great Smoky Mountains National History Association, Gatlinburg, Tennessee, 583 pp.
- Delcourt, H.R. 1979. Late Quaternary vegetation history of the western highland rim and adjacent Cumberland Plateau of Tennessee. *Ecological Monographs* 49: 255–280.
- Delcourt, H.R. 1987. The impacts of prehistoric agriculture and land occupation on natural vegetation. *Trends in Ecology and Evolution* 2: 39–44.
- Delcourt, H.R., and Delcourt, P.A. 1997. Pre-Columbian Native American use of fire on southern Appalachian landscapes. *Conservation Biology* 11: 1010–1014.
- Delcourt, P.A., and Delcourt, H.R. 1998. The influence of prehistoric human-set fires on oak-chestnut forests in the southern Appalachians. *Castanea* 63(3): 337–345.

- Delcourt, P.A., Delcourt, H.R., Cridlebaugh, P.A., and Chapman, J. 1986. Holocene ethnobotanical and paleoecological record of human impact on vegetation in the Little Tennessee River Valley, Tennessee. *Quaternary Research* 25: 330–349.
- Delcourt, P.A., Delcourt, H.R., Ison, C.R., Sharp, W.E., and Gremillion. 1998. Prehistoric human use of fire, the Eastern Agricultural Complex, and Appalachian oak-chestnut forests: paleoecology of Cliff Palace Pond, Kentucky. *American Antiquity* 63: 263–278.
- Della-Bianca, L. 1990. *Pinus pungens* Lamb. Pp. 425–432 in Burns, R.M., and Honkala, B.H., technical coordinators, *Silvics of North America: Volume 1, Conifers*. Agriculture Handbook 654. U.S. Department of Agriculture, Forest Service, Washington, D.C.
- Delwiche, L.D., and Slaughter, S.J. 2012. *The Little SAS Book: A Primer*, 5th Ed. SAS Institute, Incorporated, Cary, North Carolina, 350 pp.
- Denevan, W.M. 1992. The pristine myth: the landscape of the Americas in 1492. *Annals of the Association of American Geographers* 82: 369–385.
- DeVivo, M.S. 1991. Indian use of fire and land clearance in the southern Appalachians. Pp. 306–310 in Nodvin, S.C., and Waldrop, T.A., eds., *Fire and the Environment: Ecological and Cultural Prospectives*. General Technical Report SE-69. U.S. Department of Agriculture, Forest Service, Southern Research Station, Asheville, North Carolina.
- DeWeese, G. 2007. Past fire regimes of Table Mountain pine (*Pinus pungens* L.) stands in the central Appalachian Mountains, Virginia, U.S.A. Ph.D. dissertation, University of Tennessee, Knoxville, 308 pp.
- Dimmick, R., Dimmick, W.W., and Watson, C. 1980. *Red-Cockaded Woodpeckers in the Great Smoky Mountains National Park: Their Status and Habitat*. NPS-SER Research/Resources Management Report 38. United States Department of the Interior, National Park Service, Washington, D.C., 21 pp.
- Di Pasquale, G., Marziano, M., Impagliazzo, S., Lubritto, C., De Natale, A., and Bader, M.Y. 2008. The Holocene treeline in the northern Andes (Ecuador): first evidence from soil charcoal. *Palaeogeography, Palaeoclimatology, Palaeoecology* 259: 17–34.
- Discover Life in America (no date). All Taxa Biodiversity Index. Available: www.dlia.org/atbi/ (accessed: June 14, 2010).
- Eckmeier, E., Gerlach, R., Skjemstad, J.O., Ehrmann, O., and Schmidt, M.W.I. 2007. Minor changes in soil organic carbon and charcoal concentrations detected in a temperate deciduous forest a year after an experimental slash-and-burn. *Biogeosciences* 4(3): 377–383.

- Egan, D., and Howell, E.A., eds. 2001. *The Historical Ecology Handbook: A Restorationist's Guide to Reference Ecosystems*. Island Press, Covelo, California, 488 pp.
- Elder, Joe A. 1959. Soil Survey, Blount County, Tennessee, United States Department of Agriculture, Soil Conservation Service, 119 pp.
- Elliott, K.J., Hendrick, R.L., Major, A.E., Vose, J.M., and Swank, W.T. 1999. Vegetation dynamics after a prescribed fire in the southern Appalachians. *Forest Ecology and Management* 114: 199–213.
- Engstrom, R.T., Gilbert, S., Hunter, Jr., M.L., Merriwether, D., Nowacki, G.J., and Spencer, P. 1999. Practical applications of disturbance ecology to natural resource management. Pp. 313–330 in Szaro, R.C., Johnson, N.C., Sexton, W.T., and Malk, A.J., eds., *Ecological Stewardship: A Common Reference for Ecosystem Management. Volume II*. Elsevier Science, Oxford, UK.
- Feathers, I.C. 2010. Fire history from dendrochronological analyses at two sites near Cades Cove, Great Smoky Mountains National Park, U.S.A. M.S. thesis, University of Tennessee, Knoxville, 139 pp.
- Fenneman, N.M. 1938. *Physiography of Eastern United States*. McGraw-Hill Book Company, New York, New York, 714 pp.
- Fenneman, N.M. 1946. *Physical Divisions of the United States*. United States Geological Survey, Washington, D.C., map.
- Fesenmyer, K.A., and Christensen, Jr., N.L. 2010. Reconstructing Holocene fire history in a southern Appalachian forest using soil charcoal. *Ecology* 91(3): 662–670.
- Flatley, W.T., Lafon, C.W., and Grissino-Mayer, H.D. 2011. Climatic and topographic controls on patterns of fire in the southern and central Appalachian Mountains, USA. *Landscape Ecology* 26: 195–209.
- Forman, R.T.T., and Russell, E.W.B. 1983. Evaluation of historical data in ecology. *Bulletin of the Ecological Society of America* 64: 5–7.
- Fritts, H.C. 2001. *Tree Rings and Climate*. The Blackburn Press, Caldwell, New Jersey, 567 pp.
- Gavin, D.G. 2001. Estimation of inbuilt age in radiocarbon ages of soil charcoal for fire history studies. *Radiocarbon* 43: 27–44.
- Gavin, D.G. 2003. Forest soil disturbance intervals inferred from soil charcoal radiocarbon dates. *Canadian Journal of Forest Research* 33: 2514–2518.

- Gavin, D.G., Brubaker, L.B., and Lertzman, K.P. 2003a. Holocene fire history of a coastal temperate rain forest based on soil charcoal radiocarbon dates. *Canadian Journal of Forest Research* 33: 573–586.
- Gavin, D.G., Brubaker, L.B., and Lertzman, K.P. 2003b. An 1800-year record of the spatial and temporal distribution of fire from the west coast of Vancouver Island, Canada. *Ecology* 84: 186–201.
- Gibson K., and Negrón, J.F. 2009. Fire and bark beetle interactions. Pp. 51–70 in Hayes, J.L., and Lundquist, J.E., eds., *The Western Bark Beetle Research Group: A Unique Collaboration with Forest Health Protection*. General Technical Report PNW-GTR-784. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, Oregon.
- Goebel, P.C., and Hix, D.M. 1997. Changes in the composition and structure of mixed-oak, second-growth forest ecosystems during the understory reinitiation stage of stand development. *Ecoscience* 4: 327–339.
- Gravatt, G.F., and Gill, L.S. 1930. Chestnut blight. *USDA Farmers' Bulletin* 1641.
- Green, S., Arthur, M., and Blankenship, B. 2010. Oak and red maple seedling survival and growth following periodic prescribed fire on xeric ridgetops on the Cumberland Plateau. *Forest Ecology and Management* 259(12): 2256–2266.
- Grissino-Mayer, H.D., and Swetnam, T.W. 2000. Century-scale climate forcings of fire regimes in the American Southwest. *The Holocene* 10(2): 207–214.
- Gucker, Corey L. 2007. *Pinus rigida*. In *Fire Effects Information System* (U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory). Available: <http://www.fs.fed.us/database/feis/>.
- Guffey, S.Z. 1977. A review and analysis of the effects of pre-Columbian man on the eastern North American forests. *Tennessee Anthropologist* 2: 121–137.
- Hain, F.P., Duehl, A.J., Gardner, M.J., and Payne, T.L. 2011. Natural history of the southern pine beetle. Pp. 13–24 in Coulson, R.N., and Klepzig, K.D., eds., *Southern Pine Beetle II*. General Technical Report SRS-140. U.S. Department of Agriculture, Forest Service, Southern Research Station, Asheville, North Carolina.
- Hajdas, I., Schlumpf, N., Minikus-Stary, N., Hagedorn, F., Eckeier, E., Schoch, W., Burga, C., Bonani, G., Schmidt, M. W. I., and Cherubini, P. 2007. Radiocarbon ages of soil charcoals from the southern Alps, Ticino, Switzerland. *Nuclear Instruments and Methods in Physics Research B* 259: 398–402.

