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Fire History from Dendrochronological Analyses at Two Sites near Cades Cove, Great Smoky Mountains National Park, U.S.A.

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To the Graduate Council:

I am submitting herewith a thesis written by Ian C. Feathers entitled "Fire History from Dendrochronological Analyses at Two Sites near Cades Cove, Great Smoky Mountains National Park, U.S.A.." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Geography.

Henri D. Grissino-Mayer, Major Professor

We have read this thesis and recommend its acceptance:

Carol Harden, Sally Horn

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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FIRE HISTORY FROM DENDROCHRONOLOGICAL ANALYSES AT TWO SITES NEAR CADES COVE, GREAT SMOKY MOUNTAINS NATIONAL PARK, U.S.A.

A Thesis Presented for the
Master of Science Degree
The University of Tennessee, Knoxville

Ian Corbett Feathers
May 2010

DEDICATION

This thesis is dedicated to the Great Spirit, my family, my friends, and my home, the majestic and supernal mountains of Southern Appalachia.

"As I walk the trail of this life in the fear of the cold rain, grant oh Great Spirit, that I may walk as you intended and follow the way of your land." - Cherokee Prayer

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ABSTRACT

Fire, logging, livestock grazing, and insect outbreaks are disturbances that have significantly influenced both the historic and present fire regimes. The composition and structure of vegetation communities within Great Smoky Mountains National Park (GSMNP) have likely changed in response to these disturbances. Two study sites (CRX, the near site, and CRT, the far site) were chosen along the Cooper Road Trail based on topographic separation, presence of mixed oak-pine communities, presence of fire-scarred yellow pine trees, and GSMNP land acquisition records. To quantify and evaluate fire regimes, individual fire histories were developed for each site from fire-scarred yellow pine trees, and two 1000 m^2 (0.1 ha) study plots were established for vegetation surveys. Fire history analysis yielded mean fire intervals of 6.2 years at the near site, 3.4 years at the far site, and 3.2 years when combined. Spatial analysis showed significant differences in fire activity between study sites. Temporal analysis showed significant differences in mean fire intervals between the pre-settlement (1720–1818) and post-settlement periods (1819–1934). Superposed epoch analysis showed the over-riding influence of climate at these sites. At the near site, trees displayed greater species diversity, larger diameter, and older age. Eastern white pine, pitch pine, red maple, and black gum were the dominant species. At the far site, tree species diversity was lower and trees were generally younger. Mixed oak-pine communities are succeeding to a canopy dominated by shade-tolerant, fire-sensitive species such as eastern white pine and red maple. Without fire disturbance, yellow pine communities will cease to regenerate, as will oak species that prefer a fire-maintained habitat.

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CHAPTER 1

INTRODUCTION

1.1 Background

Fire was once a common disturbance throughout the mixed temperate forests of the southern Appalachian Mountains (Harmon 1982, Pyne 1982, Jantz 2002). Fires ignited by lightning or thermal combustion occurred naturally, while humans also used fire as a tool for agriculture and land management (Cohen *et al*. 2007, Fowler and Konopick 2007). The presence of species such as Table Mountain pine (*Pinus pungens* Lamb.), pitch pine (*P. rigida* Mill.), and shortleaf pine (*P. echinata* Mill.), all of which are fire-dependent and fire-tolerant, indicate evolution in an environment disturbed by fire (Richardson 1998). Thick bark, self pruning branches, and serotinous cones are morphologic traits that constitute adaptations to fire. The proliferation of these species was likely influenced by fluctuations in climate and the anthropogenic use of fire (Abrams 1992, Delcourt and Delcourt 1997, Jurney *et al*. 2004).

Both Native Americans and Euro-American settlers used fire as a tool to manipulate the landscape (Fowler and Konopick 2007, Jurgelski 2008). It had a variety of uses and benefits for both groups. Fire was the most commonly used tool to clear the landscape for agriculture and grazing, to increase berry yield and herbaceous ground cover, drive wild game, and maintain the understory for travel (Pyne 1982). Many residents of the southern Appalachians believed that fire removed pests and pathogens and maintained an open, herbaceous understory (Shea 1940, Pyne 1982, Jurgelski 2008). Now, in combination with intensive land-use, fire suppression, drought, and southern pine beetle (*Dendroctonus frontalis* Zimm.) infestation, yellow pine woodlands in the southeast are in decline, resulting in over 161,900 ha (400,000 acres) lost since

2000 and an estimated 202,300 ha (500,000 acres) more in 2007 (South and Buckner 2003, USFS 2008). Concurrent with this decline, current projections of forest succession indicate a decrease in yellow pine regeneration (Lafon *et al*. 2007, Waldron *et al.* 2007).

Research also shows that xeric and sub-xeric forest communities are shifting in dominance to more mesophytic, shade-tolerant species such as red maple (*Acer rubrum* L.), eastern white pine (*P. strobus* L.), black gum (*Nyssa sylvatica* Marsh.) and eastern hemlock (*Tsuga canadensis* Carr.) (Nowacki and Abrams 2008). Fire regimes (defined by fire frequency, seasonality, severity, intensity, extent, and type) also show significant changes, resulting in lower frequency and greater severity (Nowacki and Abrams 2008, FRCC 2008). This response is likely caused by forced departure (e.g. fire suppression) from the historical range of variation (HRV) (Morgan *et al.*1994).

Land use also significantly alters both fire regimes and forest composition. Intensive logging practices remove the dominant canopy trees and cause seedling and sapling mortality, resulting in poor species regeneration among herbaceous cover and woody stems (Duffy and Meier 1992). Large scale clear-cutting causes heavy land denudation, increasing rates of soil erosion and sediment transport to riparian areas (Pyle 1988, Swift *et al.* 1993). Logging activities and overgrazing may also cause soil compaction, causing changes in bulk density and restricting the ability of the soil to retain moisture (Gordon 2004). Removal of the tree canopy also causes subsequent drying of fine fuels and increases the probability of fire (Frelich 2002).

1.2 Objectives

The purpose of this research was to compare and contrast the differences and similarities of fire regimes and vegetation dynamics between two sites. My research questions include:

- Are fire regimes similar between topographically separated sites with similar vegetation?
- Are fire regimes similar between the pre-settlement (1720–1818) and post-settlement (1819–1934) periods?
- Do vegetation composition and age structure vary between the two sites?
- What is the current status of fire regimes and vegetation composition in the western portion of Great Smoky Mountains National Park (GSMNP)?
- What are future trends of succession in mixed oak-pine forests of the western portion of GSMNP?

To answer these questions, I developed quantitative fire histories from both sites, calculated importance values from surveyed tree species, calculated percentage values of seedling/sapling tallies, measured duff depth, and measured volumetric water content of the soil. These data made possible inferences of the past and present fire regimes in the western portion of GSMNP.

1.3 Significance

Fire regimes in the southern Appalachians should be characterized by low-severity surface fires of low to medium intensities (FRCC 2008). Fire suppression efforts, however, have likely reduced yellow pine regeneration in GSMNP (Harmon 1982, Harrod *et al.* 2000). When coupled with southern pine beetle outbreaks, fire suppression has increased fuel loads far beyond historic proportions, making it likely that future wildfires will be characterized by greater intensity and severity (Lafon *et al*. 2007, Waldron *et al*. 2007). Logging efforts in the late 19th and early 20th centuries cleared canopy vegetation and allowed greater abundance of mountain laurel (*Kalmia latifolia* L.) and rhododendron (*Rhododendron maximum* L.) (Monk *et al*. 1985). These ericaceous shrubs act as flammable ladder fuels that may increase the severity and spatial extent of future wildfires. In 2007, it was reported that prescribed burns in GSMNP crossed fire breaks due to excessive ladder fuels caused by southern pine beetle and years of fire suppression (Rob Klein, personal communication). Many areas in GSMNP are now considered "at risk" of stand-replacing wildfire.

Mixed oak-pine forests also provide critical habitat for whitetail deer (*Odocoileus virginianus* Zimm.), wild turkey (*Meleagris gallopavo* L.), black bear (*Ursus americanus* Pallas), ruffed grouse (*Bonasa umbellus* L.) and the endangered red-cockaded woodpecker (*Picoides borealis* Vieill.) (Walters 1991, Land and Rieske 2006, NPCA 2008). Without prescribed burns and efforts to rehabilitate habitat, these species may lose important food reserves. Increasing temperatures and drought stress will likely exacerbate the likelihood of beetle-related mortality and the susceptibility of forests to uncontrollable wildfires (Richardson 1998, Waldron *et al.* 2007).

My research provides insight on historical conditions of fire regimes and the subsequent departures of these fire regimes from historical patterns in GSMNP and in the southern Appalachian Mountains. Furthermore, my research shows differences in fire regimes between periods of settlement, which has long been questioned by other researchers and forest managers. This study also provides information on vegetation dynamics in areas of variable land use, contributing to a greater knowledge of disturbance ecology and vegetation response.

Overall, this study provides vital information that can be used to help rehabilitate declining oak-pine forests using the historical fire regime as baseline information.

CHAPTER 2

LITERATURE REVIEW

2.1 The Role of Fire in the Southern Appalachian Mountains

2.1.1 Harmon 1982

Harmon examined the fire history of the westernmost portion of GSMNP in North Carolina and Tennessee. Assuming that vegetation patterns were subjected to manipulation by Native Americans, Euro-American settlement, and fire suppression, the study sought to quantify the period of fire history during Euro-American settlement and other periods, including that period with the current period of fire suppression. Harmon also investigated the role of fires ignited by both lightning and anthropogenic sources.

The area observed for study was approximately 9,100 ha within 260 m and 942 m above sea level. Harmon focused in this area because pine forests are generally more extensive here than elsewhere within GSMNP. The dominant canopy structure consisted of shortleaf pine, Table Mountain pine, pitch pine, Virginia pine (*P. virginiana* Mill.), scarlet oak (*Quercus coccinea* Muennch.), blackjack oak, (*Q. marilandica* Muennch.), chestnut oak (*Q. montana* L.), red maple, sourwood (*Oxydendrum arboretum* L.), and black gum. Archaeological evidence revealed occupation of the Cades Cove area by aboriginal humans as early as ca. 8000 years before present. Euro-American settlement occurred after A.D. 1790, but ceased during the 1930s after lands were incorporated into GSMNP.

Fire history was determined by examining basal wound scars in both living and dead pines. Harmon distinguished fire scars from other basal wounds by the presence of charcoal, upslope position, presence of overlapping scars, and lack of other sources that could cause potential stem damage. Fire scarred samples were removed by hand-sawing partial cross sections from the damaged stem. The samples were dried, sanded, and examined with a hand lens. Harmon then examined the tree-ring record to construct a fire history. Fire management records were obtained from 1940 to 1979 to compare fire occurrence prior to the establishment of the park with current fire suppression after establishment of GSMNP.

Pine trees sampled totaled 43, revealing 115 fire scars. The oldest scar dated to "approximately" 1856, but other scarred samples were probably destroyed due to excessive decay or previous fires. Harmon reported that 96% of the pine forests he examined had burned between 1929 and 1940. The mean fire interval of pine forests was 12.7 years between 1856 and 1940, the shortest interval being 2 years and the longest being 49 years. South facing upper and lower slopes were most likely to reveal scarred trees.

Harmon stated that his method probably underestimated the actual number of fires because only fires that were intense enough to damage the tree's cambial tissue were recorded. Fire damage may also reduce accurate age determination by distorting annual ring growth. Further information is required for the period prior to 1856 to accurately analyze fire history and to clarify the effects of 20th century fire management policy on forests in the western portion of GSMNP.

2.1.2 Brose and Waldrop 2006

This study was conducted at nine different sites in northern Georgia, western South Carolina, and eastern Tennessee. Dendrochronology was used to analyze age structure, species recruitment trends, radial growth patterns, and fire scars to determine whether Table Mountain pine and pitch pine originate as a result of stand-replacing, high-intensity crown fires.

Brose and Waldrop had conducted a previous study in 1999 that determined Table Mountain pine displayed increased regeneration in areas that experienced a moderate-intensity surface fire and partial removal of canopy, rather than the full exposure created as a result of high-intensity crown fires. However, they did mention that a pine stand that exhibits unimodal age distribution is a result of catastrophic, stand-replacing fire.

Brose and Waldrop used the following criteria to select sites: (1) basal area of the main canopy was >50% Table Mountain pine; (2) the site was capable of supporting hardwood species; and (3) fire scars were present at each location. Fire events were determined by crossdating both internal and external fire scars, regardless of the species. Three visible scars per sample were necessary to determine if they were of fire origin. A total of 173 cross sections and 214 cores were analyzed from the nine sites, and almost all samples were chestnut oak. Only 24 fires were apparent. Brose and Waldrop concluded that the data collected did not support their hypothesis that Table Mountain pine-pitch pine arose mainly from stand replacing wildfires. The occurrences of all-aged Table Mountain pine-pitch pine stands that can support hardwoods suggest that a different type of disturbance regime was in place. They suggested surface fires of varying intensity at a periodic return interval were a common occurrence before the most recent recruitment of Table Mountain pine stands. The authors also suggested that a low intensity fire/grazing disturbance regime created ideal understory conditions for widespread regeneration. Their final conclusion stated that Table Mountain pine stands are not dependent on high-intensity fires and that these high-intensity fires are not essential for the perpetuation of the species. A periodic disturbance regime of canopy openings and surface fires may be a more applicable way of sustaining Table Mountain pine communities in the southern Appalachian Mountains.

2.1.3 Cohen, Dellinger, Klein, and Buchanan 2007

Lightning has long been discredited as a natural ignition source in southern Appalachia (Jurgelski 2008). The best indicator of possible changes in lightning-caused fire activity is the significant decline in oak, hickory, and pine species that are dependent on fire, especially Table Mountain pine. In the absence of fire, fire-sensitive, shade-tolerant species such as red maple, eastern hemlock, and black gum have become dominant. Cohen *et al.* gathered and analyzed fire monitoring and report data concerning suppressed and unsuppressed wildfires in GSMNP from 1940 until the present. All fires were associated with non-anthropogenic ignition. Ten of 16 naturally ignited fires were monitored in GSMNP from 1998 to 2006 under wildland fire policy, which allows fires to remain unsuppressed under the right conditions. This period was also chosen because of the first fire management policy implemented by GSMNP in 1996.

Several case studies on fire behavior were classified into three groups based on qualitative reports: (1) fire persistent through precipitation events, (2) fire emergent from dormancy (e.g. rekindled after smoldering), and (3) large, unsuppressed lightning fires. The largest fire, both in extent and duration, was the Chilly Springs Knob fire of April 3, 2006. It covered 369.5 ha (913 ac) and lasted 38 days. Most lightning-ignited fires occurred during the growing season and remained through periodic events of precipitation. Unsuppressed wildfires showed more dynamic behavior and intensity, burned for greater durations, and had greater perimeter gain. Natural extinctions were most noted at boundaries coinciding with wet, moist coves, stream beds, and drainages or depressions. These case studies display the complex relationship between fire behavior, weather, topography, vegetation, and fuel loads, especially when unimpeded. The qualitative reports suggest that isolated fires have potential to last for extended periods of time, either smoldering or spreading depending on fuel availability.

2.2 Fire and Land-Use History in the Appalachian Mountains

2.2.1 Pyle 1988

Pyle developed this study from written and mapped archival records to summarize the spatial extent and type of vegetation disturbance of GSMNP. She categorized disturbances for major watersheds and the entire Park. The main disturbances observed were settlers' activities, logging, and fire. Although the influence of Native Americans and the chestnut blight caused significant changes, these disturbances were excluded. She found that species composition and age-class distributions most likely have been altered in response to the type, intensity, and extent of historic vegetation disturbance.

To determine the spatial extent of vegetation disturbance, map overlays were created using a 256 dpi grid. Disturbance boundaries were determined using vegetation maps from Miller (1938). Logging practices included the use of narrow gauge railroad, mechanized skidders and loaders, and band sawmills. Usually, 1/2 to 2/3 of major watersheds were cleared within 10 to 15 years, cutting with little selectivity and far up slope. Most watersheds had been cleared using earlier methods, and then cleared again mechanically. Typical regeneration following logging disturbance consisted of yellow poplar (*Liriodendron tulipifera* L.), fire cherry (*Prunus pensylvanica* L.), yellow birch (*Betula alleghanienses* Brit.), and red maple. When logging was heavily mechanized, the landscape was rapidly denuded and logging wastes resulted in an abundance of fuels. After mechanized logging, 23% of these areas burned intensively.

In the western portions of GSMNP, concentrated settlement generally occurred below 760 m. Scale and intensity of land use decreased with distance from transportation routes and concentrated settlement. This area of the Park was diffusely disturbed (e.g., influenced by grazing, logging, and fire), but some areas had large tracts with abandoned homesteads and evidence of early logging. Large trees were usually harvested. Adjacent forest stands and ridgetops experienced light fires and grazing pressures. These disturbances are often indicated by trees scarred from both fire and wire fencing, and cattle trails that follow the contours of slopes. Livestock often preferred yellow poplar forage, allowing greater dominance of yellow pine. Some records indicate selective logging of oaks and pitch pine for leather tanning and tar kilns.

This study provides the best known disturbance history of GSMNP, although coarse in resolution. It also provides useful information on the extent of settler activities and land use, especially around Cades Cove. This study provided information about which areas in GSMNP had experienced fire and guided my search in determining a historic view of the fire regime.

2.2.2 Orwig and Abrams 1994

Prior to European settlement, Native Americans burned extensive portions of the landscape to facilitate travel, drive game, increase berry yields, and clear land for settlement and agriculture in eastern North America. Since European settlement, vegetation patterns changed as woodlands were cleared for agricultural fields, grazing pastures, and iron forges. Poor agricultural practices led to extreme soil erosion and degradation, and land was often abandoned. These processes shaped the composition of vegetation on a broad landscape scale. However, little information on forest composition exists prior to European historical records. This study analyzed the impact of past and present-day land use on forest succession and composition, as well as the rate and process of oak-hickory forest replacement.

The Fredericksburg and Spotsylvania National Military Parks span approximately 2500 ha across the Piedmont Plateau and Coastal Plain of northern Virginia. Within the parks, 58 sites that were undisturbed since the 1920s were surveyed. Stands were comprised of homogeneous forest vegetation ≥ 4 ha. Twenty 0.02 ha circular plots were placed systematically along transects at 30 to 40 m intervals and each tree within was surveyed by species, DBH, and canopy position. Two trees per plot were randomly selected, and increment cores were extracted at 1.4 m height. Percentage slope and directional aspect were recorded. Fire records were referenced for the state of Virginia from 1925 to 1991 to evaluate the importance of fire and its impact on present-day forests. Importance values were assigned to tree species of each stand and then evaluated by detrending correspondence analysis (DCA) to group forest stands and evaluate composition. Relationships between species importance, seedling/sapling density, physical site factors, and DCA were compared by correlation analysis.

Three ecological groups were defined from overstory dominants: (1) white oak (*Quercus alba* L.), (2) white oak-scarlet oak (*Quercus coccinea* Muenchh.), and (3) Virginia pine. Seedling and sapling diversity were different among the three stand types. Most shrubs were maple-leaved viburnum (*Viburnum acerifolium* L.), blueberry (*Vaccinium spp.*), and huckleberry (*Gaylussacia baccata* (Wang.) K. Koch). Survey records indicate that the forests of the study area were dominated by white oak and red oak (*Quercus rubra* L.). However, it is important to recognize that white oak was the preferred witness tree by early surveyors.

Most increases in radial growth followed past disturbance. These episodic growth releases were most commonly related to logging, but could also be caused by windthrow, fire, lightning, pathogens, and insect damage. Tree age-diameter relationships revealed that tulip poplar will remain an important component of old-growth forests in the future. However, black gum can survive well over 300 years. This species' slow persistence may result in dominant canopy status over time. Another unique feature of the study area was the scarcity of common eastern oak forest replacements, such as sugar maple (*Acer saccharum* Marsh), red maple, black cherry (*Prunus serotina* Ehrh.), and beech (*Fagus grandifolia* Ehrh.). Most importantly, oaks were experiencing poor recruitment caused by canopy closure and lack of disturbance under federal protection.

2.2.3 Jurney, Evans, Ippolito, and Bergstrom 2004

This article documents reference conditions for the management of fire within ecosystems of southeastern North America. After the advent of fire suppression policies, data on landscape-scale fire have been limited and much discussion has been raised on initial calculated fire return intervals. Fire records of the USDA Forest Service from 1916–1990, along with dendrochronological and dendroclimatological studies covering the period 1670–1993, historical accounts of Native American fire use for the period 1500–1870, and pollen sequence records of the last 20,000 years were examined to provide data that compare and test models of fire return intervals.

The ecology of disturbance and fire are commonly debated, revealing two extreme views: (1) fire is purely destructive and (2) fire is an essential tool for management and restoration. The first view stemmed from early traditional misconceptions that the Southeast existed in an undisturbed, climax condition before the arrival of European settlers. F.E. Clements (1916) proposed that only undisturbed areas under specific climatic control were suitable for ecological research. Theoretically, this approach defined fire as a disturbance that prevented mixed temperate forests from reaching the stage of climax. In disagreement, H.A. Gleason (1922) proposed that forests had been heavily disturbed by Native American use of fire, and climax conditions were not absolute. Furthermore, dendrochronological records of “virgin forests” revealed evidence of disturbance.

Fire has been neglected as a component of the natural ecosystem because much of the older literature reinforced the idea that all vegetation approaches a climax state. However, this assumption disregards the natural functions of fire and the relationship to vegetation. Jurney *et al.* (2004) sought to clarify this misconception by synthesizing and comparing data in an analytical framework so reference conditions and accurate fire intervals could be established.

Pollen records of the Tennessee Valley indicated that aboriginal agriculture significantly modified vegetation structure in this area from ca. AD 600 to 1500. Other palynological records from the Ouachitas and Ozark highlands displayed a prominent distribution of jack pine (*Pinus banksiana* Lamb.), which is a fire-dependent species with serotinous cones, during the last glacial episode (Wisconsonian). This reveals a definitive history of lightning-ignited fires in Ozark Plateau ecosystems during the Pleistocene.

Fire-scarred trees have provided direct evidence of past fire events, but may be circumstantial depending on fire intensity. Thus, only trees that contain multiple healed or open scars should be used to accurately determine fire return intervals. Studies of historic fire return intervals in the Ozark-St. Francis National Forest, Arkansas, display much variation from 1680–1993. During the Native American period of 1680–1819, the fire return interval was 4.8 years, changing to 1.6 years during European settlement (1820–1919), 4.3 years in the Early Modern period (1920–1949), and > 22 years in the Late Modern period (1950–1993). Historical accounts from early European settlers of the Southeast are limited, but also reveal direct evidence of Native American use of fire to manipulate vegetation and drive wild game.

Increasing dendrochronological evidence indicates that tree growth, drought severity, and fire frequency are related phenomena. Additional research will improve paleoclimatic records for southeastern North America. In recent years, ecologists have been shifting perspectives of resource management and conservation to include fire. Stand structure has always fluctuated, and management policies that reflect disturbance (i.e., logging, fire) aid in maintaining stand structure diversity and landscape patterns.

2.3 Mixed Oak-Pine Forests and Fire

2.3.1 Harrod and White 1999

Harrod and White conducted a study of age structure and radial growth in xeric pine-oak forests in GSMNP to assess changes in canopy structure and composition before and after 1940. They examined plot data from the 1930s, 1970s, and 1990s that suggested that closed canopy forests were dominated by *Pinus* species. The dominant species were shortleaf pine, Table Mountain pine, pitch pine, and Virginia pine. Other canopy species were primarily *Quercus* species.

Observations of sites between the 1930s and 1970s revealed that canopy density and basal area approximately doubled. Due to fire suppression, the historical mosaic of vegetation changed from low density basal area to dense, closed-canopy forest dominated by hardwoods. Composition of these sites has shifted from *Pinus* and *Quercus* species to shade-tolerant species such as red maple, black gum, eastern white pine, and eastern hemlock. Dendrochronological techniques were used to determine radial growth and age structure of four xeric sites. Previous observations and dendrochronological data were then compared to investigate increases in stand density and shift in canopy composition from yellow pine and oak species to more shade-tolerant species.

The results showed that the most abundant canopy tree was eastern white pine and that eastern white pine made up the majority of saplings. Yellow pines made up 32% of dominant canopy stems and were consistently large individuals (up to 54 cm DBH), but did not occur in the sapling stratum. The oldest trees in each plot were shortleaf pine, and the youngest found had been established in 1877. Growth releases observed prior to and after 1960 show that species composition has changed at the canopy level and within the understory. Growth releases prior to 1960 were mostly found in yellow pines. After 1960, species with greatest growth release were either red maple or sourwood. These changes reflect a reduction in fire frequency. Otherwise, yellow pines would be the dominant seedling to regenerate.

The results showed that yellow pines were not successfully reproducing due to exclusion of wildfires. Without a consistent fire rotation, Harrod and White found it highly probable that yellow pines will disappear from the sites they now occupy and become restricted to ultra-xeric sites, such as rock outcrops and steep, rocky ridges. Successful pine regeneration can occur at these sites without fire, and encroachment by other species is limited by poor soils. However, more research is needed to determine whether yellow pines can persist in the absence of fire.

2.3.2 Barden 2000

In 1976, Barden found a self-maintaining population of Table Mountain pine on a granite rock outcrop called Looking Glass Rock near Brevard, North Carolina. Until this discovery, it was generally thought that Table Mountain pine regeneration required medium to high intensity fire, which opens the forest canopy, reduces organic litter, and opens serotinous cones. In 1986 and 1996, Barden returned to recensus the population and determine whether it had self-maintained without fire since 1889.

In 1977 and 1996, Barden tested seed viability and measured radial growth of pines established in shallow, poor quality soils, which contribute to increasing tree sensitivity to climate variations. The analyses determined the effects of extreme drought on seed viability and tree growth during the 1980s. The area of study was located on the southwestern shoulder of Looking Glass Rock. Soil pockets that support the population of Table Mountain pine were only 10–40 cm in depth. Elevation ranged from 1040 m to 1180 m above sea level (a. s. l.) and slope was approximately 10–20%.

Fire-scarred cross sections and increment cores were obtained in 1976 that revealed a canopy-opening fire had occurred around 1810, and the most recent fire occurred in 1889. No fires have occurred since then. Demographic information was obtained from an easily accessible study area by photographs and mapping techniques. The Palmer Drought Severity Index (PDSI) was used to determine fluctuations in climatic conditions between 1925 and 1996. Annual radial growth was measured from 1980 to 1996 because these years provided the greatest fluctuations of the PDSI values. Ring widths were then averaged to calculate a reference growth index. Fluctuation of PDSI was unpredictable from 1960 to 1996, but average July temperatures of the study area increased by more than 1.5 °C during this time.

The population produced new seedlings between 1976 and 1996 without fire. The entire population declined 35% as a result of high mortality and low recruitment of the youngest age class. Radial growth and July PDSI were found to be positively correlated. Barden predicted that recruitment would increase if precipitation returned to a normal or above average range. However, it did not increase despite PDSI values within the normal range. Drought and increasing temperature may have delayed effects on seed viability and recruitment, resulting in desynchronized pollen release and lack of germination. Temperatures 28°C or greater may also limit survival of seedlings by reducing root growth. Further analysis is needed to determine the current status of this population.

2.3.3 Harrod, Harmon, and White 2000

Changes have occurred in the fire regimes of GSMNP, and results show significant changes in canopy composition and structure of the mixed temperate woodlands. Prior to the establishment of GSMNP in 1934, human settlement was extensive throughout the area and fires were set as a method of maintenance for the forests. At this time, mean fire rotation was calculated at 12.7 years. With the onset of active fire suppression, mean fire rotation increased to over 500 years. In this study, Harrod and others analyzed post-fire succession of xeric, southern Appalachian forests in GSMNP by comparing vegetation in plots that burned in 1976–1977 with other similar stands that had not burned before 1940. Observations of recent post-fire succession were then compared with data on historic fire regimes to analyze the effect of a declining fire frequency on species richness and vegetation structure.

The study area in the western regions of GSMNP consisted of 108 permanently marked plots measuring 20 x 50 m. Sites were chosen subjectively to encompass a range of conditions and disturbance histories, including old agricultural fields, previously logged areas, and areas that had burned during 1976–1977. Past disturbances were recorded, such as logging, southern pine beetle, and fire. This study focused on two groups of plots that had no distinct history of settlement or agriculture.

Evidence of fire was recorded in seven of 10 plots that had not burned since 1940, two of which displayed fire scars that dated to 1926. Pearson correlation coefficients were generated to examine and compare statistical significance of the following parameters: elevation, TMI, percent pine beetle mortality, percent basal area killed by fire, post-fire percent canopy opening, fire seasonality, *Pinus* seedling density in 1980, *Pinus* sapling density in 1984, maximum cover of shrubs and woody vines from 1977 to 1984, and maximum herbaceous cover from 1977 to 1984.

Results showed that percent of basal area killed showed a positive correlation with post-fire canopy openings, and both showed highly significant positive correlations with pine beetle damage prior to fire. Post-fire mortality was highest among smaller stems, but patterns varied with species and fire severity. Four growing seasons after fire, *Pinus* seedlings displayed a significant negative correlation with post-fire litter depth. *Pinus* saplings showed partially significant correlations with pre-fire pine beetle damage. Unburned plots revealed an abundant increase in red maple and eastern white pine at the canopy level and a decline in *Quercus* species, particularly at the sapling stratum. Shrub cover showed a positive correlation with post-fire litter depth and season. Maximum herbaceous cover showed an extremely high positive correlation with basal area killed and canopy opening, but not with post-fire litter depth. Herbaceous cover and diversity were lower on sites that had not burned since 1940, as compared to burned plots in the first decade post-fire.

The general pattern of long-term succession follows that of logging disturbance and agricultural abandonment. Succession of herbaceous species diversity was much lower in unburned plots than burned plots. The early 20th century fire rotation of 12.7 years would have time-since-fires of 8 years or less in 50% or more xeric sites. Under the late 20th century fire rotation of more than 500 years, only 2% or less xeric sites would have time-since-fires of 8 years and 90% of xeric sites would be occupied by time-since-fire dates of 50 years or more. This suggests that the historic successional communities would have relatively open canopies and high species diversity within the herbaceous layer. Now, a mature, closed canopy dominates the majority of xeric forest sites in southern Appalachia with low herbaceous species diversity. This shows that frequent fire would have restricted accumulation of woody fuels and allowed thicker growth of herbs and grasses. These conditions allowed an increase in drying of the ground layer, which further supported a low-intensity fire regime. This study adds to growing evidence of scattered, open-canopy woodland with a high diversity of herbs and grasses in Southern Appalachian landscapes.

2.4 Rehabilitation of Mixed Oak-Pine Forests

2.4.1 Waldrop, Welch, Brose, Elliot, Mohr, Gray, Tainter, and Ellis 2000

Historically, ridgetop pine communities of the southern Appalachian Mountains were perpetuated and sustained by fire caused by both humans and lightning. Table Mountain pine/pitch pine communities present today were established through landscape-scale disturbances such as fires, logging, insects, and disease. Fire suppression has increased within the last century, removing large scale disturbances, causing succession of ridgetop pine communities to dominance of hardwoods and dense, closed understories. Ridgetop pine communities generally consist of Table Mountain pine and pitch pine overstory canopy, with chestnut oak, scarlet oak, and black gum as midstory species. The understory typically contains a dense shrub layer of mountain laurel.

This review of the current research of pine communities examined the results of three pertinent studies of stand-replacement prescribed fires in National Forest and National Park lands. Corollary studies in dendrochronology, seed biology, seedbed habitat, and mycorrhizae were also discussed. The comparison of studies revealed the amount of pine regeneration under natural conditions. However, these studies only investigated conditions in the year following a prescribed burn.

The first study was conducted in the Tallulah Ranger District, Chattahoochee National Forest. USDA Forest Service staff conducted a prescribed stand-replacing fire on a 344 ha (850 ac) in April 1997. The variation of fire intensity over a large spatial area allowed comparison of successful pine regeneration within areas that burned with different intensities. The second study examined a small scale, 3 ha (7.5 ac) prescribed burn in the Grandfather Ranger District of Pisgah National Forest. USDA Forest Service personnel used a ring and head fire technique to burn the site in May of 1996. Fifty-one percent of the pine component within the stand was Table Mountain pine. The third study examined a 303.5 ha (750 ac) burn unit on a south-facing slope in the Wine Springs Creek watershed of the Nantahala National Forest. The studied ridgetop community was dominantly pitch pine, which comprised 49% of total basal area. The burn was ignited by helicopter in April of 1995 and was designed to create low intensity fire on the lower slopes and high-intensity crown fires at the ridgetop.

The prescribed burns were defined by four fire intensities described by Waldrop and Brose: low, medium-low, medium-high, and high. All four fire intensities were observed at the Chattahoochee National Forest, while only medium-low fire intensities were observed at the Nantahala and Pisgah National Forests. All failed to control hardwood and shrub competition. The studies in dendrochronology provided an informative history of stand regeneration, showing that study stands were unevenly aged, and that pine regeneration took place until fire suppression efforts were implemented. Seed biology studies revealed that the very young trees also produce viable seed, implying adaptation to frequent fire occurrence. These comparative studies suggest that additional research of fire intensity after several growing seasons is needed to assess seedling survival and successful pine regeneration.

2.4.2 Waldrop, Brose, Welch, Mohr, Gray, Tainter, and Ellis 2002

This review examined the possibility for high-intensity fire to aid in successful regeneration of Table Mountain pine. Observations of three prescribed fire studies and four supporting studies helped evaluate the need for high-intensity prescribed burns. The study areas were the same as the previous study, and also included the Buzzard's Roost Preserve of the South Carolina Heritage Trust Program.

Fire intensities were again categorized as low, medium-low, medium-high, and high. High intensity fires occurred only within the Tallulah District. The lowest pine densities found within this district were unexpected, suggesting that extreme heat killed seeds and destroyed seedbed suitability. All other study areas experienced a range of fire intensities without exceeding medium-high. Prolific hardwood sprouting followed fires of all intensities, which further suggested that multiple, low-intensity fires may reduce seedling competition and aid in maintaining seed sources.

A relevant study of seed biology revealed that seed viability increased as cones matured to 4–5 years of age. Young trees 5–10 years of age also displayed 3 year old cones with 23% viability, suggesting that Table Mountain pines are adapted to regeneration within a low-intensity fire regime. The results also implied that viable seeds become available every 2–3 years under frequent low-intensity fire, as long as overstory pines do not experience crown fire or mortality. Waldrop and Brose evaluated seedbed habitat in a greenhouse by controlling shade and duff conditions. Moderate levels of duff (5 cm) and shade (30%) were optimum for establishment, in contrast to previous work that suggested bare mineral soil and full sunlight were essential for establishment. Multiple low-intensity fires may be more suitable for maintaining these conditions. Other studies suggest that high-intensity fire negatively affects mycorrhizal root tips, causing poor regeneration. Dendrochronological studies of Table Mountain pine show variation in age class frequency from 100–158 years, suggesting that pine stands were relatively open and regenerating until the time of fire exclusion. These studies revealed that high-intensity burning may not be necessary, but detrimental to successful regeneration of Table Mountain pine in southern Appalachia.

CHAPTER 3

STUDY AREA

3.1 The Southern Appalachians

The southern Appalachian Mountains extend from West Virginia south through Virginia to northern Alabama and northern Georgia, and consist of three main physiographic provinces: the Appalachian Plateau, the Ridge and Valley, and the Blue Ridge (Fenneman 1938). The most pronounced of these regions is the Blue Ridge, containing several subsets of mountain ranges (e.g., Unaka Mountains, Iron Mountains, Snowbird Mountains, and Black Mountains) with the crest, or divide, serving as a boundary between western North Carolina and eastern Tennessee. The most well known mountains in the Blue Ridge province are protected as GSMNP. Elevations range from 450 to 2037 m a.s.l. and the greatest cross-sectional width spans approximately 80 km. Within the southern portion of the Blue Ridge, 46 peaks are found above 1828 m and 288 exceed 1524 m (Rehder 2004). The highest peak of this region is Mount Mitchell (2037 m a.s.l.), located in the Black Mountains near Asheville, North Carolina. It is closely rivaled by Clingman's Dome (2028 m a.s.l.), which is the highest elevation in GSMNP.

West of the Blue Ridge region is the Ridge and Valley province. This area is dominated by southwest to northeast trending ridges that display the geologic relationship between anticlines and synclinal folds. Ridges can range in height from 260 to 1220 m a.s.l. This province is greatest in length, stretching 2,000 km from southern Pennsylvania to northern Alabama with the greatest width approximately 120 km. The Ridge and Valley province is the most populated region of the southern Appalachians. Early farmers used the valleys with limestone-based soils that enhance agriculture, rather than valleys dominated by shale-derived soils (Rehder 2004). The largest valley of this province, referred to as the Great Valley, served as the earliest route of transportation for both Native Americans and early Euro-American settlers. This route was called the Great Wagon Road and is still a main route for transportation. It is now the main corridor for U.S. Interstate 81.

The Appalachian Plateau is the westernmost escarpment of the southern Appalachians. The northern portion is called the Allegheny Plateau, while the southern portion is referred to as the Cumberland Plateau. The landscape has a tabletop appearance and watersheds are dissected by water erosion. This eroded limestone forms sinks, caves, and gorges, which is commonly referenced as karst topography (Kohl 2001). Elevations on top of the plateau range between 600 m a.s.l. in the southern portions to 1500 m a.s.l. in the northern extent of West Virginia.

3.2 Great Smoky Mountains National Park (GSMNP)

GSMNP is the most visited national park in the United States, with over two-thirds of the nation's population in driving distance (NPCA 2004). GSMNP lies in the heart of the Blue Ridge province between western North Carolina and eastern Tennessee and covers roughly 203,200 ha. GSMNP was created on June 15, 1934 through numerous land grants, private donations, and public funds (Campbell 1960, Brown 2001). President Franklin D. Roosevelt dedicated the Park at Newfound Gap, the lowest passable road that crosses the main crest of GSMNP. The Cades Cove area attracts more visitors than any other portion of the Park because of its cultural history, the remaining folk architecture, and abundant wildlife (NPS 2008). GSMNP contains over half of the remaining old-growth forests in the eastern U.S. and is one of the most biologically diverse of all the national parks (Martin 1992, NPCA 2004). The greatest biodiversity occurs in tree species, salamanders, flora, and fungi and GSMNP is known as the "salamander capital of the world" (NPCA 2004, NPS 2008). The United Nations declared this park an International Biosphere Reserve in 1976 and a World Heritage Site in 1983 (NPS 2008).

3.2.1 Geology

GSMNP is a product of the Alleghanian orogeny, which occurred approximately 245–250 million years ago when the African plate collided with the North American plate (King *et al.* 1968). Over time, the African plate continued to shift west, causing further uplift and the full development of the Appalachian Mountain chain. Most bedrock within GSMNP is composed of metamorphosed sedimentary rocks that were deposited in an intercontinental sea called the Iapetus Ocean (King *et al.* 1968, Moore 1988). The sediments were compressed and subjected to extreme pressure and temperatures throughout the Alleghanian orogeny, which closed the Iapetus Ocean, resulting in a variety of metamorphosed sandstones, shales, and siltstones. The dominant bedrock consists of Precambrian rocks within the Ocoee supergroup, defined as Metcalf phyllite, Elkmont sandstone, and Cades sandstone, underlain by gneiss, limestone, and dolomite (King *et al.* 1968, Moore 1988, Southworth *et al.* 2000).