- Hallett, D.H., Lepofsky, D.S., Mathewes, R.W., and Lertzman, K.P. 2003. 11,000 years of fire history and climate in the mountain hemlock rain forests of southwestern British Columbia based on sedimentary charcoal. *Canadian Journal of Forest Research* 33: 292–312.
- Hammond, D.S., ter Steege, H., and van der Borg, K. 2006. Upland soil charcoal in the wet tropical forests of central Guyana. *Biotropica* 39(2): 153–160.
- Harlow, R.F. and Doyle, A.T. 1990. Food habits of southern flying squirrels (*Glaucomys volans*) collected from red-cockaded woodpecker (*Picoides borealis*) colonies in South Carolina. *American Midland Naturalist* 124(1): 187–191.
- Harlow, W.M. 1970. *Inside Wood: Masterpiece of Nature*. American Forestry Association, Washington, D.C., 120 pp.
- Harmon, M.E. 1980. The influence of fire and site factors on vegetation pattern and process: a case study of the western portion of Great Smoky Mountains National Park. M.S. thesis, University of Tennessee, Knoxville, 170 pp.
- Harmon, M.E. 1982. Fire history of the westernmost portion of Great Smoky Mountains National Park. *Bulletin of the Torrey Botanical Club* 109(1): 74–79.
- Harmon, M.E., Franklin, J.F., Swanson, F.J., Sollins, P., Gregory, S.V., Lattin, J.D., Anderson, N.H., Cline, S.P., Aumen, N.G., Sedell, J.R., Lienkaemper, G.W., Cromack, Jr., K., and Cummins, K.W. 1986. Ecology of coarse woody debris in temperate ecosystems. *Advances in Ecological Research* 15: 133–302.
- Harrod, J.C., White, P.S., and Harmon, M.E. 1998. Changes in xeric forests in western Great Smoky Mountains National Park, 1936–1995. *Castanea* 63(3): 346–360.
- Harrod, J.C., and White, R.D. 1999. Age structure and radial growth in xeric pine-oak forests in western Great Smoky Mountains National Park. *Journal of the Torrey Botanical Society* 126: 139–146.
- Hart, J.L. 2007. A multi-scale analysis of disturbance dynamics in hardwood forest communities on the Cumberland Plateau, U.S.A. Ph.D. dissertation, University of Tennessee, Knoxville, 189 pp.
- Hart, J.L., Horn, S.P., and Grissino-Mayer, H.D. 2008. Fire history from soil charcoal in a mixed hardwood forest on the Cumberland Plateau, Tennessee, USA. *Journal of the Torrey Botanical Society* 135(3): 401–410.
- Hass, A.L. 2008. Fire history of Gum Swamp and Black Pond in eastern Tennessee, U.S.A., from macroscopic sedimentary charcoal. M.S. thesis, University of Tennessee, Knoxville, 108 pp.

- Heyward, F. 1937. The effect of frequent fires on profile development of longleaf pine forest soils. *Journal of Forestry* 35: 23–27.
- Higuera, P. E., Peters, M.E., Brubaker, L.B., and Gavin, D.G. 2007. Understanding the origin and analysis of sediment charcoal records with a simulation model. *Quaternary Science Reviews* 26: 1790–1809.
- Hoadley, R. 1990. *Identifying Wood: Accurate Results with Simple Tools*. Taunton Press, Newton, Connecticut, 223 pp.
- Hopkins, M.S., Ash, J., Graham, A.W., Head, G.J., and Hewett, R.K. 1993. Charcoal evidence of the spatial extent of the Eucalyptus woodland expansions and rainforest contractions in North Queensland during the late Pleistocene. *Journal of Biogeography* 20: 357–372.
- Horn, S.P., Orvis, K.H., Kennedy, L.M., and Clark, G.M. 2000. Prehistoric fires in the highlands of the Dominican Republic: evidence from charcoal in soils and sediments. *Caribbean Journal of Science* 36(1–2): 10–18.
- Horn, S.P., and Sanford, Jr., R.L. 1992. Holocene fires in Costa Rica. *Biotropica* 24: 354–361.
- Horn, S.P., Wallin, T.R., and Northrop, L.A. 1994. Nested sampling of soil pollen, charcoal, and other soil components using a root corer. *Palynology* 18: 87–89.
- Hosner, J.F. and Graney, D.L. 1970. The relative growth of three forest tree species on soils associated with different successional stages in Virginia. *American Midland Naturalist* 84(2): 418–427.
- Hough, R.B. 2002. *The Wood Book*. Taschen, New York, New York, 863 pp.
- InsideWood (no date). Wood anatomy database. Available: <http://insidewood.lib.ncsu.edu/> (accessed: June 14, 2010).
- Jacobson, G.L., and Bradshaw, R.H.W. 1981. The selection of sites for paleovegetational studies. *Quaternary Research* 16: 80–96.
- Jane, F.W. 1970. *The Structure of Wood*, 2nd Ed., revised by Wilson, K., and White, D.J.B. A. & C. Black, London, U.K., 427 pp.
- Janssen, C.R. 1967. A comparison between the recent regional pollen rain and the sub-recent vegetation in four major vegetation types in Minnesota (U.S.A.). *Review of Paleobotany and Palynology* 2: 331–342.
- Keeley, J.E., and Zedler, P.H.. 1998. Evolution of life histories in *Pinus*. Pp. 219–250 in Richardson, D.M., ed., *Ecology and Biogeography of Pinus*. Cambridge University Press, Cambridge, U.K.