3.2.2 Soils

The dominant soils of GSMNP are part of the Ramsey series, classified as Ultisols and Inceptisols, varying by parent material, percentage slope, vegetation characteristics, and watersheds (Elder 1959). Ultisols are most prominent in areas of warm and humid climates that experience a periodic dry season. However, these soils are not limited by specific temperatures or moisture regimes other than aridity. Ultisols typically have stratified layers of aluminum-based clays that lack calcium. These soils have low fertility and supplemental minerals or fertilizers are needed for cultivation. Ultisols were occupied by both hardwood and coniferous forests upon European settlement (USDA 1999).

The Cades Cove area has its own soil classification, recently defined as the Cades series. This soil type is characterized by strongly acidic, well drained silty loams, on slopes varying from 2 to 8%. Cades soils were derived from alluvium that was formed from weathered, metamorphosed sedimentary bedrock transported from alluvial fans and terraces (NCSS 2007). Soil depth is approximately 180 cm and can be found between 420–915 m of elevation. These soils have low runoff rates and were previously forested, but have been cleared for pasture land or hay fields (NCSS 2007). The most common soil types on slopes varying from 30 to 90% along Cooper Road Trail are of the Ditny-Unicoi (34% of total area) and the Soco-Stecoah (22% of total area) complexes (WSS 2008).

3.2.3 Climate

The climate of the southeastern United States is classified as humid subtropical (Cfa), or mid-latitude wet, under the Köppen climate classification system (Shanks 1954, Pidwirny 2006). Humid subtropical climates are characterized by year-round, evenly distributed rainfall; cool, mild winters; and warm to hot summers. Thornthwaite (1931) developed a classification system based on altitudinal gradients and potential evapotranspiration that categorizes GSMNP as mesothermal or microthermal perhumid (rain forest). GSMNP receives approximately 137 cm of annual precipitation at the lower elevations, increasing to approximately 210 cm at the higher altitudes (Shanks 1954, NPS 2008). In the lower elevations, summer high temperatures range from 28 to 31 °C and summer lows range from 12 to 15.5 °C. Winter high temperatures range from 10 to 12.5 °C and lows from –2 to 1 °C. In the higher elevations, summer high temperatures range from 13 to 18 °C and summer lows range from 6 to 11.5 °C. No temperatures greater than 26.6 °C have been recorded at elevations higher than 1980 m a.s.l. (NPS 2008). Winter high temperatures range from 1.5 to 4 °C and lows from –7 to –4.5 °C. Both temperature and precipitation can change abruptly due to the effects of orographic lifting over 1600 m of relief throughout the heavily dissected landscape (Shanks 1954).

3.2.4 Forest Vegetation

The vegetation composition of GSMNP varies greatly depending on moisture gradients, elevation, and topographic barriers. Forest types are categorized by the dominant overstory and understory plants. Whittaker (1956) described vegetation based on mesic, submesic, subxeric, and xeric sites, while the U.S. Geological Survey and National Park Service Vegetation Mapping Program (1999) classified vegetation communities by elevation, species dominance, and ecological grouping. This vegetation classification system found 52 different vegetation communities on the Cades Cove and Mt. LeConte quadrangles, but should not be used as a definitive measure for the entirety of GSMNP, as it only focuses on these two areas.

Mesic sites are restricted to valley bottoms that retain moisture year-round. These sites contain most of the remaining old-growth forest within GSMNP (Martin 1992). Common species that occur on mesic sites include yellow poplar, eastern hemlock, Carolina hemlock (*T. caroliniana* Engelm.), white or American basswood (*Tilia americana* L.), yellow birch, American beech, white oak, Fraser magnolia (*Magnolia fraseri* L.), sugar maple (*Acer saccharum* Marsh.), and red maple. *Rhododendron* species dominate the understory. Species dominance on mesic sites largely depends on land-use history and disturbance (Runkle 1982). Recently, hemlock stands have experienced high rates of mortality caused by the hemlock wooly adelgid (*Adelges tsugae* Annand). Many of the old-growth stands are primarily hemlock and yellow poplar, so efforts are underway to treat the infected trees and prevent further outbreak (NPCA 2004).

Submesic and subxeric sites are dominated by a mosaic of vegetation, but are mainly composed of mixed oak-hickory forests. The most common canopy dominants are white oak, chestnut oak, red oak (*Q. rubra* L.), black oak (*Q. velutina* L.), pignut hickory (*Carya glabra* Mill.), mockernut hickory (*C. tomentosa* Poir.), yellow buckeye (*Aesculus flava* Aiton), red maple, American beech, black gum, white pine, and eastern hemlock (Whittaker 1956). The most prominent historic species of these mixed forests was the American chestnut (*Castanea dentata* Marsh.). These trees could reach sizes of 37 m in height and 1.5 m in diameter, increasing by approximately 2.5 cm in diameter per year on extremely fertile areas (Anagnostakis 1987). In the 1920s, the introduction of an exotic fungus called *Endothia parasitica* devastated the American chestnut trees by infecting the cambial growth tissue. This caused widespread mortality, destroying 99.9% of the species over its entire range (Anagnostakis 1987). These trees can still be found resprouting from remnant root bundles, but rarely reach heights over 6 m before the fungal blight inhibits growth.

Ridgetops and south/southwest facing slopes contain the most xeric forest types, supporting a variety of yellow pine species intermixed with hardwoods. Shortleaf pine, Table Mountain pine, pitch pine, and Virginia pine are the canopy dominants. The dominant hardwoods are usually black oak, blackjack oak, chestnut oak, scarlet oak, red maple, and black gum. The understory largely consists of flowering dogwood (*Cornus florida* L.), sourwood, and sassafras (*Sassafras albidum* (Nutt.) Nees). Mountain laurel and a variety of *Vaccinium* species are the dominant ericaceous shrubs.

The dominant forest type at the higher elevations is spruce-fir montane forest. The dominant tree species are Fraser fir (*Abies fraseri* (Pursh) Poir.) and red spruce (*Picea rubens* Sarg.). The introduction of the balsam wooly adelgid (*Adelges piceae* Ratz.) combined with acid rain has caused severe mortality of Fraser fir, leaving red spruce as the remaining canopy dominant (Smith and Nicholas 1998). The cooler temperatures and abundant rainfall of the higher elevations allow these unique forests to exist, mimicking the northern Appalachian Mountains from West Virginia and New York to Maine. Grassy balds are another unique feature of the southern Appalachian Mountains. The existence of these areas is still questioned by scientists, who postulate that these open, treeless areas were either created by fire, cleared by Native Americans, grazed by megaherbivores, or are remnants of the last glacial episode during the late Pleistocene (Billings and Mark 1957, Lindsay and Bratton 1979, Weigl and Knowles 1995).

3.2.5 Disturbances

Many disturbances have affected the vegetation in GSMNP. Natural disturbances include lightning strikes, windthrow, canopy gaps, insect infestation, and fungal disease. Natural disturbances also vary with forest type and topography. For example, old growth stands may experience greater change after large trees fall, creating canopy gaps, while pine stands may be more prone to windthrow, insect infestation, or lightning strikes (Runkle 1982). The greatest disturbance that impacts vegetation is most obviously human induced (Pyne 1982, Frelich 2002, Jantz 2002). Timber harvests were often heavily mechanized, using clear-cuts and narrow gauge railroads, causing complete canopy removal, soil erosion, and complete restructuring of the historic vegetation composition (Lambert 1961, Pyle 1988, Duffy and Meier 1992).

Wildfires may be the most controversial natural disturbance among governmental agencies, conservation groups, and scientific researchers. Initial viewpoints suggested that fire was purely destructive to forests and timber, and expensive efforts to suppress fire were implemented on most government-owned lands (McDaniel 2004). However, Native Americans and early settlers had used fire for centuries to manipulate the landscape for a variety of reasons. They would set fire to the forests to drive game, facilitate travel, increase berry yields, and increase grasses and herbs for grazing (Orwig and Abrams 1994, Delcourt and Delcourt 1997, Jurney *et al*. 2004). Recently, researchers and land managers have started to see the benefits of periodic fire, which promotes biodiversity in a variety of ecosystems (McDaniel 2004).

3.3 Cades Cove

Cades Cove is the most visited area of GSMNP (NPCA 2004, NPS 2008) (Figure 3.1). Its deep-rooted cultural history, as well natural beauty and abundant wildlife, make this area the most favored attraction of GSMNP. A cove is defined as an eroded valley surrounded on all sides by mountains or other higher features of younger geologic rocks (Moore 1988, Kohl 2001). Coves are generally characterized by limestone or dolomite valley bottoms that eroded more quickly than the surrounding bedrock, resulting in an oval or bowl-shaped depression. The primary stream drainage for Cades Cove is Abrams Creek.

Cades Cove was initially inhabited by Native Americans as early as 10,000 years ago (Bass 1977). Chert and flint spear points and arrowheads, as well as excavations of small hunting camps, revealed that indigenous populations hunted in this valley from the early Archaic period (8000–6000 BC) until Euro-American settlement in the early 19th century (Bass 1977, Chapman 1985). No permanent settlements have been discovered, but evidence of small-scale

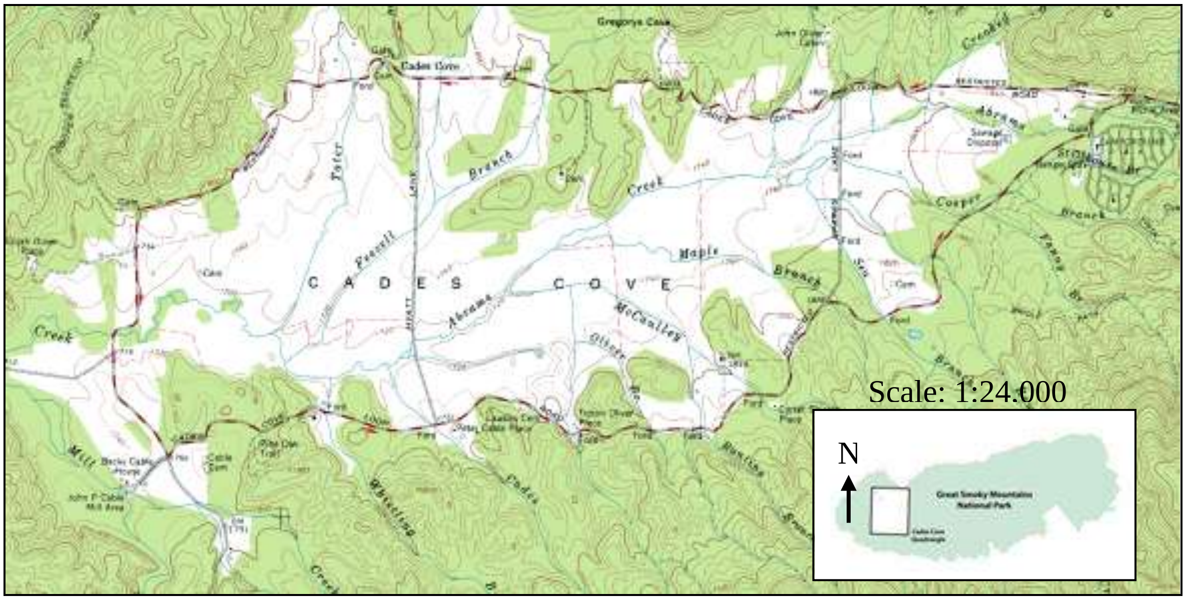

Figure 3.1 Map of Cades Cove from USGS 7.5 minute Quadrangle.

hunting camps and animal bone fragments indicate seasonal use for hunting.

Cades Cove was named for a Cherokee leader named chief Kade (Dunn 1988). The Cherokee name for the cove was Tsiyahi, meaning "otter place" (Mooney 1900, Dunn 1988). Henry Timberlake, an early British explorer known for maps and records of Cherokee country, mentioned the cove in early surveys of the Little Tennessee River in 1762 (Fink 1933, Dunn 1988). The earliest Euro-Americans were John and Lucretia Oliver of Carter County, Tennessee. They arrived in the fall of 1818 using the Rich Mountain road, a well traveled route used by the Native Americans (Jantz 2002). Further settlement throughout the 19th century resulted in scattered farmsteads throughout the isolated cove.

3.3.1 Cooper Road Trail

The Cooper Road Trail leads northwest from Cades Cove toward the Abrams Creek campground and westernmost boundary of GSMNP (Figure 3.2). Before the arrival of European settlers, the route had been previously constructed by Native Americans who used the trail to follow wild game into the cove (Gove 1994). Daniel Foute was given permission by the Tennessee General Assembly to further develop the Cooper Road in 1852, formally known then as the Cane Creek Road (Dunn 1988). This route allowed much easier access than Rich Mountain and continued to serve as the main commercial thoroughfare to Montvale Springs, Maryville, and Knoxville until the early 20th century. House foundations, spring boxes, and fence boundaries still exist along the trail today, indicating settlement until creation of GSMNP in 1934 (Dunn 1988, Gove 1994).

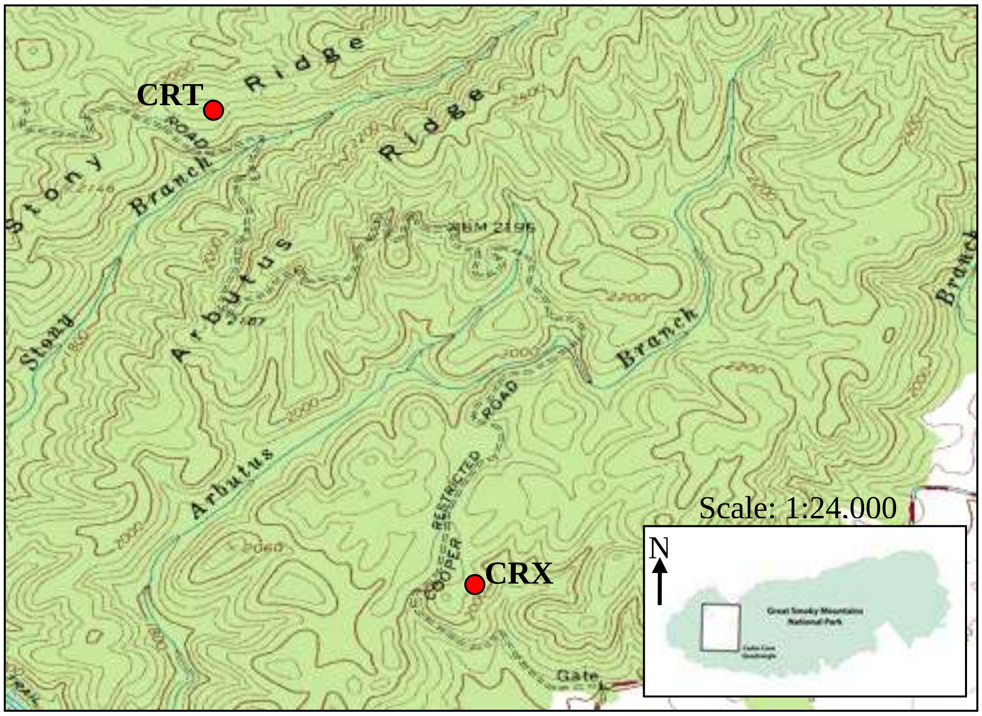

Figure 3.2 Map showing the Cooper Road Trail and study sites from USGS 7.5 minute Quadrangle.

3.4 Site Selection

I chose two sites along the Cooper Road Trail to quantify fire history. The Cooper Road Trail covers a broad area, allowing fire regimes to be compared by topographic separation. The ridges adjacent to Cades Cove were grazed by cattle and timber was selectively cut depending on species and use (Lambert 1961, Bratton *et al.* 1980, Pyle 1988). Ridges along Cooper Road Trail contain several stands with old-aged yellow pines that provided adequate samples for comparison of fire regimes and stand dynamics. To determine differences and spatial variation in vegetation and fire history, I chose two sites that were distinctly separated by watershed boundaries, topographic separation, and vegetation disturbance history (Figure 3.2, Figure 3.3). Prior land ownership was determined by maps from the Land Status Atlas (Book 2, Maps 35–59), Pyle (1988), and land acquisition deeds located at GSMNP headquarters (Master Deed List 2009).

3.4.1 The Cooper Road Trail "Near" Site: CRX

The first site is located upon the adjacent ridges of the Cades Cove ca. 1.4 km from the Cades Cove loop road along the Cooper Road Trail (N 35° 36.156', W 83° 50.861', 630 m a.s.l.) (Figure 3.4). The property was acquired by GSMNP from John W. Oliver, but was formerly owned by heirs of W.H. Myers, Noah Burchfield, and Samuel L. Sparks (Deed 14, Tract 393; Deed 29, Tract 397; GSMNP Headquarters). The property covered 121 ha (300 ac) and was probably used for both grazing and small timber supplies. I saw trees damaged by wire fence at the top of the ridge, indicating that settlers may have disturbed this site. Canopy species include shortleaf pine, pitch pine, Virginia pine, and white pine, to various hardwoods such as red maple,

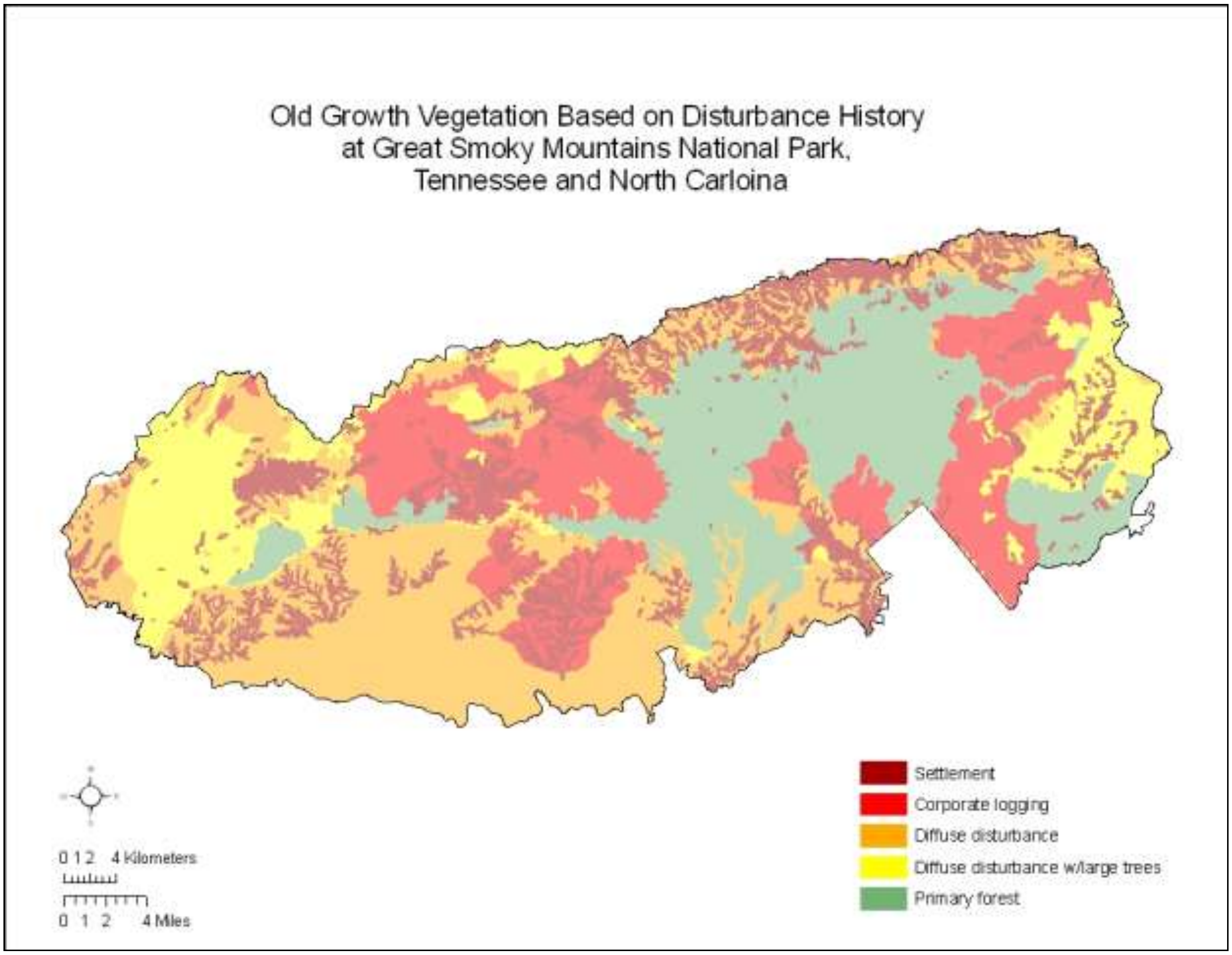

Figure 3.3 Map showing vegetation disturbance history in GSMNP; adapted from Pyle 1988. <http://science.nature.nps.gov/nrdata/datastore.cfm?ID=45868>

Figure 3.4 Vegetation at the CRX study site.

red oak, scarlet oak, and chestnut oak. The understory consists of *Rhododendron* species at the lower limits and American holly, sourwood, sassafras, black gum, eastern hemlock, and Fraser magnolia. Fire scars were present on both living and standing dead trees. Numerous game trails persist throughout the area, suggesting that the understory was impacted by heavy herbivore browsing. Southern pine beetle damage is also evident.

3.4.2 The Cooper Road Trail "Far" Site: CRT

The second study site is located on Stony Ridge, just north of Stony Branch and the Cooper Road Trail (N 35° 37.150', W 83° 51.422', 653 m a.s.l.) (Figure 3.5). This area was obtained by GSMNP from the Morton-Butler Timber Company, which owned 10,596 ha (26,184 ac) along Cooper Road Trail. Morton-Butler Timber Company had acquired most of the property in 11 different tracts from local residents. Some portions were obtained in land swaps with the Aluminum Company of America, some conveyed by Frank T. Wilson, and some obtained residences unknown with the nature of claims unknown (Deed 31, Tract 382; GSMNP Headquarters). This site was most likely logged and maintained for grazing by nearby settlements. Harmon (1982) sampled in this area when previously compiling a fire history for the westernmost portions of GSMNP. At this site, I sampled a fire-scarred pitch pine (sample ID: CRT 307) previously sampled by Harmon. Fire scars were present throughout the study site.

Canopy species include shortleaf pine, pitch pine, Virginia pine, and white pine as well as chestnut oak, scarlet oak, and red maple. The understory consisted of American holly (*Ilex opaca* Aiton), black gum, sourwood, and sassafras. Young cohorts of white pine and eastern hemlock were also present, with abundant mountain laurel, *Vaccinium* species, and greenbriar (*Similax rotundifolia* L.) forming a dense understory. Many living and standing dead trees

Figure 3.5 Vegetation at the CRT study site.

showed evidence of southern pine beetle infestation. Pressures from settlement are only known to have existed in adjacent bottomlands, although it is likely that the ridge top was used for grazing.

CHAPTER 4

METHODS

4.1 Field Methods

4.1.1 Fire History

Fire history information was obtained from both living and dead fire-scarred yellow pine trees, primarily pitch pine and shortleaf pine. These species were targeted because wildfire may damage the cambial tissue of the tree and cause pine resins to fill the basal wound, thus preserving a scar that reveals the fire event in the annual growth ring (Fritts 1976, Grissino-Mayer 1995, Richardson 1998). The living trees can then record subsequent fires because the resin actually promotes scarring during later fire events. To find fire-scarred samples, I searched for the presence of old-growth yellow pines and mountain laurel on south to southwest facing slopes. After locating appropriate samples, we took the coordinates of each sample location with a GPS unit. We used a chain saw to remove fire-scarred sections from snags, downed trees, and standing dead trees by removing complete cross sections, while smaller wedge-shaped cross sections were cut from a few living trees (Figure 4.1). This method maintains the structural integrity of living trees without causing mortality, and is necessary to obtain the history of fires in the 20th century.

4.1.2 Stand Composition

Stand composition was determined by establishing two 20 x 50 m (1000 m^2, 0.1 ha) study plots at each of the sites where fire-scarred samples were removed. Study plots were chosen randomly by walking 10 paces in a 235° bearing from a randomly selected yellow pine

Figure 4.1 Photograph showing sample collection.

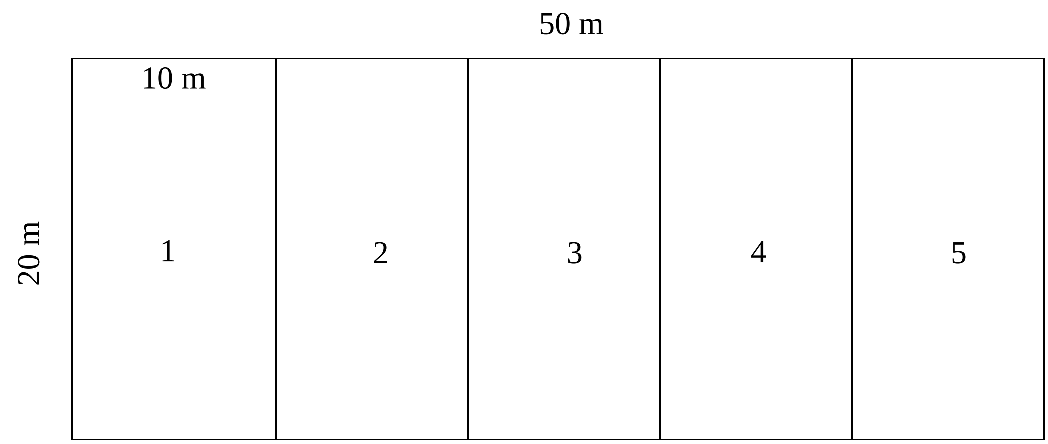

Figure 4.2 Dimensions of the study plot and sub-plots.

within the study area. I chose this bearing because fires are most probable on south to southwest-facing slopes. GPS coordinates and photographs were taken at each corner of the study plots. I placed 20 m transects at 10 m increments across the horizontal axis to divide the area into five, 200 m^2 subplots (Figure 4.2). Every living tree (any stem greater than 5 cm diameter at breast height) within the plots was identified by species, given a sample ID, then flagged and labeled with sample ID, species code, and DBH. I tallied seedlings (stems less than 10 cm height) by species within 1 m along the first, third, and fifth transects. I tallied saplings (stems greater than 10 cm height and 5 cm DBH) by species in the first and fifth subplots.

4.1.3 Age Structure

I collected age structure information by removing increment cores from each surveyed tree in one plot at each study site. Each tree was cored using an increment borer and all cores were placed in a paper straw. I attempted to obtain cores from two radii of each tree to ensure at least one core was sound. Cores were taken parallel to the contour of the slope and as close to the ground as possible to minimize distortion of the annual growth rings and determine the most accurate date of establishment (Grissino-Mayer 2003). Cores collected from trees with extensive internal rot and decay were discarded, but these were few in number.

4.1.4 Volumetric Water Content and Duff Depth

Volumetric water content (VWC) of the soil was measured with time domain reflectometry, which pulses electromagnetic waves at millisecond intervals to determine the amount of available water in the soil pores based on the relationship with an object's electrical conductivity (Topp and Davis 1985, Noborio 2001). VWC measurements were recorded with a

Campbell Hydrosense time domain reflectometer (soil moisture probe) using 12 cm stainless steel rods. Measurements were taken at the upper, middle, and lower parts of each vertical transect within the study plots. A total of 15 readings were taken from each plot, totaling 30 samples from each study area and a total sample size of 60. Duff depths were recorded in cm at each end of the 10 m transect at each study plot, totaling 20 measurements at each site.

4.2 Lab Methods

4.2.1 Fire History

Fire-scarred cross sections were mounted on particle board with wood glue for stability. All samples were then sanded with progressively finer-grit sandpaper, beginning with ANSI 80-grit (177–210 μm) and ending with ANSI 400-grit (20.6–23.6 μm) to display the annual ring boundaries with cellular resolution (Orvis and Grissino-Mayer 2002). The widths of all annual rings of each sample were measured using a stereoscopic boom-arm microscope with Measure J2X computer software. The tree-ring series were then crossdated visually and statistically (Holmes 1983, Yamaguchi 1991, Stokes and Smiley 1996, Grissino-Mayer 2001a). Ring-width measurements were entered into COFECHA computer software as an undated series and compared to the nearby Gold Mine Trail tree-ring chronology created by Lisa LaForest and Jessica Slayton of the University of Tennessee Laboratory of Tree-Ring Science. COFECHA conducted correlation analysis on each measured radius using 40-year tree-ring segments overlapped by 5 years to confirm statistical crossdating. Correlation coefficients of each segment had to exceed 0.37 ($p < 0.01$) before being considered statistically significant and therefore crossdated. After verification, statistically significant correlations for overlapped segments were then assigned and shifted to absolute dates with EDRM (Holmes 1999).

Once each sample was crossdated, I examined fire scars and assigned each scar a year of occurrence. Seasonality was determined by the position of the scar within the earlywood or latewood portion of the annual growth ring (Baisan and Swetnam 1990). Seasonality assignments were described using the following letters:

- Early season (E): The fire scar was located in the early portion of the earlywood, after the boundary of the previous annual growth ring. This indicates a fire event in early spring (February, March, and April).
- Middle season (M): The fire scar was located in the middle portion of the earlywood, indicating a fire event in the height of the growing season (May, June, and July).
- Late season (L): The fire scar was located in the latter portion of earlywood or the first portion of latewood. This indicates a fire event in the end of the growing season (August, September, and October).
- Dormant Season (D): The fire scar was located on the boundary of the latewood of the previous growth ring and before the earlywood of the following growth ring.
- Undetermined (U): The position of the fire scar in the annual growth ring was unclear and indeterminable.

Because a tree must be initially scarred to record fires, rings were labeled as either "recorder" or "non-recorder" rings. Recorder rings represent the span of years in which a tree can subsequently record fires after the initial scarring. Non-recorder rings are those that formed before scarification, after basal wounds had completely healed, or after rings had been obscured by decay and erosion. Differentiating between recorder and non-recorder rings allows fire history data to be more accurately modeled by a statistical distribution and further validates subsequent statistical analyses (Grissino-Mayer 2001b). Most fire history data can be more accurately modeled with the Weibull distribution rather than with a normal distribution (Grissino-Mayer 1995, Grissino-Mayer 2001b). The Weibull distribution is most commonly used to model dynamic fluvial systems, providing flexibility and optimal fit for outliers, which are often excluded from statistical analysis (Gordon 2004). This distribution, in turn, provides more accurate statistical inference and validity of fire history data (Grissino-Mayer 2001b).

I used the following descriptive statistics to analyze fire history data from the Cooper Road Trail study sites:

- Mean Fire Interval: The average number of years between recorded fire events.
- Median Fire Interval: The median value of the distribution for fire intervals.
- Weibull Modal Interval: The modal value that represents the most common frequency in the probability distribution.
- Weibull Median Interval: The 50^{th} percentile value of fire intervals associated with the Weibull distribution.
- Lower Exceedance Interval: The interval that describes a statistically significant short fire interval as derived from the Weibull distribution.
- Upper Exceedance Interval: The interval that describes a statistically significant long fire interval as derived from the Weibull distribution.
- Maximum Hazard Interval: The maximum fire-free interval a fire regime can experience before a fire event becomes highly probable; theoretically derived from the Weibull distribution.

After all fire-scarred samples were analyzed, the information was entered into FHX2 computer software to determine the statistical distribution of the data, and evaluate fire frequency, fire seasonality, spatial differences, and temporal changes between the two study areas (Grissino-Mayer 2001b). Spatial differences were tested using a 2 x 2 Chi-square contingency table, which essentially compares synchronous and asynchronous fire events between separate fire chronologies to determine statistical independence (Grissino-Mayer 2001b). Temporal changes were tested statistically using a t-test (difference of means), F-test (difference of variance), and a Kolmogorov-Smirnov test. I used the period 1740 to 1817 as a control period to test for changes from 1818 to 1934, which represents the time before Euro-American settlement of Cades Cove. I then used the FHX2 graphics module to create graphs showing independent site and combined site fire chronologies for Cooper Road Trail.

4.2.2 Superposed Epoch Analysis

I used superposed epoch analysis to analyze tree growth in years prior, during, and after fire events. Superposed epoch analysis aligns fire events and averages growth conditions prior and during fire events. Bootstrapping methods are used to develop confidence intervals on simulated events (Grissino-Mayer 2001b). Exceedance of the mean value from the calculated confidence intervals shows a statistically significant departure from average growth conditions, which in turn are related to the climate conditions that influenced the fire event.

4.2.3 Stand Composition

Stand composition data were entered into a Microsoft Excel spreadsheet to calculate density, basal area, and importance values of each species at each study site. Forest mensuration data were calculated using methods described by Matthews and Mackie (2007). Stand density was calculated by dividing the total number of individuals of a species by the plot area. Basal area (BA) in m^2 per tree was calculated by squaring DBH and then multiplying by 0.00007854. Stand dominance was calculated by dividing the total BA of each tree of a species on all plots by the total area of all measured plots. Relative density was calculated by dividing the density of each individual species by the total of densities of all species and then multiplying by 100. Relative dominance was calculated by dividing the total BA of each individual species by the total of the BA of all species and then multiplying by 100. Importance values were then calculated on a 200-point scale by adding the relative density and relative dominance of each species. Relative frequency calculations were omitted because the presence or absence of tree species is indicated by a 0 value. Size distributions for each site were sorted by type (yellow pine, hardwoods, and other species) and graphed by DBH and age of establishment using scatter plots in Microsoft Excel. Seedling and sapling tallies from each study site were represented by relative dominance.

4.2.4 Age Structure

Each core sample was thoroughly dried and glued to a wooden core mount. The samples were then sanded using the methods described in section 4.2.1. After sanding, each ring of each sample was counted and visually crossdated using the corresponding radius, if available, and using the local reference chronology from the Gold Mine Trail (Yamaguchi 1991, Stokes and Smiley 1996). Most samples had at least one radius that intersected the pith. If an increment core did not intersect the pith, a pith estimator was used to estimate the age of the tree

(Applequist 1958). Age information was then entered into a Microsoft Excel spreadsheet, sorted by type, and then graphed by year of establishment and diameter at breast height.

4.2.5 Volumetric Water Content and Duff Depth

The percentage of volumetric water content between the study sites was entered and compared statistically through the computer software package SPSS (Pallant 2007). Measures of volumetric water content were first compared using Lavene's test for equality of variance. Sample means were then compared using the independent samples t-test. Duff depth measurements were averaged to represent the mean duff depth at each study site.

CHAPTER 5

RESULTS

5.1 Crossdating Quality

A total of 49 fire-scarred samples were collected from the two study sites along Cooper Road Trail, of which 35 were conclusively crossdated. The total chronology spanned 330 years with individual series ranging from 40 to 164 years in length. Samples that met or exceeded interseries correlations of 0.35 when compared to the Gold Mine Trail master chronology were included in the Cooper Road Trail fire chronology. Most fire-scarred samples were graphically verified with especially narrow rings that formed in 1772–1774, 1856, 1872–1873, 1924–1925, 1954, and 1985–1988. Wide growth rings that formed in 1744–1745, 1859–1861, and 1937–1939 were also especially useful.

5.2 Fire History

At CRX, a total of 44 fire scars from 15 samples were found between 1685 and 2008, with the earliest fire in 1735 and the latest fire in 1970 (Table 5.1). A total of 28 fire events occurred during the period of reliability between 1749 and 1934. At CRT, a total of 60 fire scars from 20 samples were found between 1678 and 2008, with the earliest fire in 1720 and the last fire in 1945 (Table 5.2). A total of 36 fire events occurred during the period of reliability between 1810 and 1934.

Table 5.1 Fire-scarred, crossdated samples collected at CRX.

Sample ID	**Inner/Outer Year**	**Fire Years/Seasonality***	**Interseries Correlations****
CRX323	1822–2007	1830U, 1833E, 1839U, 1847E, 1857E, 1870E, 1878U	0.45
CRX327	1865–1924	1902U	0.45
CRX331A	1819–1886	1839E, 1853E, 1857E, 1865E, 1870E, 1873U	0.38
CRX331B	1685–1778	1735U, 1749E, 1765E, 1768M	0.39
CRX333B	1800–1926	1902E, 1916M	0.37
CRX338	1932–2007	1970L	0.49
CRX339	1772–1847	1796U, 1806E, 1809E, 1813E	0.40
CRX340	1734–1799	1754E	0.45
CRX341	1730–1796	1749E, 1757E	0.46
CRX346	1740–1802	1757E, 1766E	0.41
CRX348	1765–1811	1777E, 1787E	0.50
CRX349	1745–1804	1772E, 1777E, 1780E	0.48
CRX350	1761–1820	1777E, 1787E	0.39
CRX351	1889–1933	1898E, 1906E, 1916E	0.52
CRX352	1892–1935	1898E, 1906E, 1916E	0.40

* E = early season, M = middle season, L = late season, U = undetermined
** Interseries correlations = correlation coefficients with the master chronology with the sample removed

Table 5.2 Fire-scarred, crossdated samples collected at CRT.

Sample ID	Inner/Outer Year	Fire Years/Seasonality*	Interseries Correlations**
CRT304	1783–1918	1856M, 1884E, 1902E	0.48
CRT307	1868–1978	1871E, 1888E, 1896E, 1900E, 1902L, 1906E, 1909E, 1912M, 1916E, 1920E	0.61
CRT308	1823–1897	1872E, 1874E, 1889U	0.45
CRT312	1780–1846	1814U	0.45
CRT314	1678–1747	1740E	0.55
CRT315	1858–1947	1906E, 1920E	0.41
CRT316	1848–1933	1849E, 1854E, 1861E, 1900E, 1922E	0.45
CRT317	1869–1921	1902E, 1909U	0.40
CRT318	1872–1933	1896E, 1909E	0.46
CRT319A	1823–1867	1838E	0.61
CRT319B	1839–1878	1858E, 1862U	0.49
CRT401	1870–1960	1888E, 1896E, 1902E, 1909M, 1922E, 1926E, 1934M, 1945E	0.54
CRT402	1863–2007	1888E, 1916E	0.51
CRT403	1792–1881	1818E, 1843E, 1847E, 1850E, 1856E, 1863E	0.50
CRT404	1819–1870	1828E, 1835M, 1848M	0.35
CRT406	1850–1949	1914E, 1923E, 1930E, 1934E	0.41
CRT407A	1739–1802	1786E	0.40
CRT407B	1833–1932	1912E, 1916E	0.41
CRT411	1774–1837	1777U	0.46
CRT412	1704–1769	1720U	0.42

* E = early season, M = middle season, L = late season, U = undetermined
** Interseries correlations = correlation coefficients with the master chronology with the sample removed.

The minimum fire intervals of the separate fire chronologies ranged from 1 to 10 years, while the maximum fire intervals ranged from 10 to 20 years. The mean fire intervals ranged from 3 to 6 years, while the median fire intervals ranged from 3 to 5 years (Table 5.3). The Weibull modal intervals ranged from 1.9 to 3.8 years, while the Weibull median intervals ranged from 3 to 5.6 years. The lower exceedance intervals were 1 to 2 years, while the upper exceedance intervals ranged from 6 to 11 years. The maximum hazard interval was 24.4 years at CRX, compared to 5.7 years at CRT (Table 5.3).

At CRX, fire events in 1777 and 1916 were the most prominent, with three scars observed in 1777 and 1916 (Figure 5.1, Figure 5.4A). Fires that occurred in the dormant and early seasons accounted for 91.7% of all fires observed, while only 8.3% occurred during the middle and late seasons. At CRT, the most prominent fire events were recorded in 1902 and 1909 with four scars, and 1916 with three scars (Figure 5.2, Figure 5.4B). Fires that occurred in the dormant and early seasons accounted for 87% of all fires observed, while 13% occurred during the middle and late seasons.