- Kloeppel, B.D., Clinton, B.D., and Vose, J.M. 2003. Drought impacts on tree growth and mortality of southern Appalachian forests. Pp. 43–55 in Greenland, D., Gooding, D.G., and Smith, R.C., eds., *Climate Variability and Ecosystem Response at Long-term Ecological Research Sites*. Oxford University Press, New York, New York.
- Konrad, II, C.E. 1995. Maximum precipitation rates in the southern Blue Ridge Mountains of the southeastern United States. *Climate Research* 5: 159–166.
- Köppen, W. 1931. *Grundriss der Klimakunde*. Walter de Gruyter and Company, Berlin, Germany, 388 pp.
- Kuddes-Fischer, L.M. and Arthur, M.A. 2002. Response of understory vegetation and tree regeneration to a single prescribed fire in oak-pine forests. *Natural Areas Journal* 22(1): 43–52.
- Lafon, C.W. 2010. Fire in the American South: vegetation impacts, history, and climatic relations. *Geography Compass* 4(8): 919–944.
- Lafon, C.W., and Grissino-Mayer, H.D. 2007. Spatial patterns of fire occurrence in the central Appalachian Mountains and implications for wildland fire management. *Physical Geography* 28: 1–20.
- Lafon, C.W., Hoss, J.A., and Grissino-Mayer, H.D. 2005. The contemporary fire regime of the central Appalachian Mountains and its relation to climate. *Physical Geography* 26(2): 126–146.
- LaForest, L.B. 2012. Fire regimes of lower-elevation forests in Great Smoky Mountains National Park, Tennessee, U.S.A. Ph.D. dissertation, University of Tennessee, Knoxville, 279 pp.
- Lambert, R.S. 1958. *Logging in the Great Smoky Mountains National Park: a report to the superintendent*. Unpublished mimeograph, Great Smoky Mountains National Park Archives. United States Department of the Interior, National Park Service, Washington, D.C., 71 pp.
- Lavee, H., Kutiel, P., Segev, M., Benyamini, Y. 1995. Effect of surface roughness on runoff and erosion in a Mediterranean ecosystem: the role of fire. *Geomorphology* 11: 227–234.
- Lawson, E.R. 1990. *Pinus echinata* Mill. Pp. 316–326 in Burns, R.M., and Honkala, B.H., technical coordinators, *Silvics of North America: Volume 1, Conifers*. Agriculture Handbook 654. U.S. Department of Agriculture, Forest Service, Washington, D.C.
- Ledig, F.T., and Little, S. 1979. Pitch pine (*Pinus rigida* Mill.): ecology, physiology, and genetics. Pp 347–371 in Forman, R.T.T., ed., *Pine Barrens: Ecosystem and Landscape*. Academic Press, New York, New York.

- Lertzman, K., Gavin, D., Hallett, D., Brubaker, L., Lepofsky, D., and Mathewes, R. 2002. Long-term fire regime estimated from soil charcoal in coastal temperate rainforests. *Conservation Ecology* 6(2): 5. Available: <http://www.ecologyandsociety.org/vol6/iss2/art5/>.
- Lewis, H. T. 1982. Fire technology and resource management in aboriginal North America and Australia. Pp. 45–67 in Williams, N.M., and Hunn, E.S., eds., *Resource Managers: North American and Australian Hunter-Gatherers, AAAS Selected Symposia 67*. Westview Press, Boulder, Colorado.
- Licata, C.W., and Sanford, Jr. 2010. Soil charcoal from shrublands to sub-alpine forests in the Colorado Front Range. *Annual Meeting of the Geological Society of America*. Abstract available: https://gsa.confex.com/gsa/2010AM/finalprogram/abstract_182432.htm (accessed: November 7, 2012).
- Little, S. 1974. Effects of fire on temperate forests: northeastern United States. Pp. 225–250 in Koslowski, T.T., and Ahlgren, E.E., eds., *Fire and Ecosystems*. Academic Press, New York, New York.
- Little, S., and Garrett, P.W. 1990. *Pinus rigida* Mill. Pp. 456–462 in Burns, R.M., and Honkala, B.H., technical coordinators, *Silvics of North America: Volume I, Conifers*. Agriculture Handbook 654. U.S. Department of Agriculture, Forest Service, Washington, D.C.
- Lorimer, C.G. 1984. Development of the red maple understory in northeastern oak forests. *Forest Science* 30: 3–22.
- Lorimer, C.G. 1985. Methodological considerations in the analysis of forest disturbance history. *Canadian Journal of Forest Research* 15: 200–213.
- Lorimer, C.G. 1989. The oak regeneration problem: new evidence on causes and possible solutions. *Forest Resources Analyses Number 8*, Publication R3484, Department of Forestry, University of Wisconsin, Madison, 31 pp.
- Lorimer, C.G. 1993. Causes of the oak regeneration problem. Pp. 14–39 in Loftis, D.L., and McGee, C.E., eds., *Oak Regeneration: Serious Problems, Practical Recommendations*. General Technical Report SE-84. U.S. Department of Agriculture, Forest Service, Southern Research Station, Asheville, North Carolina.
- Lorimer, C.G. 2001. Historical and ecological roles of disturbance in eastern North American forests: 9,000 years of change. *Wildlife Society Bulletin* 29: 425–439.
- Lorimer, C.G., Chapman, J.W., and Lambert, W.D. 1994. Tall understory vegetation as a factor in the poor development of oak seedlings beneath mature stands. *Journal of Ecology* 82: 227–237.

- Lynch, J. A., Clark, J.S., and Stocks, B.J. 2004. Charcoal production, dispersal, and deposition from the Fort Providence experimental fire: interpreting fire regimes from charcoal records in boreal forests. *Canadian Journal of Forest Research* 34: 1642–1656.
- Maryland Archaeological Conservation Laboratory. 2009. Wood and charcoal identification. Available:
http://www.jefpat.org/Wood&CharcoalIdentification/Wood&Charcoal_Part2.htm
 (accessed: June 14, 2010).
- McCarthy, B.C., and Bailey, D.R. 1996. Composition, structure, and disturbance history of Crabtree Woods: an old-growth forest of western Maryland. *Bulletin of the Torrey Botanical Club* 123: 350–365.
- McCarthy, B.C., Hammer, C.A., Kauffman, G.L., and Cantino, P.D. 1987. Vegetation patterns and structure of an old-growth forest in southeastern Ohio. *Bulletin of the Torrey Botanical Club* 114: 33–45.
- McEwan, R.W., Hutchinson, T.F., Ford, R., Long, R., and McCarthy, B.C. 2007. Temporal and spatial patterns of fire occurrence during the establishment of mixed-oak forests in eastern North America. *Journal of Vegetation Science* 18: 655–664.
- McWilliams, W.H., O'Brien, R.A., Reese, G.C., and Waddell, K.L. 2002. Distribution and abundance of oaks in North America. Pp. 13–33 in McShea, W.J., and Healy, W.M., eds., *Oak Forest Ecosystems: Ecology and Management for Wildlife*. The Johns Hopkins University Press, Baltimore, Maryland.
- Meyer, G.A., and Wells, S.G. 1997. Fire-related sedimentation events on alluvial fans, Yellowstone National Park, USA. *Journal of Sedimentary Research A: Sedimentary Petrology and Processes* 67: 776–791.
- Meyer, G.A., Wells, S.G., Balling, Jr., R.C., and Jull, A.J.T. 1992. Response of alluvial systems to fire and climate change in Yellowstone National Park. *Nature* 357: 147–150.
- Miller, R.A. 1974. The geologic history of Tennessee. *Division of Geology Bulletin 74*, State of Tennessee, Department of Conservation, Nashville, Tennessee, 63 pp.
- Moore, P.D., Webb, J.A., and Collinson, M.E. 1991. *Pollen Analysis*, 2nd Ed. Oxford, Blackwell Scientific Publications, London, 216 pp.
- Munsell Color. 2000. *Munsell Soil Color Charts*. GretagMacbeth, New Windsor, New York.
- National Climatic Data Center (no date). Precipitation data, Gatlinburg, Tennessee. Available:
<http://lwf.ncdc.noaa.gov/oa/ncdc.html> (accessed: October 10, 2011).