The separate fire chronologies were then combined to evaluate fire history across a broader spatial scale. A total of 60 fire intervals occurred during the period of reliability between 1740 and 1934 (Figure 5.3, Figure 5.4C). During this period, a total of 97 scars were analyzed, 90.7% of which occurred during the dormant and early seasons, while 9.3% occurred during the middle and late seasons. The mean and median fire intervals were relatively similar at approximately 3 years. The Weibull modal and median intervals ranged from 1.6 to 2.7 years. The lower exceedance interval was relatively low (1 year), while the upper exceedance interval was 5.8 years. The maximum hazard interval was 5.3 years (Table 5.3).

Table 5.3 Descriptive statistics calculated from the fire chronologies.*

	CRX	**CRT**	**Combined Site Fire History**
Mean Fire Interval	6.2	3.4	3.2
Median Fire Interval	5.0	3.0	3.0
Weibull Modal Interval	3.8	1.9	1.6
Weibull Median Interval	5.6	3.0	2.7
Lower Exceedance Interval	2.0	1.0	0.9
Upper Exceedance Interval	10.9	6.2	5.8
Maximum Hazard Interval	24.4	5.7	5.3

*units = years

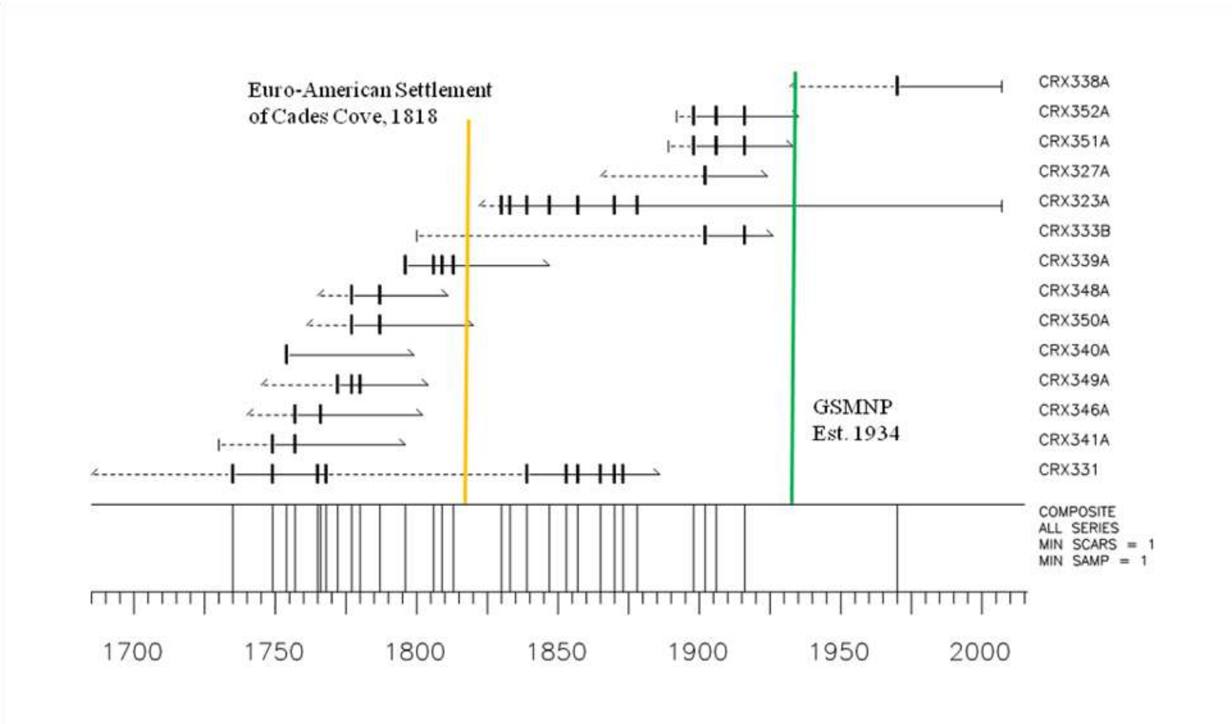

Figure 5.1 Crossdated fire events at CRX.

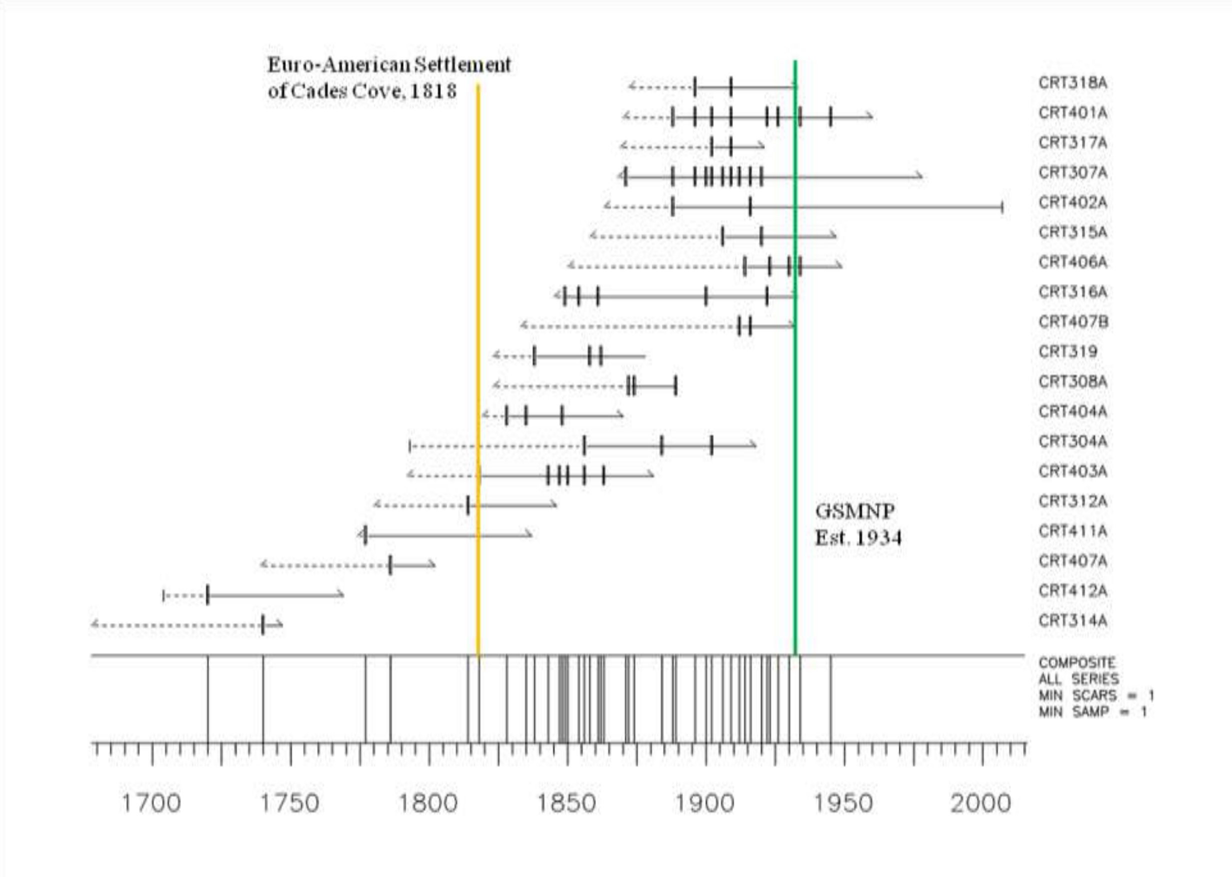

Figure 5.2 Crossdated fire events at CRT.

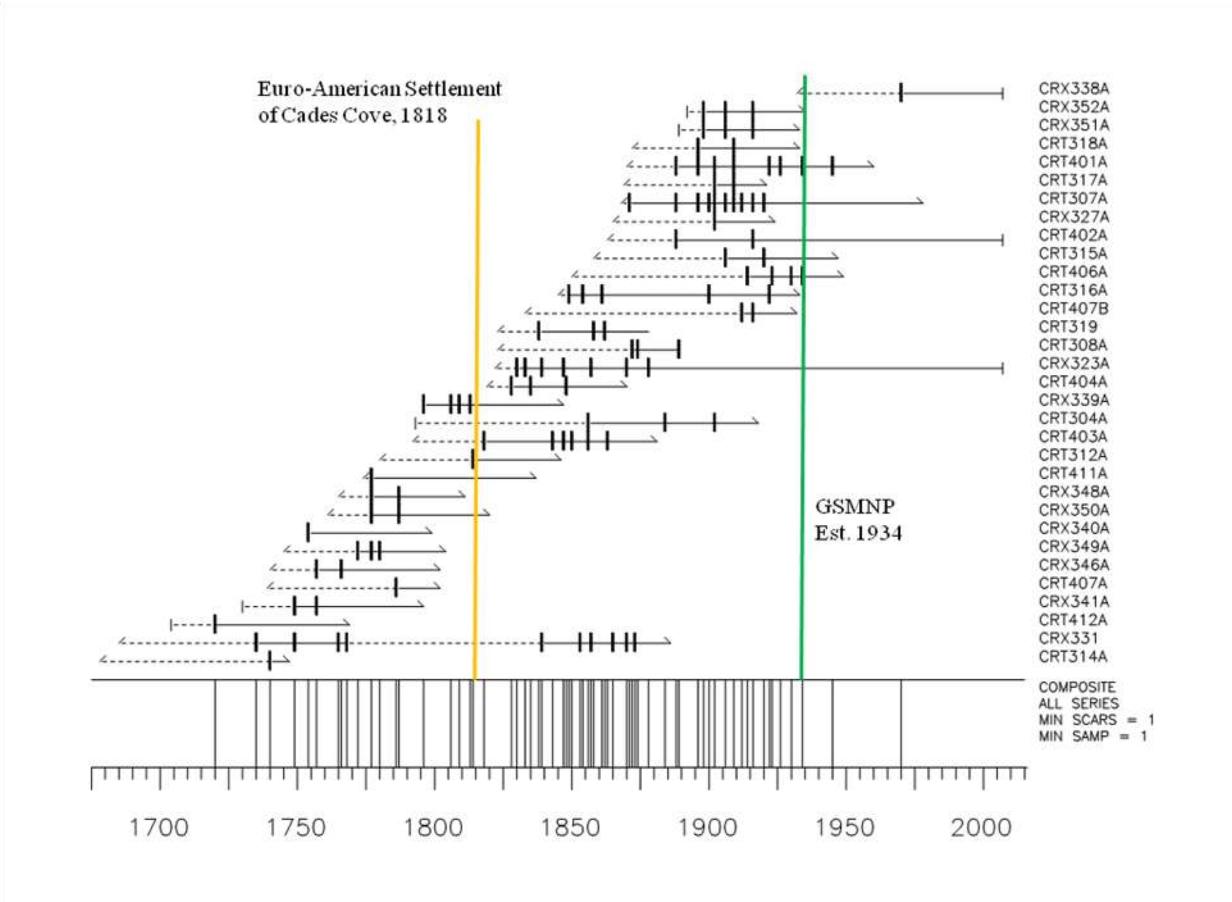

Figure 5.3 Crossdated fire events from the combined fire chronologies of CRX and CRT.

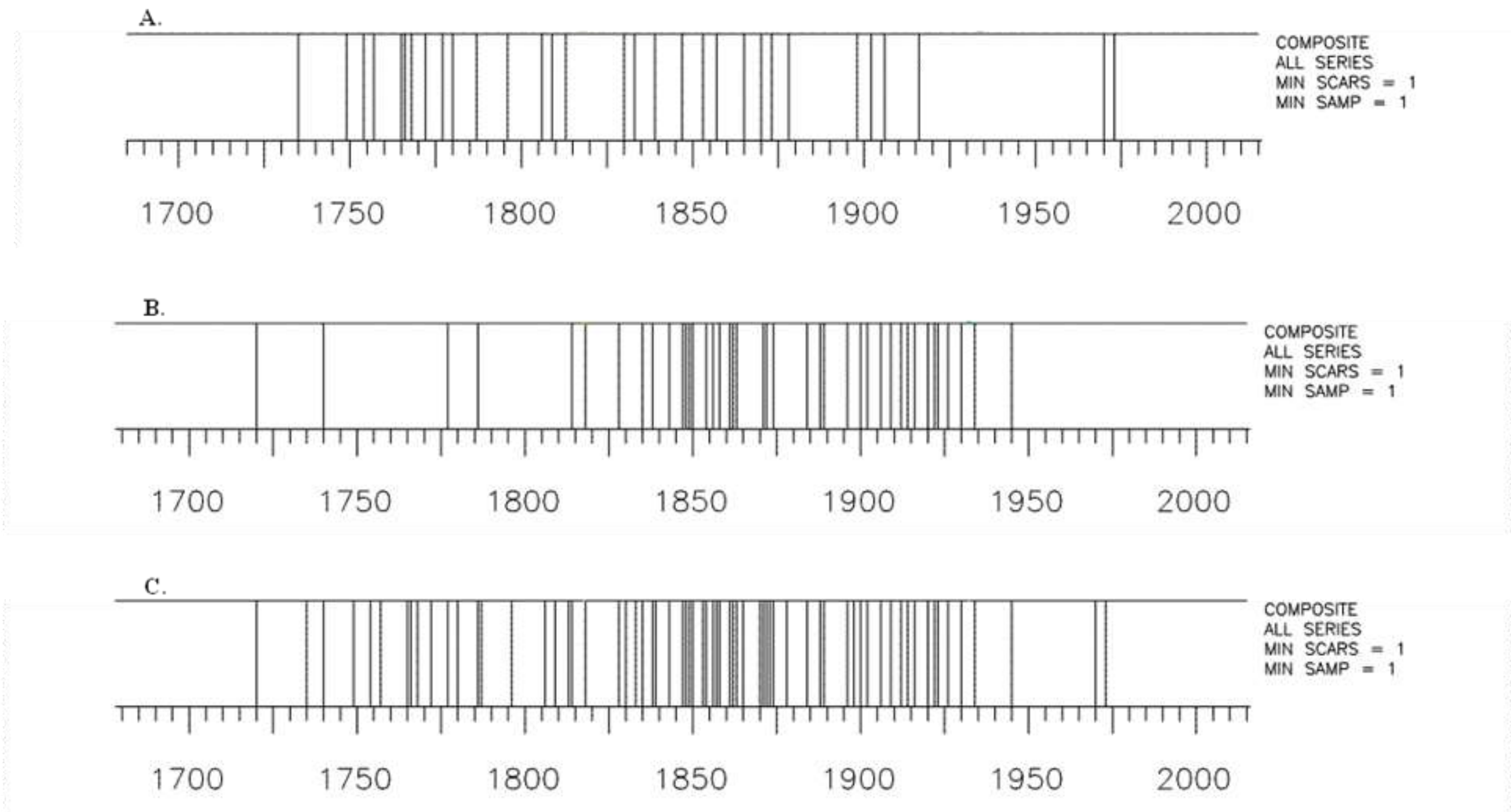

Figure 5.4 Composite fire chronologies from (A) CRX, (B) CRT, and (C) the two sites combined.

5.3 Temporal Analysis

Temporal changes were analyzed using 19 fire intervals in the pre-settlement period (1720–1818) and 43 fire intervals in the post-settlement period (1819–1934). Although sample size was smaller in the pre-settlement period, there were enough intervals in the two periods to test for temporal changes in fire regimes (Grissino-Mayer 2001b). Temporal analysis yielded significant differences between the mean fire intervals of the pre-settlement and post-settlement periods ($p < 0.001$) (Table 5.4). The mean fire interval of the pre-settlement period was 5.1 years, which is over twice as long as the mean fire interval of the post-settlement period at 2.4 years. No statistically significant differences were observed between the variances of the pre-settlement and post-settlement periods. However, significant differences were found between the distributions of fire intervals in the pre-settlement and post-settlement periods ($p < 0.05$) (Table 5.4).

5.4 Spatial Analysis

The most significant and synchronous fires occurred in years 1777, 1847, 1902, 1906, and 1916. Spatial analysis yielded significant differences in fire chronologies between the study sites. Mean fire intervals were found statistically different between CRX and CRT ($p < 0.05$) (Table 5.5). No statistically significant differences were observed in variance or statistical distributions between the study sites. The Chi-square test for synchroneity (2 X 1 contingency table) showed that fire chronologies were statistically independent between study sites ($p < 0.005$) (Table 5.5).

Table 5.4 Results of temporal changes analysis on the pre-settlement (1720–1818) and post–settlement (1819–1934) periods for all fire-scarred samples in the combined Cooper Road Trail fire chronology.

1720–1818 (*n*)	19
1819–1934 (*n*)	43
1720–1818 mean	5.2
1819–1934 mean	2.5
t-value	3.3
$p > t$	0.003**
1720–1818 variance	13.3
1819–1934 variance	2.3
F-value	1.8
$p > F$	0.124
KS *d*-statistic	0.4
$p > d$	0.027*

*$p < 0.05$, **$p < 0.01$

Table 5.5 Results of spatial analysis for differences in fire intervals and fire date synchroneity between the CRX and CRT fire chronologies.

t-value	–2.21
$p > t$	0.03*
F-value:	1.98
$p > F$	0.07
KS d-statistic	0.32
$p > d$	0.08
2x1 Chi-squared	18.76**
2x2 Chi-squared	0.04

*$p < 0.05$, **$p < 0.005$

5.5 Superposed Epoch Analysis

Using SEA, I found significant relationships between climate and fire in both test periods. During the pre-settlement period (1720–1818), SEA yielded below average climate and tree growth *t*–3 years before the fire event, exceeding 95% significance at the lower confidence interval (Figure 5.5). Average climate conditions existed from *t*–1 to 5 years after the fire event. During the post-settlement period (1819–1934), slightly below average climate conditions existed until the year before the fire event, exceeding 95% significance at the lower confidence interval (Figure 5.6). Average conditions were observed after the fire event.

Although SEA found no statistically significant relationships when analyzing the entire period of reliability (1740–1934), *t*–3 years before the fire event came very close to exceeding the 95% lower confidence interval (Figure 5.7). During and after the fire event, tree growth remained average throughout the 5-year window. In general, the entire period of reliability provided a more comprehensive model on the regional influence of climate on fire events. This period provided information on more meaningful relationships between climate, tree growth, and fire activity, despite anthropogenic influence throughout both test periods.

5.6 Stand Composition and Age Structure

A total of 534 trees were surveyed between the two sites, 242 at CRX and 292 at CRT. The near site yielded a total of 1210 stems per ha, with 9.17 total m^2 per ha (BA) (Table 5.6). Eastern white pine had the greatest density, followed by red maple, black gum, American holly, and pitch pine. Eastern white pine also had the highest number of stems per hectare, followed by pitch pine, Virginia pine, scarlet oak, and red maple. Tree species yielding the highest

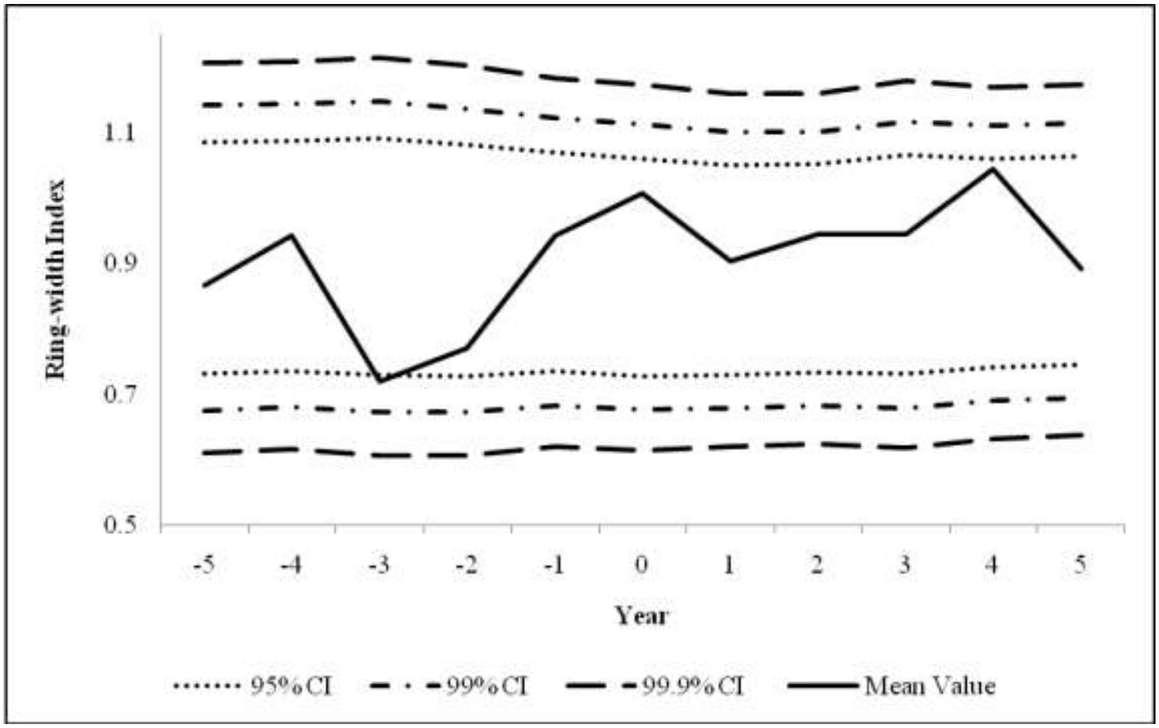

Figure 5.5 Results from superposed epoch analysis showing the relationship between climate, tree growth, and fire events during the pre-settlement period (1720–1818).
*CI = Confidence Interval

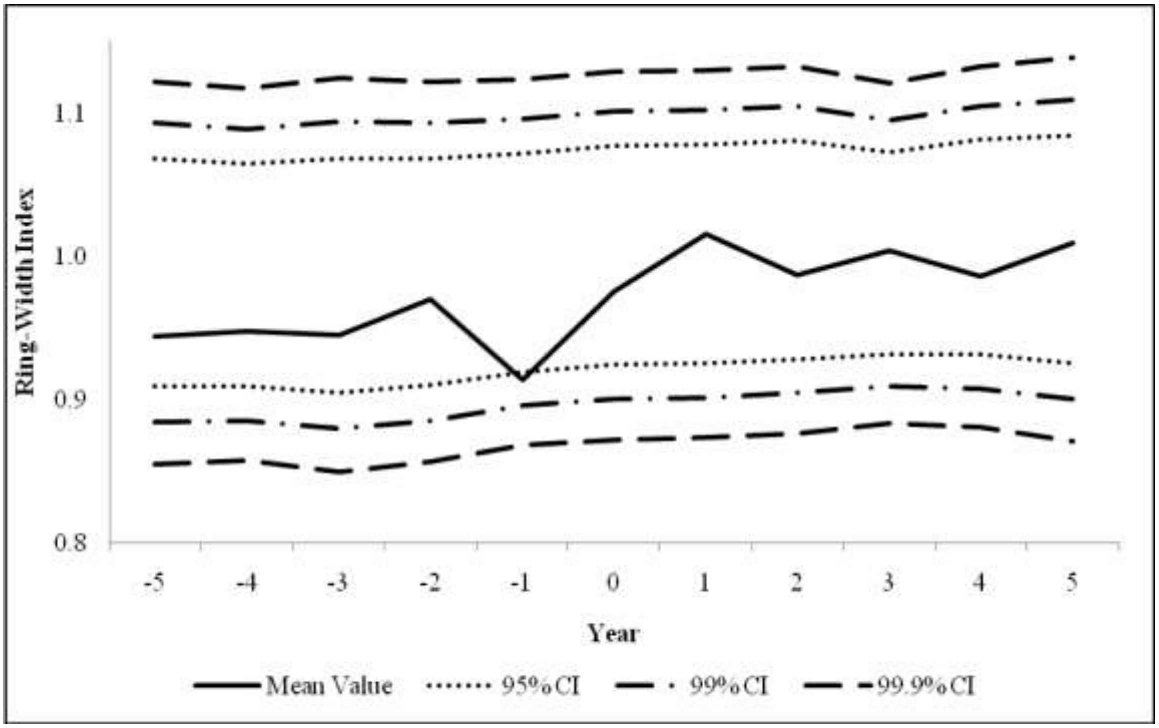

Figure 5.6 Results from superposed epoch analysis showing the relationship between climate, tree growth, and fire events from post-settlement period (1819–1934).
* CI = Confidence Interval

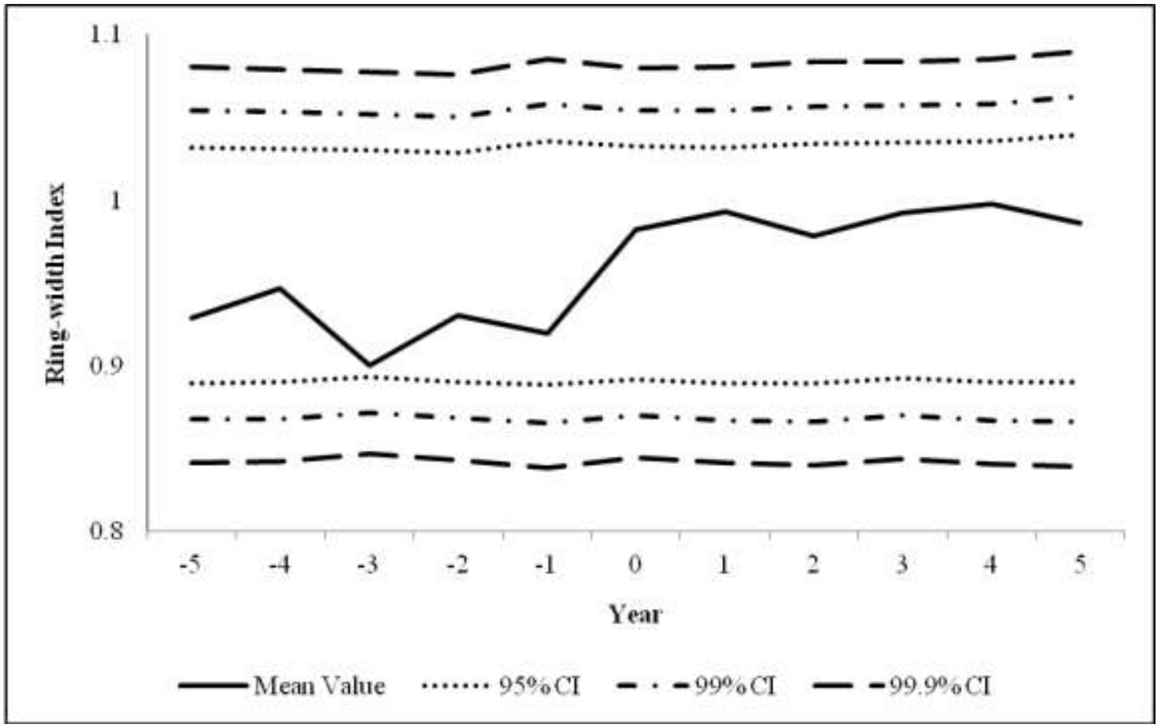

Figure 5.7 Results from superposed epoch analysis showing the relationship between climate, tree growth, and regional fire events for the combined fire chronology.
* CI = Confidence Interval

importance value percentages were eastern white pine, pitch pine, red maple, and black gum, while the least important species were American chestnut, black oak, and mountain magnolia (Table 5.6). Red maple, eastern white pine, and scarlet oak were the dominant seedlings, while eastern white pine, American holly, sourwood, and red maple were the dominant saplings (Table 5.7). No yellow pine seedlings or saplings were observed at CRX. Seedlings with least dominance were sassafras, eastern hemlock, and mountain magnolia. Saplings with least dominance were black oak, black gum, and eastern hemlock (Table 5.7).

A total of 91 trees were successfully aged at CRX, yielding a mean age of 70.45 years and mean size class of 20.1 cm DBH. White oak, pitch pine, and Virginia pine showed the strongest size-age relationship (Figure 5.8). The youngest species at this site were eastern hemlock, mountain magnolia, and red maple. The oldest individuals were pitch pine, Virginia pine, and white oak. At the near site, pine and oak species established until approximately 1900. Only four oaks had established by 1930. Eastern white pines established continuously from 1917 until the mid-1950s. At that point, red maple, eastern white pine, and American holly became dominantly established.

The far site (CRT) yielded a total of 1460 stems per ha, with 7.72 total BA (m^2 per ha) (Table 5.8). Red maple showed greatest density, followed by Virginia pine, eastern white pine, black gum, and scarlet oak. Virginia pine showed greatest dominance, followed by scarlet oak, red maple, and eastern white pine. The species with highest importance value percentages were red maple, Virginia pine, eastern white pine, and scarlet oak, while the least important species were pignut hickory, chestnut oak, and sourwood (Table 5.8). American holly, mountain magnolia, shortleaf pine, white oak, red oak, black oak, and sassafras were not surveyed at this site. The dominant saplings observed were eastern white pine and red maple. Red maple,

Table 5.6 Measures of stand composition at CRX.

Species	Stems/ha	Relative Density	BA/ha	Relative Dominance	Importance Value (%)
red maple	120	9.92	0.41	4.49	7.20
American chestnut	5	0.41	0.00	0.03	0.22
pignut hickory	0	0.00	0.00	0.00	0.00
American holly	75	6.20	0.09	0.99	3.59
mountain magnolia	10	0.83	0.01	0.06	0.45
black gum	120	9.92	0.33	3.61	6.77
sourwood	40	3.31	0.17	1.81	2.56
shortleaf pine	10	0.83	0.38	4.13	2.48
pitch pine	75	6.20	1.52	16.54	11.37
eastern white pine	575	47.52	4.37	47.64	47.58
Virginia pine	60	4.96	0.63	6.90	5.93
white oak	10	0.83	0.14	1.54	1.19
scarlet oak	25	2.07	0.46	5.07	3.57
chestnut oak	20	1.65	0.23	2.51	2.08
red oak	5	0.41	0.27	2.98	1.70
black oak	5	0.41	0.00	0.04	0.23
sassafras	35	2.89	0.06	0.65	1.77
eastern hemlock	20	1.65	0.09	1.01	1.33
Total	1210	100.00	9.17	100.00	100.00

Table 5.7 Measures of stand composition among seedlings and saplings at CRX.

Species	Seedlings Number	Seedlings Stem/ha	Seedlings Relative Density	Saplings Number	Saplings Stem/ha	Saplings Relative Density
red maple	94	470	41.05	8	40	7.14
American holly	12	60	5.24	20	100	17.86
black gum	13	65	5.68	2	10	1.79
sourwood	13	65	5.68	16	80	14.29
eastern white pine	50	250	21.83	56	280	50.00
scarlet oak	24	120	10.48	0	0	0.00
chestnut oak	14	70	6.11	2	10	1.79
black oak	0	0	0.00	1	5	0.89
eastern hemlock	2	10	0.87	1	5	0.89
sassafras	1	5	0.44	3	15	2.68
mountain magnolia	6	30	2.62	3	15	2.68
Totals	229	1145	100.00	112	560	100.00

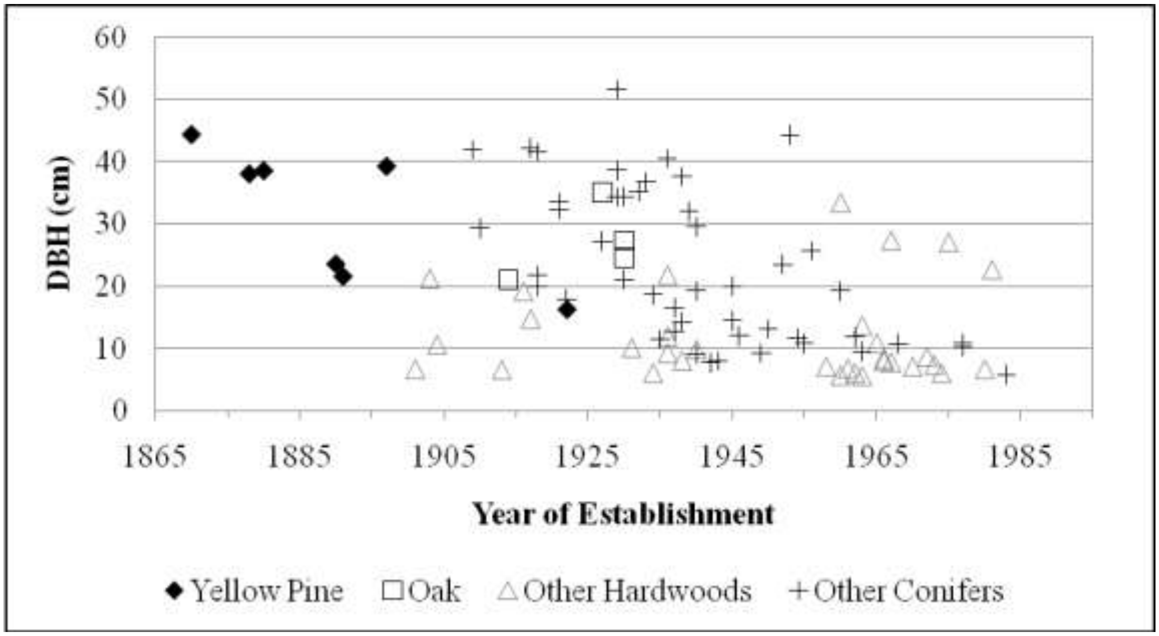

Figure 5.8 Age structure and size distributions at CRX.
*Other hardwoods = red maple, American holly, black gum, mountain magnolia, sassafras, and sourwood
**Other conifers = eastern white pine and eastern hemlock

eastern white pine, and scarlet oak were the dominant seedlings (Table 5.9). No yellow pine seedlings or saplings were recorded at this site.

A total of 131 trees were successfully aged at CRT, yielding a mean age of 60.35 years and mean size class of 16.2 cm DBH. Tree establishment showed an almost uniform distribution, with only a few outliers. The youngest species at this site were eastern white pine and eastern hemlock, while the oldest individuals were red maple, black gum, and pitch pine (Figure 5.9). The oldest pitch pine established in 1902. Red maple, black gum, and scarlet oak established throughout the 1920s, followed by a surge of Virginia pine from the 1930s through the 1950s. Eastern white pine and eastern hemlock established abundantly from 1972 until present.

5.7 Volumetric Water Content and Duff Depth

Mean VWC of the top 12 cm of soil ranged from 5.67% to 5.83% at the two study sites (Table 5.10). Variances between the sample sites were considered statistically equal. The mean percentage of VWC between CRT and CRX did not differ significantly. Mean duff depth ranged between 4 and 5.5 cm (Table 5.11).

Table 5.8 Measures of stand composition at CRT.

Species	Stems/ha	Relative Density	BA/ha	Relative Dominance	Importance Value (%)
red maple	485	33.22	1.30	16.84	25.03
American chestnut	0	0.00	0.00	0.00	0.00
pignut hickory	5	0.34	0.01	0.12	0.23
American holly	0	0.00	0.00	0.00	0.00
mountain magnolia	0	0.00	0.00	0.00	0.00
black gum	135	9.25	0.29	3.75	6.50
sourwood	45	3.08	0.17	2.21	2.65
shortleaf pine	0	0.00	0.00	0.00	0.00
pitch pine	25	1.71	0.41	5.25	3.48
eastern white pine	260	17.81	1.30	16.77	17.29
Virginia pine	280	19.18	2.29	29.59	24.39
white oak	0	0.00	0.00	0.00	0.00
scarlet oak	125	8.56	1.78	23.01	15.79
chestnut oak	20	1.37	0.08	1.09	1.23
red oak	0	0.00	0.00	0.00	0.00
black oak	0	0.00	0.00	0.00	0.00
sassafras	0	0.00	0.00	0.00	0.00
eastern hemlock	80	5.48	0.11	1.37	3.43
Totals	1460	100.00	7.72	100.00	100.00

Table 5.9 Measures of stand composition among seedlings and saplings at CRT.

	Seedlings			Saplings		
Species	**tallied**	**stem/ha**	**Relative Density**	**tallied**	**stem/ha**	**Relative Density**
red maple	94	470	41.05	8	40	7.14
American holly	12	60	5.24	20	100	17.86
black gum	13	65	5.68	2	10	1.79
sourwood	13	65	5.68	16	80	14.29
eastern white pine	50	250	21.83	56	280	50.00
scarlet oak	24	120	10.48	0	0	0.00
chestnut oak	14	70	6.11	2	10	1.79
black oak	0	0	0.00	1	5	0.89
eastern hemlock	2	10	0.87	1	5	0.89
sassafras	1	5	0.44	3	15	2.68
mountain magnolia	6	30	2.62	3	15	2.68
Totals	229	1145	100.00	112	560	100.00

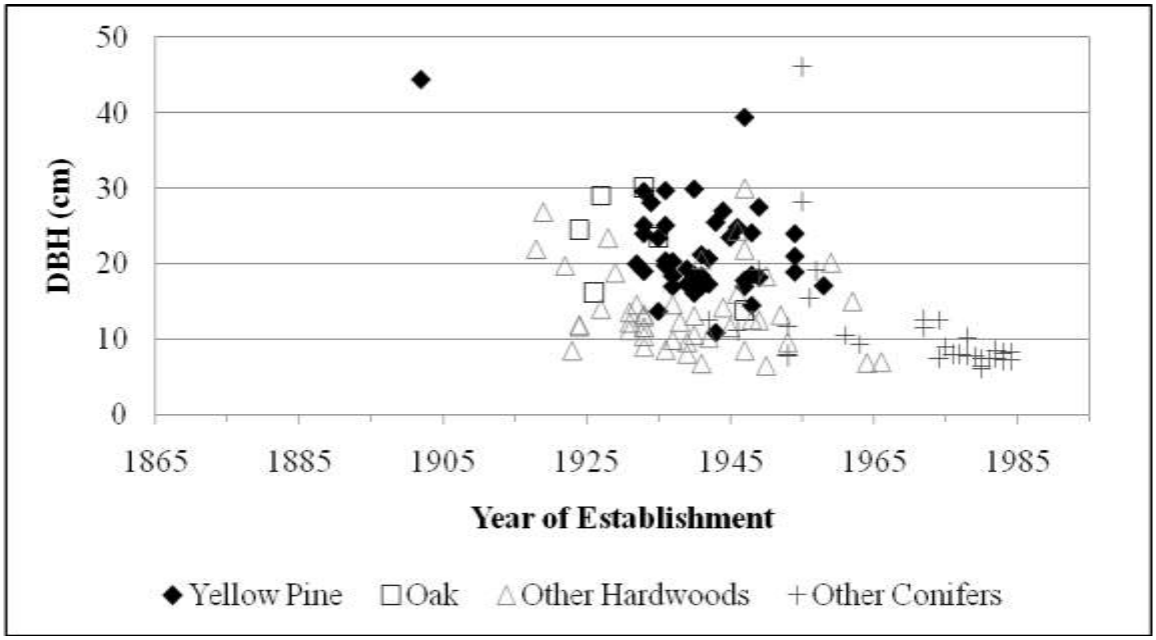

Figure 5.9 Age structure and size distributions at CRT.
*Other hardwoods = red maple, American holly, black gum, mountain magnolia, sassafras, and sourwood
**Other conifers = eastern white pine and eastern hemlock,

Table 5.10 Descriptive statistics of volumetric water content.

	Location	N	Mean	Std. Deviation	Std. Error Mean
Volumetric Water Content	**CRT**	30	5.67	1.56	0.29
	CRX	30	5.83	1.51	0.28

Table 5.11 Measures of duff depth (cm).