- National Geographic Society. 2007. *TOPO! Outdoor Recreation Mapping Software, Tennessee and Kentucky*. National Geographic Maps, Evergreen, Colorado.
- National Park Service (2012). Great Smoky Mountains National Park climate. Available: <http://www.nps.gov/grsm/index.htm> (accessed: September 23, 2012)
- NSF-Arizona AMS Laboratory (no date, a). Sample-size requirement. Available: <http://www.physics.arizona.edu/ams/service/size.htm> (accessed: December 14, 2011).
- NSF-Arizona AMS Laboratory (no date, b). Sample pretreatment. Available: <http://www.physics.arizona.edu/ams/index2011c.htm> (accessed: December 14, 2011).
- Natural Resources Conservation Service (no date). Inceptisols map. Available: http://soils.usda.gov/technical/classification/orders/inceptisols_map.html (accessed: October 10, 2011).
- Nelson, R.M., Sims, I.H., and Abell, M.S. 1933. Basal fire wounds on some southern Appalachian hardwoods. *Journal of Forestry* 31: 829–837.
- Nowacki, G.J., and Abrams, M.D. 2008. The demise of fire and the “mesophication” of forests in the eastern United States. *BioScience* 58: 124–138.
- Ohlson, M., and Tryterud, E. 2000. Interpretation of the charcoal record in forest soils: forest fires and their production and deposition of macroscopic charcoal. *The Holocene* 10: 519–525.
- Orvis, K.H., Lane, C.S., and Horn, S.P. 2005. Laboratory production of vouchered reference charcoal from small wood samples and non-woody plant tissues. *Palynology* 29: 1–11.
- Panshin, A.J., and de Zeeuw, C. 1980. *Textbook of Wood Technology: Structure, Identification, Properties, and Uses of the Commercial Woods of the United States and Canada*, 4th Ed. McGraw-Hill, New York, New York, 722 pp.
- Phillips, J.D. 2007. Formation of texture contrast soils by a combination of bioturbation and translocation. *Catena* 70: 92–104.
- Phillips, J.D., and Marion, D.A. 2006. The biomechanical effects of trees on soils and regoliths: beyond treethrow. *Annals of the Association of American Geographers* 96: 233–247.
- Pierce, D.S. 2000. *The Great Smokies: From Natural Habitat to National Park*. The University of Tennessee Press, Knoxville, 254 pp.

- Piperno, D.R., and Becker, P. 1996. Vegetation history of a site in the Central Amazon Basin derived from phytolith and charcoal records from natural soils. *Quaternary Research* 45(2): 202–209.
- Pyle, C. 1988. The type and extent of anthropogenic vegetation disturbance in the Great Smoky Mountains before National Park Service acquisition. *Castanea* 53(3): 183–196.
- Pyne, S.J. 1982. *Fire in America: A Cultural History of Wildland and Rural Fire*. University of Washington Press, Seattle, Washington, 654 pp.
- Pyne, S.J. 1983. Indian fires. *Natural History* 2: 6–11.
- Pyne, S.J., Andrews, P.L., and Laven, R.D. 1996. *Introduction to Wildland Fire*, 2nd Ed. John Wiley and Sons, New York, New York, 769 pp.
- Raup, H.M. 1937. Recent changes in climate and vegetation in southern New England and adjacent New York. *Journal of the Arnold Arboretum* 18: 79–117.
- Record, S.J. 1934. *Identification of the Timbers of Temperate North America, Including Anatomy and Certain Physical Properties of Wood*. J. Wiley, New York, New York, 196 pp.
- Rehder, J.B. 2004. *Appalachian Folkways*. The Johns Hopkins University Press, Baltimore, Maryland, 353 pp.
- Reimer, P.J., Baillie, M.G.L., Bard, E., Bayliss, A., Beck, J.W., Bertrand, C.J.H., Blackwell, P.G., Buck, C.E., Burr, G.S., Cutler, K.B., Damon, P.E., Edwards, R.L., Fairbanks, R.G., Friedrich, M., Guilderson, T.P., Hogg, A.G., Hughen, K.A., Kromer, B., McCormac, F.G., Manning, S.W., Ramsey, C.B., Reimer, R.R., Remmele, S., Southon, J.R., Stuiver, M., Talamo, S., Taylor, F.W., van der Plicht, J., and Weyhenmeyer, C.E. 2004. IntCal04 terrestrial radiocarbon age calibration, 26–0 ka BP. *Radiocarbon* 46: 1029–1058.
- Reneau, S.L., and Dietrich, W.E. 1990. Depositional history of hollows on steep hillslopes, coastal Oregon and Washington. *National Geographic Research* 6: 220–230.
- Richardson, D.M., and Rundel, P.W. 1998. Ecology and biogeography of *Pinus*: an introduction. Pp. 3–46 in Richardson, D.M., ed., *Ecology and Biogeography of Pinus*. Cambridge University Press, Cambridge, U.K.
- Rogers, R. 1990. *Quercus alba* L. Pp. 605–613 in Burns, R.M., and Honkala, B.H., technical coordinators, *Silvics of North America: Volume 2, Hardwoods*. Agriculture Handbook 654. U.S. Department of Agriculture, Forest Service, Washington, D.C.
- Runkle, J.R. 1985. Disturbance regimes in temperate forests. Pp. 17–34 in Pickett, S.T.A., and White, P.S., eds., *The Ecology of Natural Disturbance and Patch Dynamics*. Academic Press, Orlando, Florida.

- Russell, E.W.B. 1983. Indian-set fires in the forests of the northeastern United States. *Ecology* 64: 78–88.
- Sanborn, P., Geertsema, M., Jull, A.J.T., and Hawkes, B. 2006. Soil and sedimentary charcoal evidence for Holocene forest fires in an inland temperate rainforest, east-central British Columbia, Canada. *The Holocene* 16(3): 415–427.
- Sanford, Jr., R.L. and Horn, S.P. 2000. Holocene rain-forest wilderness: a neotropical perspective on humans as an exotic, invasive species. Pp. 168–173 in Cole, D.N., and McCool, S.F., eds., *Proceedings: Wilderness Science in a Time of Change, Volume 3*. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, Colorado.
- Sanford, Jr., R.L., Saldarriaga, J., Clark, K.E., Uhl, C., and Herrera, R. 1985. Amazon rain forest fires. *Science* 227: 53–55.
- SAS Institute, Inc. 2011. Version 9.3 of the SAS System for Microsoft Windows. SAS Institute, Incorporated, Cary, North Carolina.
- Scales, S.A. 2011. Spatial distribution of charcoal after a prescribed fire on Middle Mountain, VA. M.S. thesis, Virginia Polytechnic Institute and State University, 65 pp.
- Scarry, C.M. 2003. Patterns of wild plant utilization in the prehistoric Eastern Woodlands. Pp. 50–104 in Minnis, P.E., ed., *People and Plants in Ancient Eastern North America*. Smithsonian Institution Scholarly Press, Washington, D.C.
- Schweingruber, F.H. 1978. *Mikroskopische Holzanatomie*. Eidgenössische Anstalt für das forstliche Versuchswesen, Birmensdorff, Switzerland, 226 pp.
- Schweingruber, F.H., Börner, A., and Schulze, E.D. 2006. *Atlas of Woody Plant Stems: Evolution, Structure, and Environmental Modifications*. Springer, Berlin, Germany, 229 pp.
- Shanks, R.E. 1954. *Reference Lists of Native Plants of the Great Smoky Mountains*. University of Tennessee, Knoxville, Botany Department, 17 pp.
- Shields, A.R. 1981. *The Cades Cove Story*, 3rd Ed. Great Smoky Mountains Natural History Association, Gatlinburg, 116 pp.
- Smith, B.D. and Cowan, C.W. 2003. Domesticated crop plants and the evolution of food production economies in eastern North America. Pp. 105–125 in Minnis, P.E., ed., *People and Plants in Ancient Eastern North America*. Smithsonian Institution Scholarly Press, Washington, D.C.

- Southworth, S., Schultz, A., and Denenny, D. 2005. *Geologic Map of the Great Smoky Mountains National Park Region, Tennessee and North Carolina*. United States Geological Survey, Washington, D.C., map.
- Stokes, M.A., and Smiley, T.L. 1968. *An Introduction to Tree-Ring Dating*. University of Chicago Press, Chicago, 73 pp.
- Stuiver, M., and Reimer, P.J. 1993. Extended ^{14}C database and revised CALIB 3.0 ^{14}C age calibration program. *Radiocarbon* 35: 215–230.
- Stupka, A. 1989. *Trees, Shrubs, and Woody Vines of Great Smoky Mountains National Park*. The University of Tennessee Press, Knoxville, Tennessee, 186 pp.
- Swan, Jr., F.R. 1970. Post-fire response of four plant communities in south central New York state. *Ecology* 51: 1074–1082.
- Swiss Federal Institute for Forest, Snow, and Landscape Research. 2005. The xylem database. Available: <http://www.wsl.ch/dendro/xylemdb/index.php> (accessed: June 14, 2010).
- Talon, B., Payette, S., Filion, L., and Delwaide, A. 2005. Reconstruction of the long-term fire history of an old-growth deciduous forest in southern Québec, Canada, from charred wood in mineral soils. *Quaternary Research* 64: 36–43.
- Taylor, R.E. 1987. *Radiocarbon Dating: An Archaeological Perspective*. Academic Press, Inc., Orlando, Florida, 212 pp.
- Telford, R.J., Heegaard, E., and Birks, H.J.B. 2004. The intercept is a poor estimate of a calibrated radiocarbon age. *The Holocene* 14: 296–298.
- Thor, E., and Nichols, G.M. 1974. Some effects of fire on litter, soil, and hardwood regeneration. *Proceeding of the Annual Tall Timbers Fire Ecology Conference* 13: 455–482.
- Thornthwaite, C.W. 1931. The climates of North America according to a new classification. *Geographical Review* 21: 633–655.
- Tinner, W., Hofstetter, S., Fabienne, Z., Conedera, M., Wohlgemuth, T., Zummermann, L., and Zweifel, R. 2006. Long-distance transport of macroscopic charcoal by an intensive crown fire in the Swiss Alps – implications for fire history reconstruction. *The Holocene* 16(2): 287–292.
- Titiz, B., and Sanford, Jr., R.L. 2007. Soil charcoal in old growth rainforests from sea level to the continental divide. *Biotropica* 39(6): 673–682.

- Titmuss, F.H. 1949. *A Concise Encyclopedia of World Timbers: A Useful Work of Reference for All Users of Timber, Containing Detailed Descriptions of Nearly 200 Different Timbers, with Macroscopic Identifications of the Woods in More Common Use*. Philosophical Library, New York, New York, 156 pp.
- Topoliantz, S., and Ponge, J.F. 2003. Burrowing activity of the geophagous earthworm *Pontoscolex corethrurus* (Oligochaeta: Glossoscolecidae) in the presence of charcoal. *Applied Soil Ecology* 23(3): 267–271.
- Topoliantz, S., and Ponge, J.F. 2005. Charcoal consumption and casting activity by *Pontoscolex corethrurus* (Glossoscolecidae). *Applied Soil Ecology* 28(3): 217–224.
- United Nations Environment Programme (UNEP). 2000. *A Global Overview of Protected Areas on the World Heritage List of Particular Importance for Biodiversity*. UNEP World Conservation Monitoring Centre, Cambridge, U.K., 111 pp.
- Vale, T.R. 2002. The pre-European landscape of the United States: pristine or humanized? Pp. 1–39 in Vale, T.R., ed., *Fire, Native Peoples, and the Natural Landscape*. Island Press, Washington, D.C.
- Van Dersal, W.R. 1938. Native woody plants of the United States: their erosion-control and wildlife values. Miscellaneous Publication 303. U.S. Department of Agriculture, Soil Conservation Service, Washington, D.C., 362 pp.
- Van Doren, M., ed. 1955. *Travels of William Bartram*. Dover Publications, New York, New York, 414 pp.
- Van Lear, D.H., and Brose, P.H. 2002. Fire and Oak Management. Pp. 269–279 in McShea, W.J., and Healy, W.M., eds., *Oak Forest Ecosystems: Ecology and Management for Wildlife*. The Johns Hopkins University Press, Baltimore, Maryland.
- Van Lear, D.H., and Johnson, V.J. 1983. Effects of prescribed burning in southern Appalachian and Piedmont forests: a review. *Clemson University Department of Forestry, Forestry Bulletin* 36.
- Van Lear, D.H., and Waldrop, T.A. 1989. *History, Uses, and Effects of Fire in the Appalachians*. General Technical Report SE-54. U.S. Department of Agriculture, Forest Service, Southern Research Station, Asheville, North Carolina, 20 pp.
- Vose, J.M., Swank, W.T., Clinton, B.D., Knoepp, J.D., and Swift, L.W. 1999. Using stand replacement fires to restore southern Appalachian pine-hardwood ecosystems: effects on mass, carbon, and nutrient pools. *Forest Ecology and Management* 114: 215–226.

- Waldrop, T.A., Brose, P.H., Welch, N.T., Mohr, H.H., Gray, E.A., Tainter, F.H., and Ellis, L.E. 2002. High-intensity fires may be unnecessary for stand replacement of Table Mountain pine: an overview of current research. Pp. 137–142 in Outcalt, K.W., ed. *Proceedings: 11th Biennial Southern Silvicultural Research Conference*. General Technical Report SRS-48. U.S. Department of Agriculture, Forest Service, Southern Research Station, Asheville, North Carolina.
- Waldrop, T.A., and Lloyd, F.T. 1991. Forty years of prescribed burning on the Santee fire plots: effects on overstory and midstory vegetation. Pp. 45–50 in Nodvin, S.C., and Waldrop, T.A., eds., *Fire and the Environment: Ecological and Cultural Prospectives*. General Technical Report SE-69. U.S. Department of Agriculture, Forest Service, Southern Research Station, Asheville, North Carolina.
- Waldrop, T.A., Van Lear, D.H., Lloyd, F.T., and Harms, W.H. 1987. *Long-Term Studies of Prescribed Burning in Loblolly Pine Forests of the Southeastern Coastal Plain*. General Technical Report SE-45. U.S. Department of Agriculture, Forest Service, Southern Research Station, Asheville, North Carolina, 23 pp.
- Ward, H.T., and Davis, Jr., R.P.S. 1999. *Time Before History: The Archaeology of North Carolina*. The University of North Carolina Press, Chapel Hill, North Carolina, 312 pp.
- Weaver, K.M. 2000. Black bear ecology and the use of prescribed fire to enhance bear habitat. Pp. 89–96 in Yaussy, D.A., ed. *Proceedings: Workshop on Fire, People, and the Central Hardwood Landscape*. General Technical Report NE-274. U.S. Department of Agriculture, Forest Service, Northeastern Research Station, Newtown Square, Pennsylvania.
- Webb, III, T. 1988. Glacial and Holocene vegetation history: eastern North America. Pp. 385–414 in Huntley, B., and Webb, T., eds., *Vegetation History*. Kluwer Academic Publishers, Amsterdam, The Netherlands.
- Welch, N.T. 1999. Occurrence of fire in southern Appalachian yellow pine forests as indicated by macroscopic charcoal in soil. *Castanea* 64(4): 310–317.
- Wendel, W.H., and Smith, H.C. 1986. *Effects of Prescribed Fire in a Central Appalachian Oak-Hickory Stand*. Research Paper NE-594. U.S. Department of Agriculture, Forest Service, Northeastern Research Station, Newtown Square, Pennsylvania, 8 pp.
- Wendel, W.H., and Smith, H.C. 1990. *Pinus strobus* L. Pp. 476–488 in Burns, R.M., and Honkala, B.H., technical coordinators, *Silvics of North America: Volume 1, Conifers*. Agriculture Handbook 654. U.S. Department of Agriculture, Forest Service, Washington, D.C.