Location	CRXA	CRXB	CRTA	CRTB
10 T	1.9	3.5	5.5	3.0
B	3.5	3.5	9.0	5.0
20 T	2.5	2.5	6.1	4.0
B	3.8	6.3	4.6	6.2
30 T	3.0	6.0	4.4	8.4
B	2.8	3.0	6.5	7.4
40 T	4.5	6.0	6.4	5.5
B	6.4	6.0	3.2	5.4
50 T	5.5	3.5	4.0	5.4
B	3.2	4.0	5.6	4.0
Mean	3.71	4.43	5.53	5.43
Site Mean	**4.07**		**5.41**	

* T = measured at top of transect; B = measured at bottom of transect

** A= subplot A; B = subplot B

CHAPTER 6

DISCUSSION

My analyses of fire-scarred samples and forest surveys provided baseline information about fire regimes and the historic range of variation (HRV) near Cades Cove. The fire regimes between my two study sites were similar, but fires were not synchronous. I expected to find more synchronous fires between my study sites. Based on my original research objectives, I found that study areas close in proximity, separated by distinct topography and possible differences in land use, could have completely different fire histories, species compositions, and trends of establishment. This allowed me to draw better inferences on the true characteristics of fire regimes in this part of the southern Appalachian Mountains. The results from this study suggest that historic fire regimes in the western part of GSMNP were characterized by low-severity surface fires that were distinct by topographic boundaries. The differences between study sites further suggest topographic boundaries do indeed affect various components of fire regimes.

6.1 Comparisons between Study Sites

6.1.1 Fire History

One of the most important aspects of this study was verification of statistically significant differences between mean fire intervals of topographically separated study sites. My results show that historic fire regimes near Cades Cove were characterized by low-severity surface fires, but were distinctly different in two areas separated by approximately 5 km. Only five fire events occurred synchronously between study sites, those in 1777, 1847, 1902, 1906, and 1916.

Although widespread fires were uncommon, they were not absent. Years in which synchronous fires occurred show that widespread fire events were possible, but unlikely because of the more frequent fires that consumed most available fuels and because of the topographic barriers that limited the extent of fire spread.

Compared to site nearest Cades Cove (CRX), the distant site (CRT) had more frequent fires. Mean and median fire intervals at CRT were almost half that of CRX, and the Weibull modal and median intervals were 2 to 2.5 years less at CRT. At CRT, I also found some 1-year intervals between fires from 1840 to 1870. Another important difference between the study sites is the stark contrast in maximum hazard intervals. The maximum hazard interval delimits the critical threshold for fire based on fire-free intervals. This roughly 18 year difference between sites likely represents the different intensities of land use and suggests that CRT was more heavily used than CRX. This suggests that greater population pressures or increased effects of land use influenced the amount of fine fuels and logging slash. Therefore, fuels may have been in greater abundance after heavier disturbance. Consequently, this would subject the site to more frequent fires. Pyle (1988) also reported that most areas experienced fires after heavy disturbance, most likely after mechanical logging operations. Furthermore, Cooper Road Trail likely served as a logging access road, as it was the most convenient route into Cades Cove at that time. However, fewer fire-scarred samples were found at CRX, possibly due to the closer proximity of Cades Cove and more active fire suppression efforts to protect nearby homes or structures.

Approximately 90% of all fires observed occurred in the dormant/early seasons. This indicates fire seasonality in GSMNP was mostly influenced by natural ignitions because this period is when most fires have occurred without human influence. However, humans may also have influenced fire activity after Euro-American settlement of Cades Cove. The presence of humans in GSMNP has been documented as far back as ca. 10,000 years before present, or to the Early Archaic period (8,000–6,000 BC) (Bass 1977). Therefore, anthropogenic burning practices can be considered part of the natural fire regime. However, naturally ignited wildfires are more likely to occur in the fall and spring, when fuels are generally drier and both frontal and convective thunderstorms dominate the southern Appalachians. Furthermore, this would explain why I found most fire scars in the generally accepted fire season. Naturally ignited fires are now used for ecological benefit if no threat exists to cultural or natural resources (NPS 2008).

Overall, my study suggests that fires were more frequent prior to establishment of GSMNP, as often as one fire every 3 to 6 years. The maximum hazard interval also provided further evidence that when fire-free intervals exceed the critical threshold, it is highly probable that the observed forests will experience wildfire. This information, in turn, should help forest management officials use fire to maintain and create conditions that were present in the historic fire regime. Fire regime condition classes are assigned to landscapes to describe departure from natural and historic conditions of the fire regime, without modern human influence (FRCC 2008). The fire regime condition class descriptions in GSMNP were historically categorized as Class 1: 0–35 year fire frequency and low to mixed severity. Now, current conditions are far different than historic reference conditions. Mixed oak-pine forests should now likely be categorized as Class 3: 35–100 year fire frequency and mixed severity (FRCC 2008).

6.1.2 Stand Dynamics

Both study sites varied considerably with age, size, and composition of trees. At CRT, pitch pine and Virginia pine established from 1870 until 1897, with only one Virginia pine having established later around 1922. Only one pitch pine core was successfully aged, indicating the tree established in 1902, a date that aligns with a fire in 1902 recorded at both sites. A coinciding fire event most likely represents the last time in which pitch pines successfully established at both sites. Scarlet oak and Virginia pine continued establishing until the 1950s, but ceased establishing after the last recorded fire at CRT in 1945. Virginia pine, a disturbance species often referred to as "old-field" or scrub pine, was far more abundant, suggesting that this site experienced more intense disturbance in the 20th century. Thereafter, establishment of eastern white pine and red maple increased considerably. Black gum and sourwood also established consistently throughout the 20th century.

Unlike CRT, which exhibited cohort establishment of Virginia pine, the establishment patterns at CRX were far more consistent among various species. The oldest individual at this site was a white oak that established around 1813. This tree may have served as a "witness tree" or boundary marker (Orwig and Abrams 1994). A few oaks established around 1930, followed by an enormous surge of eastern white pines. Red maple established throughout the 1900s and increased in abundance in 1955. This study site probably experienced more human-related impacts because of its proximity to Cades Cove, thus explaining less frequent fires because of more active fire suppression efforts. The basal area of trees was greater at CRX, but tree density was lower. This site had a more open understory. It most likely represents historic conditions of less disturbed forests in GSMNP.

Although this study did not directly quantify other forms of disturbance, they should be noted. In the early 20th century, the widespread mortality of the American chestnut reduced forest canopies by approximately 10–15%, resulting in vast successional changes throughout the southeastern U.S. (Anagnostakis 1987, Duffy and Meier 1992). The effects in the southern

Appalachian Mountains have been extensively studied (Woods and Shanks 1959, Stephenson 1986), but the full impact on succession still remains a question. Based on basal stem sprouts found within my study plots, it is likely that chestnut will continue to sprout, but not become a dominant canopy tree because the blight causes mortality in saplings. These trees played a prominent role in the historic composition of mixed oak-pine forests, and their decline should also be considered when discussing possible reasons for widespread changes in succession. However, the role of American chestnut in historic fire regimes of the southern Appalachian Mountains may never be fully understood.

The effects of southern pine beetle infestation were highly visible within my study sites. Fire and pine beetle mortality are obviously related through fuel loading and subsequent fire, as yellow pines are dependent on fire disturbance (Schowalter *et al.* 1981, Richardson 1998). In general, both study sites lacked yellow pine regeneration and showed heavy decline from pine beetle mortality. The apparent lack of recent fire may also be responsible for such high mortality due to limited amounts of resin production. Resin production in yellow pines is a natural defense and increases after exposure to fire (Fritts 1976, Knebel and Wentworth 2007). Fire suppression may therefore be responsible for increased susceptibility of pine forests to southern pine beetle infestation.

6.1.3 Land-Use History

My study shows that the extent, type, and intensity of human-related disturbances likely affected the fire regimes, stand composition, and structure of both sites differently, and indicated that CRT may have been more heavily disturbed despite the distance from Cades Cove and concentrated settlement. CRX had fewer fires and greater species diversity. To better understand these differences, I compared the study sites based on historic documentation of land ownership and proximity to concentrated settlement. Major differences arose between the study sites.

In general, CRT showed signs of heavier disturbance. Overall, this site had less species diversity among seedlings, saplings, and trees > 5 cm DBH. The stand consisted of mostly young trees with less basal area. Virginia pine was more dominantly established because it favors open conditions created after disturbance, which most likely indicates more intense land-use or grazing pressures. CRX showed greater diversity among canopy species. In contrast, American chestnut, American holly, mountain magnolia, shortleaf pine, white oak, red oak, black oak, and sassafras were completely absent from CRT.

Fire chronologies showed variation between study sites, most likely due to the extent and intensity of disturbance, and topographic separation. CRT showed a more frequent fire return interval of 3.4 years, whereas the fire return interval at the near site was 6.2 years. The differences in upper exceedance intervals also help explain the probability of wildfire in these forests. CRX had an upper exceedance interval approximately 5 years longer than CRT, further suggesting different degrees of disturbance. However, CRX, which appeared to be far less disturbed, had an upper exceedance interval of 11 years, which is an unusually long fire-free period. My research suggests that sites with greater pressures had been burned more frequently, as this was the most common and affordable method of forest maintenance at that time. Settlers relied on this practice to increase conditions favorable to livestock and wild game.

The extent to which Native Americans burned the landscape still remains a prominent question among fire ecologists and fire managers (Pyne 1982, Jurgelski 2008). Native and Euro-Americans burned the forests in the fall and early spring for many reasons: (1) to gather chestnuts, (2) to increase abundance of grasses, (3) to improve berry yield, (4) to improve wild game habitat, and (5) to hunt wild game (Harmon 1982, Pyle 1988). Religious and cultural reverence for fire also shows its place among Native American tribes. Burning the landscape may have been practiced ritually in the fall to indicate the change in season and shift in behavior for the colder months ahead (Fowler and Konopik 2007).

Early Euro-American settlers likely adopted burning practices from Native Americans (Pyne 1982). Cades Cove is an area with a history of early relations between Native Americans and Euro-American settlers. Initial settlement efforts by the Oliver family would have never succeeded without the help of the Native Americans who occupied the cove at the time of their arrival. The Native Americans provided sustenance to the starving settlers when they arrived in the fall of 1818 without ample time to begin agriculture (Dunn 1988). These early interactions suggest that settlers were influenced by Native American practices to increase the chances of survival in an undeveloped landscape.

Adjacent valley bottoms were used for homesteads and row-crop agriculture, while ridges or upper limits of watersheds were logged or grazed (Pyle 1988). This process usually involved fire in some manner, whether by felling single trees or burning entire portions of the landscape. This is supported by the visible increase of fires after Euro-American settlement in Cades Cove. Euro-Americans indeed modified this practice to create vegetation structure favorable to livestock (Pyle 1988). Settlers also harvested pitch pines for their resin to create turpentine and used various oaks for tanbark, which was used to treat and stain leather. The extents of these practices are unknown, but only a small percentage of trees in GSMNP were used for these purposes (Pyle 1988). All these reasons help explain why a discrepancy is found in fire histories between areas separated by complex topography. Furthermore, it explains why I found only five synchronous fire events between my study sites, where the most widespread fires occurred in the early 20th century. The fires may have been the result of fuel loading from logging practices. Although no direct evidence shows mechanized logging occurred directly on my study sites, the Morgan-Butler Timber Company did own most of the property at CRT.

6.2 The Influences of Topography and Fire

Most importantly, my study suggests that topographic boundaries may play a primary role in determining the size, type, and severity of wildfires in mixed oak-pine forests of the Appalachian Mountains. Although many factors contribute to fire behavior, surface fires in the southern Appalachian Mountains are largely influenced by topographic boundaries, limiting the extent to which they spread. Cohen *et al.* (2007) documented wildfires ignited by lightning in the Park. These fires were not suppressed and exhibited variable behavior for several reasons, including fuel type, fuel moisture, stand density, and topographic barriers. These factors support the abundance of asyncronous fires I documented at the two sites, and the work of Cohen *et al.* supports the argument that topographic boundaries are a major influence on fire regimes in GSMNP. This explains the asynchronous fires at the two sites, because most fires were contained by topographic boundaries and most certainly were uninhibited before governmental regulation, as efforts in fire suppression were enforced after creation of the Park.

Frequent burns likely facilitated the growth of herbs and grasses, recycled available nutrients, and reduced competition, allowing optimal conditions to sustain oak and pine species in the canopy and understory. Harrod *et al.* (2000) found that richness and diversity among herbaceous species increased 8 to 10 years after a burn on permanent plots, when compared to unburned plots. Forests with oak and pine as the dominant species would, in turn, create microsite conditions that favored frequent surface fires. Pine needles provided fine fuels, and an open canopy would allow more penetration of sunlight, drying the ground layer and increasing susceptibility to fire. My study also provides evidence that forest stands were historically dominated by large oak and yellow pine species. These stands were characterized by frequent, low-severity surface fires that supported a more diverse forest community, depending on the type and intensity of land use. However, CRT showed more frequent fires, but less diversity among canopy trees. This suggests that more frequent fires could actually inhibit tree diversity, although the lack of diversity may also be attributed to selective logging and removal of trees to create suitable grazing conditions. Furthermore, fire generally increases regeneration among oak and pine species, while maintaining a more diverse understory with less susceptibility to invasive species (Harmon 1984).

6.3 The Spatial and Temporal Characteristics of Fire Regimes near Cades Cove

Spatial analysis between the separate fire chronologies showed that fire activity was unrelated between my study sites except for five synchronous fire events. This also explains why I found such disparity between the fire and vegetation properties of the two study sites. Temporal analysis of the combined fire chronologies yielded interesting differences between the pre-settlement (1740–1818) and post-settlement periods (1819–1934). The results showed statistically significant differences between mean fire intervals in the pre-settlement and post-settlement periods. The mean fire interval in the pre-settlement period was over twice as long as the post-settlement period. Differences in variance and distributions also show that fires in the pre-settlement period were less frequent when compared with fires during the post-settlement period. Population pressures could account for increased fire frequency throughout that time and region. Although sample depth of the control period was less than half of that for the test period, it does provide useful information about fire intervals dominantly influenced by climate or Native American burning practices in the pre-settlement period. Samples dated to the pre-settlement period are expected to be more representative of the natural conditions of the fire regime, before heavy Euro-American impact.

Superposed epoch analysis showed significant differences between climate and fire events in the pre-settlement and post-settlement periods. In the pre-settlement period, year 3 before the fire events showed a significant relationship with climate at the lower 95% confidence interval, suggesting that fire frequency was influenced by limiting climatic conditions, most likely drought, three years prior to fires. Although not statistically significant, slightly below average climate conditions existed two years before the fire event, followed by average climate the year before and during the fire event. In the post-settlement period, the year before the fire event showed a significant relationship at the lower 95% confidence interval. This most likely indicates fire activity influenced by yearly anthropogenic burning practices, or climate conditions that were favorable for annual burning. Average climate occurred throughout the remainder of the event window. When analyzing the entire period of fire events, year 3 before the fire year comes close to 95% significance, but does not exceed the confidence interval. Although not statistically significant, it is important to note that climate was limiting 1 to 3 years before the fire event for the entire period of reliability, allowing better inference of the regional relationship between fire and climate. Overall, the below average conditions suggest that drought preconditioned fuels up to three years prior to fire events. These results help further explain the natural fire regime in the western portion of GSMNP.

6.4 Changes in Species Composition due to Fire Suppression

Forest surveys at both sites indicated succession to shade-tolerant species, such as eastern white pine, red maple, and eastern hemlock. These species should be restricted to more mesic sites or coves that support subsequent regeneration of similar species. Evidence found at my study sites suggest that historic oak-pine forests currently are not supporting establishment of yellow pine species because of increased stand density and dominance of shade-tolerant species. Increased duff layers caused by fire suppression also seem to have restricted yellow pine and oak seedlings, allowing optimal conditions for establishment of other hardwoods and conifers. Yellow pine prefer open seedbed habitat and are most likely to regenerate when seedbed habitat has experienced surface fire and receives ample sunlight. Canopy openings would have increased from widespread chestnut mortality and mortality caused by pine beetles. Fire suppression would have increased stand density in both the canopy and understory (Harrod *et al.* 2000, Land and Rieske 2006). Increased stand density, decreased dominance of yellow pine, and lack of successful pine and oak recruitment are clearly outcomes of fire exclusion. The combination of these factors accounts for the change in composition of the forest, from historic mixed oak-pine communities to shade-tolerant, fire-intolerant species. Fire suppression likely has decreased the natural tolerance of yellow pines to pine beetle infestation. Frequent fire would have allowed more resin production, serving as a natural defense to bark beetle infestation and other insects and pathogens (Knebel and Wentworth 2007).

6.5 Future Trends of Forests along the Cooper Road Trail

Surveys of mature trees, seedlings, and saplings from both of my study sites strongly suggest that oak-pine forests near Cades Cove are experiencing mesophication and succession to fire-intolerant hardwoods. Mesophication is a term used to describe the transition of a formerly xeric environment to a moist, mesic environment (Nowacki and Abrams 2008). Both sites showed increased abundance of eastern white pine, eastern hemlock, and red maple. Half of the abundance of saplings was composed of eastern white pine. The most notable lack of species in the seedling/sapling tallies are yellow pines and oak. Although few scarlet and chestnut oaks were observed, black gum and sassafras are, and will likely remain, a prominent mid-story species. The abundance of mountain laurel was not quantified in this study, though its abundance has increased due to canopy gaps caused by pine beetle infestation and fire exclusion (Monk *et al*. 1985, Lafon *et al.* 2007). If management practices and pests remain the same, eastern white pine and red maple will dominate the future canopy of these forests. Fire-tolerant and fire-adapted yellow pines and oaks were previously more abundant in the southern Appalachian Mountains due to more frequent fires. Without fire, these forests will continue succession to hardwood dominance, while yellow pines will continue to decline.

6.6 Comparisons to Previous Research

Harmon (1982) found the mean fire interval for the westernmost portion of GSMNP to be 12.7 years. His study had several conclusions relevant to the findings in this study. First, he stated that his study probably underestimated the actual number of fires. In some cases, low-intensity surface fires may not have caused basal wounds, limiting the actual number of fires recorded by the tree. Second, he noted that 96% of the pine forests he sampled had burned between 1929 and 1940. Finally, he concluded by stating that more information prior to 1856 was needed to accurately assess the historic fire regime.

My study provides fire interval information as far back as 1720. Tree-ring measurements were conclusively crossdated using statistical techniques, providing finer resolution of fire events in the tree-ring record than was possible in Harmon's study. We also were able to use much remnant wood that could be statistically crossdated, whereas Harmon produced his study before statistical crossdating was widely accepted among fire ecologists. His study used only samples extracted from living trees and the tree rings were not crossdated. The data obtained from my study were also modeled with a statistical distribution, allowing additional inferences on the characteristics of the historical range of variation in GSMNP.

Several reasons exist for discrepancies in fire frequency between the two studies, including field and laboratory methods, elevation, topography, vegetation structure, sample area, sample methodology, and the scale of anthropogenic influence. I was allowed to remove samples using a chain saw, which tremendously improved sample quality, sample depth, and data quality. Chain saws were much more efficient than manually hand sawing fire-scarred samples. We also chose yellow pine species to maximize the potential for a robust fire history, rather than using hardwoods, which usually decay much faster. My study focused more on the spatial and temporal variation of fire regimes in mixed oak-pine forests, while Harmon's study included fires found over a much broader spatial area, including Table Mountain pine stands, which occupy higher, more xeric ridges. While Harmon's study addressed fire history for the entire westernmost portion of GSMNP, my study focused on a more localized area.

Guyette and Spetich (2003) found similar mean fire intervals for oak-pine forests in the Boston Mountains of Arkansas. Their study analyzed four periods of fire history during human settlement: the Native American (1680–1820), Euro-American (1821–1880), Regional development (1881–1920), and Fire suppression (1920–2000). They found mean fire intervals during the Native American period ranging from 4.5 to 16 years, which coincides with the less frequent mean fire interval I found during the pre-settlement period in GSMNP. During the Euro-American and Regional development periods, they found mean fire intervals that ranged between 1 and 5 years. This also coincides with the more frequent fires I found during the post-settlement period. Although I was unable to reliably analyze fire history from 1920 to present, they found mean fire intervals in the fire suppression period ranging from 60 to 80 years. They also found similar fire seasonality, with most fires occurring in the dormant and early seasons. When comparing the relationship between mean fire intervals and population density, they found a positive association during the Native and Euro-Americans periods, and an inverse association during the Regional development period. These results show that as population density increased during the Native and Euro-American periods, mean fire intervals also increased. This finding is similar to the increase in mean fire intervals I found during the post-settlement period, coinciding with an increased population in Cades Cove between 1850 and 1880. Likewise, the inverse relationship found in Arkansas in the Regional development period shows that population density increased and mean fire intervals decreased. This was most likely due to fire suppression.