- Whitlock, C., and Larsen C.P.S. 2001. Charcoal as a fire proxy. Pp. 75–97 in Smol, J.P., Birks, H.J.B., and Last, W., eds., *Tracking Environmental Change Using Lake Sediments, Volume 3: Terrestrial, Algal, and Siliceous Indicators*. Kluwer Academic Publishers, Dordrecht, The Netherlands.
- Whittaker, R.H. 1956. Vegetation of the Great Smoky Mountains. *Ecological Monographs* 26: 1–80.
- Williams, C.E. 1998. History and status of Table Mountain pine-pitch pine forests of the southern Appalachian Mountains (USA). *Natural Areas Journal* 18(1): 81–90.
- Williams, C.E., and Johnson, W.C. 1992. Factors affecting recruitment of *Pinus pungens* in the southern Appalachian Mountains. *Canadian Journal of Forest Research* 22: 878–887.
- Williams, C.E., Lipscomb, M.V., Johnson, W.C., and Nilsen, E.T. 1990. Influence of leaf litter and soil moisture regime on early establishment of *Pinus pungens*. *American Midland Naturalist* 124: 142–152.
- Wimberly, M.C., and Reilly, M.J. 2007. Using satellite imagery to map fire severity and forest community change in the southern Appalachians. *Proceedings of the EastFIRE Conference, 2005*.
- Woods, F.W., and Shanks, R.E. 1957. Replacement of chestnut in the Great Smoky Mountains of Tennessee and North Carolina. *Journal of Forestry* 55(11): 847.
- Woods, F.W., and Shanks, R.E. 1959. Natural replacement of chestnut by other species in the Great Smoky Mountains National Park. *Ecology* 40(3): 349–361.

Appendix

Appendix 1. Color characteristics of soil-core increments (Munsell Color 2000).

Sample #	Depth (cm)	Hue	Value	Chroma	Color
GMA 1A	0-10	10YR	3	2	very dark grayish brown
GMA 1A	10-20	2.5Y	5	4	light olive brown
GMA 1A	20-30	10YR	5	3	brown
GMA 1A	30-40	10YR	5	3	brown
GMA 1A	40-50	10YR	5	4	yellowish brown
GMA 1A	50-60	10YR	6	4	light yellowish brown
GMA 1A	60-70	10YR	6	6	brownish yellow
GMA 1B	0-10	10YR	5	2	grayish brown
GMA 1B	10-20	10YR	5	3	brown
GMA 1B	20-30	10YR	6	4	light yellowish brown
GMA 1B	30-40	10YR	6	4	light yellowish brown
GMA 1B	40-50	10YR	7	6	yellow
GMA 1B	50-60	10YR	5	4	yellowish brown
GMA 1B	60-68	10YR	6	6	brownish yellow
GMA 1C	0-10	10YR	6	2	light brownish gray
GMA 1C	10-20	10YR	5	2	grayish brown
GMA 1C	20-30	10YR	5	3	brown
GMA 1C	30-40	10YR	5	3	brown
GMA 1C	40-50	10YR	5	4	yellowish brown
GMA 1C	50-60	10YR	5	8	yellowish brown
GMA 2A	0-10	2.5Y	6	4	light yellowish brown
GMA 2A	10-20	2.5Y	6	4	light yellowish brown
GMA 2A	20-30	10YR	6	2	light brownish gray
GMA 2A	30-40	10YR	6	4	light yellowish brown
GMA 2A	40-50	10YR	6	4	light yellowish brown
GMA 2A	50-60	10YR	6	4	light yellowish brown
GMA 2A	60-70	10YR	6	3	pale brown
GMA 2B	0-10	10YR	3	2	very dark grayish brown
GMA 2B	10-20	10YR	5	3	brown
GMA 2B	20-30	2.5Y	5	4	light olive brown
GMA 2B	30-40	2.5Y	5	4	light olive brown
GMA 2B	40-50	10YR	5	4	yellowish brown
GMA 2B	50-60	10YR	5	4	yellowish brown
GMA 2B	60-70	10YR	5	6	yellowish brown
GMA 2B	70-78	7.5YR	5	6	strong brown
GMA 2C	0-10	10YR	3	2	very dark grayish brown
GMA 2C	10-20	10YR	5	4	yellowish brown
GMA 2C	20-30	2.5Y	5	4	light olive brown
GMA 2C	30-40	2.5Y	5	6	light olive brown
GMA 2C	40-50	10YR	5	4	yellowish brown
GMA 2C	50-60	10YR	5	4	yellowish brown
GMA 2C	60-70	10YR	5	4	yellowish brown
GMA 2C	70-80	10YR	6	6	brownish yellow
GMA 2C	80-90	10YR	6	5	brownish yellow
GMB 1A	0-10	10YR	4	2	dark grayish brown

Appendix 1. (continued)

Sample #	Depth (cm)	Hue	Value	Chroma	Color
GMB 1A	10-20	10YR	5	3	brown
GMB 1A	20-30	10YR	5	3	brown
GMB 1A	30-40	10YR	5	3	brown
GMB 1A	40-50	10YR	5	3	brown
GMB 1A	50-60	10YR	5	3	brown
GMB 1A	60-70	10YR	5	4	yellowish brown
GMB 1A	70-80	10YR	5	4	yellowish brown
GMB 1B	0-10	10YR	4	2	dark grayish brown
GMB 1B	10-20	10YR	5	3	brown
GMB 1B	20-30	10YR	5	3	brown
GMB 1B	30-40	10YR	5	3	brown
GMB 1B	40-50	10YR	5	4	yellowish brown
GMB 1B	50-60	10YR	6	4	light yellowish brown
GMB 1B	60-70	10YR	5	4	yellowish brown
GMB 1B	70-80	10YR	5	4	yellowish brown
GMB 1B	80-88	10YR	5	4	yellowish brown
GMB 1C	0-10	10YR	4	1	dark gray
GMB 1C	10-20	10YR	4	2	dark grayish brown
GMB 1C	20-30	10YR	4	2	dark grayish brown
GMB 1C	30-40	10YR	5	3	brown
GMB 1C	40-50	10YR	5	3	brown
GMB 1C	50-60	10YR	5	3	brown
GMB 2A	0-10	10YR	4	3	brown/dark brown
GMB 2A	10-20	10YR	5	3	brown
GMB 2A	20-30	10YR	5	4	yellowish brown
GMB 2A	30-40	10YR	5	4	yellowish brown
GMB 2A	40-45	10YR	5	4	yellowish brown
GMB 2B	0-10	10YR	4	2	dark grayish brown
GMB 2B	10-20	10YR	5	3	brown
GMB 2B	20-30	10YR	5	3	brown
GMB 2B	30-40	10YR	5	3	brown
GMB 2B	40-50	10YR	6	3	pale brown
GMB 2B	50-60	10YR	6	3	pale brown
GMB 2B	60-65	10YR	6	3	pale brown
GMB 2C	0-10	10YR	5	4	yellowish brown
GMB 2C	10-20	10YR	5	3	brown
GMB 2C	20-30	10YR	5	3	brown
GMB 2C	30-40	10YR	5	3	brown
GMB 2C	40-47	10YR	5	1	gray
RCA 1A	0-10	10YR	2	1	black
RCA 1A	10-20	10YR	3	3	dark brown
RCA 1A	20-30	10YR	4	6	dark yellowish brown
RCA 1A	30-40	10YR	5	8	yellowish brown
RCA 1A	40-50	10YR	5	8	yellowish brown
RCA 1B	0-10	10YR	4	3	brown/dark brown
RCA 1B	10-20	10YR	4	4	dark yellowish brown
RCA 1B	20-30	10YR	4	4	dark yellowish brown

Appendix 1. (continued)

Sample #	Depth (cm)	Hue	Value	Chroma	Color
RCA 1B	30-40	10YR	4	4	dark yellowish brown
RCA 1C	0-10	10YR	4	3	brown/dark brown
RCA 1C	10-20	10YR	4	3	brown/dark brown
RCA 1C	20-30	10YR	4	4	dark yellowish brown
RCA 1C	30-40	10YR	4	3	brown/dark brown
RCA 1C	40-50	10YR	4	4	dark yellowish brown
RCA 1C	50-60	10YR	4	4	dark yellowish brown
RCA 1C	60-70	10YR	4	4	dark yellowish brown
RCA 2A	0-10	10YR	5	4	yellowish brown
RCA 2A	10-20	10YR	4	4	dark yellowish brown
RCA 2A	20-30	10YR	4	4	dark yellowish brown
RCA 2A	30-40	7.5YR	4	6	strong brown
RCA 2A	40-50	10YR	5	8	yellowish brown
RCA 2A	50-60	10YR	5	8	yellowish brown
RCA 2B	0-10	10YR	3	3	dark brown
RCA 2B	10-20	10YR	4	4	dark yellowish brown
RCA 2B	20-30	10YR	4	6	dark yellowish brown
RCA 2B	30-40	10YR	4	6	dark yellowish brown
RCA 2B	40-50	10YR	3	6	dark yellowish brown
RCA 2B	50-60	10YR	4	6	dark yellowish brown
RCA 2B	60-70	10YR	4	4	dark yellowish brown
RCA 2B	70-80	10YR	5	4	yellowish brown
RCA 2B	80-90	10YR	5	6	yellowish brown
RCA 2C	0-10	10YR	4	3	brown/dark brown
RCA 2C	10-20	10YR	4	4	dark yellowish brown
RCA 2C	20-30	10YR	4	4	dark yellowish brown
RCA 2C	30-40	10YR	4	4	dark yellowish brown
RCA 2C	40-50	10YR	5	4	yellowish brown
RCA 2C	50-60	10YR	5	8	yellowish brown
RCA 2C	60-70	10YR	5	4	yellowish brown
RCB 1A	0-10	10YR	5	3	brown
RCB 1A	10-20	10YR	4	3	brown/dark brown
RCB 1A	20-30	10YR	4	3	brown/dark brown
RCB 1A	30-40	10YR	6	6	brownish yellow
RCB 1A	40-50	10YR	6	6	brownish yellow
RCB 1A	50-60	10YR	6	6	brownish yellow
RCB 1A	60-68	10YR	6	6	brownish yellow
RCB 1B	0-10	10YR	2	1	black
RCB 1B	10-20	10YR	5	4	yellowish brown
RCB 1B	20-30	10YR	6	6	brownish yellow
RCB 1B	30-36	10YR	6	4	light yellowish brown
RCB 1C	0-10	10YR	3	2	very dark grayish brown
RCB 1C	10-20	10YR	5	4	yellowish brown
RCB 1C	20-30	10YR	5	4	yellowish brown
RCB 1C	30-40	10YR	6	6	brownish yellow
RCB 1C	40-50	10YR	6	6	brownish yellow
RCB 1C	50-60	10YR	6	6	brownish yellow

Appendix 1. (continued)

Sample #	Depth (cm)	Hue	Value	Chroma	Color
RCB 1C	60-69	10YR	6	6	brownish yellow
RCB 2A	0-10	10YR	3	2	very dark grayish brown
RCB 2A	10-20	10YR	5	4	yellowish brown
RCB 2A	20-30	10YR	5	4	yellowish brown
RCB 2A	30-40	10YR	6	6	brownish yellow
RCB 2A	40-48	10YR	5	8	yellowish brown
RCB 2B	0-10	10YR	2	1	black
RCB 2B	10-20	10YR	5	4	yellowish brown
RCB 2B	20-30	10YR	6	6	brownish yellow
RCB 2B	30-40	10YR	6	4	light yellowish brown
RCB 2B	40-49	10YR	6	4	light yellowish brown
RCB 2C	0-10	10YR	2	1	black
RCB 2C	10-20	10YR	5	4	yellowish brown
RCB 2C	20-30	10YR	6	6	brownish yellow
RCB 2C	30-40	10YR	6	4	light yellowish brown
RCB 2C	40-50	10YR	6	6	brownish yellow
RCB 2C	50-60	10YR	6	8	brownish yellow
RCB 2C	60-70	10YR	6	6	brownish yellow
RCC 1A	0-10	10YR	5	4	yellowish brown
RCC 1A	10-20	10YR	5	6	yellowish brown
RCC 1A	20-30	10YR	5	6	yellowish brown
RCC 1A	30-40	10YR	6	6	brownish yellow
RCC 1A	40-50	10YR	6	6	brownish yellow
RCC 1A	50-55	10YR	6	6	brownish yellow
RCC 1B	0-10	10YR	2	2	very dark brown
RCC 1B	10-20	10YR	5	4	yellowish brown
RCC 1B	20-30	10YR	5	4	yellowish brown
RCC 1B	30-40	10YR	6	6	brownish yellow
RCC 1B	40-50	10YR	5	6	yellowish brown
RCC 1B	50-60	7.5YR	5	6	strong brown
RCC 1C	0-10	10YR	5	4	yellowish brown
RCC 1C	10-20	10YR	4	4	dark yellowish brown
RCC 1C	20-30	10YR	5	4	yellowish brown
RCC 1C	30-40	10YR	5	6	yellowish brown
RCC 1C	40-50	10YR	6	6	brownish yellow
RCC 1C	50-60	10YR	6	6	brownish yellow
RCC 2A	0-10	10YR	2	2	very dark brown
RCC 2A	10-20	10YR	5	4	yellowish brown
RCC 2A	20-30	10YR	5	6	yellowish brown
RCC 2A	30-40	10YR	5	6	yellowish brown
RCC 2A	40-50	10YR	5	4	yellowish brown
RCC 2A	50-60	7.5YR	5	6	strong brown
RCC 2B	0-10	10YR	5	4	yellowish brown
RCC 2B	10-20	10YR	5	4	yellowish brown
RCC 2B	20-30	10YR	5	4	yellowish brown
RCC 2C	0-10	10YR	6	6	brownish yellow
RCC 2C	10-20	10YR	5	4	yellowish brown

Appendix 1. (continued)

Sample #	Depth (cm)	Hue	Value	Chroma	Color
RCC 2C	20-30	10YR	6	6	brownish yellow
RCC 2C	30-40	10YR	6	6	brownish yellow
RCC 2C	40-50	10YR	6	6	brownish yellow
RCC 2C	50-60	7.5YR	5	6	strong brown
RCC 2C	60-70	7.5YR	5	6	strong brown
RCC 2C	70-75	7.5YR	5	8	strong brown
PMA 1A	0-10	10YR	3	3	dark brown
PMA 1A	10-20	10YR	5	3	brown
PMA 1A	20-30	10YR	5	4	yellowish brown
PMA 1A	30-34	10YR	5	4	yellowish brown
PMA 1B	0-10	10YR	5	2	grayish brown
PMA 1B	10-20	10YR	5	4	yellowish brown
PMA 1B	20-30	7.5YR	4	3	dark brown
PMA 1B	30-40	10YR	5	4	yellowish brown
PMA 1C	0-10	10YR	3	2	very dark grayish brown
PMA 1C	10-20	10YR	4	3	brown/dark brown
PMA 1C	20-30	10YR	4	3	brown/dark brown
PMA 1C	30-40	10YR	5	3	brown
PMA 1C	40-50	10YR	5	4	yellowish brown
PMA 1C	50-60	10YR	5	4	yellowish brown
PMA 1C	60-70	10YR	5	6	yellowish brown
PMA 1C	70-72	10YR	6	4	light yellowish brown
PMA 2A	0-10	10YR	4	3	brown/dark brown
PMA 2A	10-20	10YR	5	4	yellowish brown
PMA 2A	20-30	10YR	6	3	pale brown
PMA 2A	30-40	10YR	6	4	light yellowish brown
PMA 2A	40-50	10YR	5	6	yellowish brown
PMA 2A	50-60	10YR	5	6	yellowish brown
PMA 2A	60-66	10YR	5	6	yellowish brown
PMA 2B	0-10	10YR	5	2	grayish brown
PMA 2B	10-20	10YR	6	3	pale brown
PMA 2B	20-30	10YR	6	3	pale brown
PMA 2B	30-40	10YR	6	4	light yellowish brown
PMA 2B	40-50	10YR	5	4	yellowish brown
PMA 2B	50-57	10YR	6	4	light yellowish brown
PMA 2C	0-10	10YR	4	1	dark gray
PMA 2C	10-20	10YR	4	3	brown/dark brown
PMA 2C	20-30	10YR	5	4	yellowish brown
PMA 2C	30-40	10YR	5	4	yellowish brown
PMA 2C	40-42	10YR	5	4	yellowish brown
PMB 1A	0-10	10YR	5	3	brown
PMB 1A	10-20	10YR	5	4	yellowish brown
PMB 1A	20-30	10YR	5	4	yellowish brown
PMB 1A	30-40	10YR	6	6	brownish yellow
PMB 1A	40-50	10YR	6	6	brownish yellow
PMB 1A	50-60	10YR	6	6	brownish yellow
PMB 1A	60-70	10YR	6	8	brownish yellow

Appendix 1. (continued)

Sample #	Depth (cm)	Hue	Value	Chroma	Color
PMB 1A	70-78	10YR	6	6	brownish yellow
PMB 1B	0-10	10YR	4	2	dark grayish brown
PMB 1B	10-20	10YR	5	3	brown
PMB 1B	20-30	10YR	6	4	light yellowish brown
PMB 1B	30-40	10YR	6	6	brownish yellow
PMB 1B	40-50	10YR	6	6	brownish yellow
PMB 1B	50-60	10YR	6	6	brownish yellow
PMB 1B	60-70	10YR	6	6	brownish yellow
PMB 1B	70-80	10YR	6	6	brownish yellow
PMB 1B	80-90	10YR	6	6	brownish yellow
PMB 1C	0-10	10YR	5	3	brown
PMB 1C	10-20	10YR	6	4	light yellowish brown
PMB 1C	20-30	10YR	6	4	light yellowish brown
PMB 1C	30-34	10YR	6	4	light yellowish brown
PMB 2A	0-10	10YR	5	3	brown
PMB 2A	10-20	10YR	5	4	yellowish brown
PMB 2A	20-30	10YR	6	4	light yellowish brown
PMB 2A	30-40	10YR	6	4	light yellowish brown
PMB 2A	40-50	10YR	6	6	brownish yellow
PMB 2A	50-55	10YR	6	6	brownish yellow
PMB 2B	0-10	10YR	5	3	brown
PMB 2B	10-20	10YR	5	4	yellowish brown
PMB 2B	20-30	10YR	6	4	light yellowish brown
PMB 2B	30-40	10YR	6	4	light yellowish brown
PMB 2B	40-50	10YR	6	4	light yellowish brown
PMB 2B	50-60	10YR	6	6	brownish yellow
PMB 2B	60-63	10YR	6	6	brownish yellow
PMB 2C	0-10	10YR	5	3	brown
PMB 2C	10-20	10YR	5	3	brown
PMB 2C	20-30	10YR	5	3	brown
PMB 2C	30-40	10YR	6	4	light yellowish brown
PMB 2C	40-50	2.5Y	6	4	light yellowish brown
PMB 2C	50-60	10YR	5	3	brown
PMB 2C	60-66	10YR	6	4	light yellowish brown
PMC 1A	0-10	10YR	4	2	dark grayish brown
PMC 1A	10-20	10YR	5	3	brown
PMC 1A	20-30	10YR	6	4	light yellowish brown
PMC 1A	30-40	10YR	6	6	brownish yellow
PMC 1A	40-50	10YR	6	6	brownish yellow
PMC 1A	50-60	10YR	6	6	brownish yellow
PMC 1A	60-70	10YR	6	8	brownish yellow
PMC 1A	70-78	10YR	6	8	brownish yellow
PMC 1B	0-10	10YR	4	2	dark grayish brown
PMC 1B	10-20	10YR	5	4	yellowish brown
PMC 1B	20-30	10YR	5	4	yellowish brown
PMC 1B	30-40	10YR	5	4	yellowish brown
PMC 1B	40-50	10YR	5	4	yellowish brown

Appendix 1. (continued)

Sample #	Depth (cm)	Hue	Value	Chroma	Color
PMC 1B	50-60	10YR	6	4	light yellowish brown
PMC 1B	60-70	10YR	6	6	brownish yellow
PMC 1B	70-80	10YR	6	6	brownish yellow
PMC 1B	80-90	10YR	6	6	brownish yellow
PMC 1B	90-100	10YR	6	8	brownish yellow
PMC 1C	0-10	10YR	5	2	grayish brown
PMC 1C	10-20	10YR	5	6	yellowish brown
PMC 1C	20-30	10YR	6	6	brownish yellow
PMC 1C	30-40	10YR	6	6	brownish yellow
PMC 1C	40-48	10YR	6	4	light yellowish brown
PMC 2A	0-10	10YR	5	4	yellowish brown
PMC 2A	10-20	10YR	6	4	light yellowish brown
PMC 2A	20-30	10YR	6	6	brownish yellow
PMC 2A	30-40	10YR	6	4	light yellowish brown
PMC 2A	40-50	10YR	6	6	brownish yellow
PMC 2A	50-60	10YR	6	6	brownish yellow
PMC 2A	60-70	10YR	6	8	brownish yellow
PMC 2A	70-80	10YR	6	8	brownish yellow
PMC 2B	0-10	10YR	5	4	yellowish brown
PMC 2B	10-20	10YR	6	4	light yellowish brown
PMC 2B	20-30	10YR	6	4	light yellowish brown
PMC 2B	30-40	10YR	6	4	light yellowish brown
PMC 2B	40-50	10YR	5	6	yellowish brown
PMC 2B	50-60	10YR	5	4	yellowish brown
PMC 2B	60-64	10YR	6	6	brownish yellow
PMC 2C	0-10	10YR	5	4	yellowish brown
PMC 2C	10-20	10YR	5	4	yellowish brown
PMC 2C	20-30	10YR	5	4	yellowish brown
PMC 2C	30-40	10YR	5	4	yellowish brown
PMC 2C	40-50	10YR	5	4	yellowish brown
PMC 2C	50-60	10YR	5	6	yellowish brown
PMC 2C	60-70	10YR	6	6	brownish yellow
PMC 2C	70-80	10YR	5	6	yellowish brown
PMC 2C	80-90	10YR	6	6	brownish yellow
PMC 2C	90-100	10YR	6	6	brownish yellow

Vita

Christopher A. Underwood earned a bachelor of science degree from the Department of Environmental Health at East Tennessee State University with a concentration in industrial hygiene and a minor in chemistry in 1997. He received the master of science degree in 2007 and the doctor of philosophy degree in 2013, both from the Department of Geography at the University of Tennessee, Knoxville. While working toward these graduate degrees, he served as a National Science Foundation fellow for the University of Tennessee GK-12 Earth Project, taught lecture and laboratory classes in introductory physical geography as a graduate teaching associate and assistant in the Department of Geography, and served as an academic advisor in the College of Arts and Sciences. In 2010, he accepted a position as lecturer in Geography and Geology at the University of Wisconsin-Platteville. In August 2013, Christopher will join the faculty at Lincoln Memorial University in Harrogate, Tennessee, where he will serve as program director and assistant professor of geography.