Although studies in soil charcoal provide no annually-resolved data about fire frequency, they are quite relevant when analyzing the historic fire regime. The relative abundance of macroscopic charcoal found at various depths within a soil core may reveal changes in fire activity. A study conducted by Welch (1999) examined macroscopic soil charcoal in yellow pine forests throughout the southeastern United States. She found macroscopic charcoal in each soil core obtained in Cherokee National Forest, with the greatest amounts at depths of 10–20 cm and 60–70 cm. The greatest abundance was found in the upper depths, which most likely indicated the widespread fires that were documented after logging operations. However, no consistencies were found between amounts of charcoal at different depths. Although charcoal can be deposited by overland flow, she found that the presence or absence of macroscopic charcoal did not vary according to slope position.

Hass (2008) conducted a study which analyzed macroscopic soil charcoal at Gum Swamp in the Cades Cove area of GSMNP. She found an increase in charcoal abundance between the early 1800s and 1950s, which was most likely related to agricultural fires. A subsequent decline in charcoal concentrations after 1950 was likely associated with fire suppression. Her study corroborates the history of fire I developed using tree-ring data. The increase of charcoal concentrations from the early 1800s is consistent with the increase of fires I found in the post-settlement period, as well as with the subsequent decline following the creation of the Park in 1934.

Underwood (2010, unpublished data) is currently conducting fire history research in mixed oak-pine forests of GSMNP using macroscopic soil charcoal. His study aims to extend the fire history of these forests by identifying trends in fire history and species composition that predate the tree-ring record. Taxonomic classification and AMS radiocarbon dating of macroscopic soil charcoal fragments revealed that over 75% of 500 individual fragments were from southern yellow pine species. The oldest fragment came from a southern yellow pine that burned ca. 2,800 years ago. This research further complements the fire history developed from tree-ring data, and will also help determine the transition of tree species prior to current forest inventories. Furthermore, this study provides crucial evidence of fire in GSMNP that predates the tree-ring record, which most likely relates to fire regimes dominated by lightning ignitions.

6.7 Implications for Management

Frequent prescribed burns would be very beneficial for this area of GSMNP, while further exclusion of fire will only increase the current successional trend to shade-tolerant and fire- intolerant species. Prescribed burns conducted in April of 2007 used Cooper Road Trail as a fire break. Subsequent regeneration of both yellow pine and oak were noted after the burn (Rob Klein, personal communication). Similar regeneration was recorded in permanent plots established on Polecat Ridge in western GSMNP after fires in 1976 and 1977 (Harrod *et al.* 1999; 2000), and was also noted in another study conducted by Swift *et al.* (1993).

To rehabilitate these ecosystems, burns should be conducted approximately every 3 to 6 years. Seedbed habitat would return to conditions that favor oak and pine regeneration, while frequent burns might also help increase resistance to pests and pathogens (Knebel and Wentworth 2007). The greatest concern for fire management personnel is the large amount of ladder fuels created by recent southern pine beetle infestations between 1999 and 2007, which destroyed over 400,000 ha of yellow pine in southeastern forests (USFS 2008). The U.S. Forest Service estimates that over 23 million ha of southeastern forests are at risk of southern pine beetle infestation (USFS 2008). Coupled with changes in fire frequency, this departure from reference conditions presents an enormous wildland fire hazard.

Current efforts are underway in GSMNP to rehabilitate ecosystems using fire (NPCA 2008). This study provides fire managers with useful information about fire regimes during both the pre-settlement and post-settlement periods, as well as possible explanations about the effects of land-use on fire regimes. The new information from this study suggests the possibility of increasing the frequency of prescribed burns, and further suggests categorizing forests based on land-use history together with disturbance intensity. Although this study does not focus on the entire western portion of GSMNP, information can be applied to include other similar sites that require prescribed burns to rehabilitate historic conditions. Furthermore, this study also differentiates fire regimes between periods of settlement. Although fires were less frequent prior to the arrival of Euro-Americans, the data can be used as a general measure of how often forests were burning without pressures from modern settlement, or more importantly, how often naturally ignited fires were occurring.

Alternatively, this study suggests that oak-pine forests have already shifted to fire-intolerant species, providing limited opportunity to rehabilitate the historic ecosystem. The apparent lack of newly established and mature yellow pine and oak suggests that regeneration of favored species may be impossible. New measures should be taken to re-classify forests that may have been historically dominated by these species, but now consist of shade-tolerant, fire-intolerant species. More resources should be focused on maintaining communities that are still dominated by oaks and mature yellow pines. This approach would help restore historic trends of regeneration, and increase the probability of yellow pine establishment.

CHAPTER 7

CONCLUSIONS AND FUTURE RESEARCH

The purpose of this study was to examine possible differences in fire regimes and vegetation composition at two sites along the Cooper Road Trail in GSMNP. Few studies exist that investigate fire regimes in the southern Appalachian Mountains. I directly identified differences in fire regimes, based mostly on topographic boundaries. I also found differences in fire regimes between periods of settlement, which have been documented by other researchers in other locations of the southeastern U.S. Furthermore, decades of fire suppression have changed the successional pattern of forests historically dominated by yellow pines and oaks. Currently, these forests are no longer supporting establishment of the vegetation that existed prior to Euro-American settlement, but instead are succeeding to shade-tolerant and fire-intolerant species such as eastern white pine and red maple. I close this thesis with several major conclusions derived from my original research questions and provide future recommendations and avenues for research in fire history in the southern Appalachian Mountains.

7.1 Major Conclusions

1. Tree-ring samples collected along the Cooper Road Trail provided crucial information about fire regimes in GSMNP.

Tree-ring samples collected from fire-scarred yellow pines along the Cooper Road Trail in GSMNP provided a history of fire for approximately 300 years. I accomplished this using the technique of crossdating, which ensured resolute placement of calendar years with the associated tree rings. Variable ring widths and high interseries correlations allowed me to precisely date fire scars in both living and dead yellow pines. Most scars were easily identified and properly dated. However, I was unable to crossdate some samples due to ring distortion or extensive decay. The yellow pine forests of GSMNP provide further potential for analyzing fire history from tree rings, as well as the associated climatic factors. Samples obtained for age structure also provided information about stand dynamics and differences in establishment between the two sites.

2. Fires burned more frequently in my study sites than previously reported for the westernmost portion of GSMNP.

All descriptive statistics calculated from the fire chronologies were lower than previously reported by Harmon (1982). The mean and median fire intervals from both sites ranged from 3 to 6 years, while the Weibull median and modal intervals ranged from 1 to 6 years. Prior to the creation of GSMNP, fires near Cades Cove were burning at least this often. The upper exceedance intervals and maximum hazard intervals further provided information about the future potential for wildfire in western GSMNP. A significantly long fire-free period ranges from 6 to 10 years, depending on the severity of fire disturbance. The maximum hazard intervals also suggested that less disturbed sites are at less risk, while more disturbed sites are at greater risk when fire return intervals exceed 5 years, approximately.

The frequent fires I found throughout the period of reliability indicate a fire regime dominated by low-severity fires. These fires consumed most fuels, limiting the possibility for higher severity fires. However, widespread fires were possible. Two fires were recorded in trees at both sites in 1902 and in 1916, showing that fires could spread over considerably greater distances, despite the presence of topographic barriers between the two sites. Therefore, the historic fire regime in this area of GSMNP included low and possibly moderate severity fires that were not stand replacing.

3. Fire regimes at the two sites were significantly different.

The fire regimes at the two study sites were different, likely caused by distinct topography and possible differences in land use. CRX, which was closer in proximity to Cades Cove, generally appeared less disturbed. This site showed less frequent fires, older trees, and greater tree species diversity. CRT proved to be more disturbed: it had experienced more frequent fires, had younger trees, and possibly had a greater intensity of land use. This was most likely caused by selective logging and grazing from adjacent homesteads, or logging efforts from the Morgan Butler Timber Company. Because I found only five fires that were synchronous between the two sites, I infer that topographic barriers are the primary reason that can lead to distinct fire regimes in GSMNP.

4. In the historic fire regime of western GSMNP, most fires occurred in the dormant period and in the early portions of the growing season.

Historically, most fires near Cades Cove burned during the dormant and early seasons. I found little variation in fire seasonality, with few fires in the middle or late seasons. Fires during the growing season were rare due to increased understory plant cover and relative humidity. These fires were most likely caused by lightning strikes associated with summer thunderstorms. However, conditions in the fall and winter were more conducive to surface fires because leaf litter is more readily flammable than living understory vegetation.

5. Fire regimes showed significant differences in frequency between the pre-settlement and post-settlement periods.

A definitive history of Euro-American settlement provided ample opportunity to differentiate fire frequency in the context of human intervention. Fire regimes at my two study sites proved significantly different between the pre-settlement and post-settlement periods. Temporal analysis showed that the mean fire interval was approximately 5 years before Euro-American settlement and approximately 2.5 years after settlement. The pre-settlement period is assumed to represent more “natural” conditions of the fire regime due to less anthropogenic influence, although Native American burning remains a possibility. Anthropogenic burning practices, however, are considered part of the historic fire regime, and these practices were generally unmodified by early settlers until the 20th century. The change in fire frequencies between the pre-settlement and post-settlement periods suggests that settlement affected the frequency of fire.

6. Superposed epoch analysis yielded important evidence that climate may have influenced fire regimes differently between the pre-settlement and post-settlement periods, likely indicating a shift in the disturbance regime.

In the pre-settlement period, superposed epoch analysis showed that drought was significantly prevalent three years before fires and likely preconditioned forests leading up to the fire year. In contrast, drought during the post-settlement period was prevalent one year before a fire year. Several reasons can be offered for the disparity in climate influence between the two periods. It is probable that this discrepancy was caused by post-settlement augmentation of the disturbance regime, most likely from the introduction of livestock grazing or anthropogenic ignition of yearly fires. In addition, superposed epoch analysis also evaluated conditions after fires to describe prolonged periods of climate that may influence fire activity. Climate remained average after fire events in both periods, showing no indication that anthropogenic burning altered forest conditions after fire disturbance.

7. Vegetation composition and age structure were different between sites of different land-use histories.

Vegetation composition and age structure varied considerably between my study sites. CRX consisted of older trees with greater basal area and greater tree species diversity. This site probably experienced some human-related impacts, but to a lesser extent than CRT. CRT generally had younger trees, with less diversity, but greater stand density. These conditions indicate a disturbed environment. The dominance of Virginia pine at this site further indicates a greater intensity of anthropogenic disturbance, suggesting that CRT may have been partially cleared to produce conditions more favorable to livestock, thus explaining the greater abundance of Virginia (or "old-field") pine.

8. The current status of fire regimes in western GSMNP shows significant departure from the historical range of variation found in this study.

An examination of several components of the fire regimes near Cades Cove shows that current conditions are very different from those before the creation of GSMNP. I found fire intervals ranging from 3 to 6 years throughout the entire period of reliability (1740–1934). Although there were some differences between the periods of settlement, 3 to 6 years should be used as a general measure for the historic fire frequency in mixed oak-pine forests. Now, after many years of fire suppression, the fire regimes near Cades Cove show significant departure from natural conditions. Fires have become less common after Park establishment. Excluding fire from this natural fire-prone ecosystem caused changes in fire frequency, fine fuels, and vegetation composition. Under current conditions, these forests will likely experience more severe but less frequent wildfires, unless the natural fire regime is somehow partially re-introduced.

9. ***Mixed oak-pine forests in GSMNP are succeeding to shade-tolerant and fire-intolerant species, and are failing to regenerate under current conditions.***

Mixed oak-pine communities are succeeding to a canopy dominated by shade-tolerant, fire-sensitive species such as eastern white pine and red maple. Furthermore, no yellow pine and few oaks were observed in the seedling/sapling surveys. This provides further evidence that these species are in decline. The future canopy of mixed oak-pine forests in western GSMNP will be dominated by eastern white pine and red maple. Without fire disturbance, yellow pine communities will cease to regenerate, as will oak species that prefer a fire-maintained habitat. To rehabilitate the appropriate establishment trends of oak-pine forests, I recommend that fires should be prescribed at a minimum of once every 6 years, with a range of fire-free years from 3 to 9 years.

7.2 Future Research

Future research that could potentially build upon this study could include analyses of macroscopic soil charcoal, seedling/sapling response to surface fires, and the effects of high-severity crown fires on succession in mixed oak-pine forests. Studies that use macroscopic soil charcoal will likely reveal the long-term paleoecological trends of fire and species composition in these forests. Together, both tree-ring and soil charcoal data provide a more comprehensive definition of the historic range of variation in GSMNP. Furthermore, the higher elevations of GSMNP contain large areas of old-growth spruce and fir that remain untouched from logging efforts of the early 20th century. Fire histories developed in these areas may also help differentiate fire frequency between lower elevation sites from higher elevation sites, which most likely experience mixed to high-severity fires.

Few studies exist that investigate interactions between fire and climate in the eastern United States. Oceanic teleconnections may be a primary influence on fire regimes of the southern Appalachian Mountains. It is possible that oscillations in sea surface temperature, such as the Atlantic Multidecadal Oscillation (AMO) and the North Atlantic Oscillation (NAO), play a key role in the fluctuation of fire regimes in GSMNP (Cook *et al*. 1998, Gray *et al*. 2004). It is possible to model the influence of AMO and NAO on fire regimes using tree-ring analysis. This may provide useful information about the multidecadal variation of climate and the subsequent influence on wildfires in GSMNP. Another topic that must be addressed is the augmentation of fire regimes in the context of climate change. Little is known of the changes expected in fire regimes in GSMNP in response to global warming.

Many living fire-scarred yellow pines can still be found in portions of western GSMNP. Greater sample depth would vastly improve this study. With more time and resources, I expect that the fire history of the Cades Cove area could be extended back to the 1600s, providing additional insights of conditions in the pre-settlement period. Greater sample depth would also increase the capability of superposed epoch analysis when investigating fire-climate relationships in GSMNP. It is possible to describe longer-term (> 10 years) ecological trends using SEA, although my study only addressed a 10-year window superposed with the fire event.

Most importantly, the knowledge and attitudes regarding fire must be congruent among government agencies and the general public. The only way to truly understand the complex interactions between fire, humans, and the environment is through awareness and education of the natural influence of fire in the southern Appalachian Mountains. Within the last two decades, research has shown the significance of fire in southern Appalachian ecosystems and the subsequent response and increased risk of high severity fire when fire is excluded from these forests. This information reveals the urgent need for rehabilitation of mixed oak-pine forests through the reintroduction of historic fire frequencies. However, continuous development of the wildland-urban interface further restricts the potential for rehabilitation. Therefore, more restrictions should be applied to residential development in the wildland-urban interface. Development in fire-prone areas only increases the probability of property damage, limits the extent to which fires can be prescribed, and causes further departure from the historic fire regime, resulting in further decline of preferred, fire-adapted species. Overall, my research contributes to a growing body of knowledge that describes the vital need for public education in fire ecology. It is imperative that the results of studies in fire ecology are made known among government agencies and the general public. This may be the only way to truly achieve the desired ecological conditions in the southern Appalachian Mountains.

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APPENDICES

APPENDIX A1. Scientific species name, common species name, and ITRDB species code.

Scientific Name	**Common Name**	**ITRDB* Species Code**
Acer rubrum L.	red maple	ACRU
Sassafras albinum (Nutt.) Nees	sassafras	SAAL
Carya glabra (Mill.) Sweet	pignut hickory	CAGL
Castanea dentata (Marsh.) Borkh.	American chestnut	CADE
Ilex opaca Ait.	American holly	ILOP
Magnolia fraseri Walt.	mountain magnolia	MAFR
Nyssa sylvatica Marsh.	black gum	NSSY
Oxydendrum arboreum (L.) DC	sourwood	OXAR
Pinus echinata Mill.	shortleaf pine	PIEC
Pinus pungens Lamb.	Table Mountain pine	PIPU
Pinus rigida Mill.	pitch pine	PIRI
Pinus strobus L.	eastern white pine	PIST
Pinus virginiana Mill.	Virginia pine	PIVI
Quercus alba L.	white oak	QUAL
Quercus coccinea Muenchh.	scarlet oak	QUCO
Quercus montana L.	chestnut oak	QUMO
Quercus rubra L.	red oak	QURU
Quercus velutina Lam.	black oak	QUVE
Tsuga canadensis (L.) Carr.	eastern hemlock	TSCA

* International Tree-Ring Data Bank

APPENDIX A2. Survey information for study plot CRXA.

Sub-Plot	Sample #	Species Code	DBH (cm)	BA (m^2)
1	1	PIST	10.5	0.0087
1	2	QUCO	32.0	0.0804
1	3	PIST	23.1	0.0419
1	4	PIST	7.7	0.0047
1	5	PIST	19.0	0.0284
1	6	NYSY	22.5	0.0398
1	7	PIST	16.5	0.0214
1	8	PIVI	26.5	0.0552
1	9	PIVI	25.3	0.0503
1	10	NYSY	10.2	0.0082
1	11	PIST	15.8	0.0196
1	12	PIST	11.0	0.0095
1	13	PIST	8.8	0.0061
1	14	PIST	5.8	0.0026
1	15	PIST	7.2	0.0041
1	16	PIST	12.7	0.0127
1	17	QUVE	6.6	0.0034
1	18	NYSY	10.3	0.0083
1	19	PIVI	26.1	0.0535
1	20	PIST	9.5	0.0071
1	21	PIVI	23.3	0.0426
1	22	ACRU	6.6	0.0034
1	23	PIST	15.0	0.0177
1	24	OXAR	13.4	0.0141
1	25	PIST	24.7	0.0479
1	26	PIST	19.5	0.0299
1	27	SAAL	10.5	0.0087
1	28	PIST	7.7	0.0047
1	29	PIST	8.6	0.0058
1	30	PIST	5.7	0.0026
1	31	PIST	21.7	0.0370
1	32	PIVI	34.9	0.0957
1	33	PIST	7.2	0.0041
1	34	PIST	5.9	0.0027
1	35	SAAL	11.2	0.0099
1	36	ILOP	13.4	0.0141

APPENDIX A2. *Continued*

1	37	ILOP	7.6	0.0045
1	38	OXAR	14.1	0.0156
1	39	PIST	21.7	0.0370
1	40	PIST	6.9	0.0037
1	41	ILOP	6.0	0.0028
1	42	NYSY	6.3	0.0031
1	43	PIVI	20.2	0.0320
2	44	CADE	6.1	0.0029
2	45	SAAL	14.6	0.0167
2	46	PIST	14.6	0.0167
2	47	PIST	23.8	0.0445
2	48	NYSY	6.2	0.0030
2	49	PIST	12.2	0.0117
2	50	PIST	10.5	0.0087
2	51	SAAL	10	0.0079
2	52	PIST	17.7	0.0246
2	53	QUCO	39.8	0.1244
2	54	NYSY	9.4	0.0069
2	55	PIST	12.6	0.0125
2	56	ILOP	5.7	0.0026
2	57	OXAR	18.7	0.0275
2	58	PIST	8.1	0.0052
2	59	PIST	16.1	0.0204
2	60	PIEC	43.8	0.1507
2	61	PIVI	22.5	0.0398
2	62	NYSY	6.3	0.0031
3	63	PIST	16	0.0201
3	64	PIST	22.2	0.0387
3	65	ILOP	8.8	0.0061
3	66	PIST	14.7	0.0170
3	67	NYSY	12	0.0113
3	68	PIST	14.9	0.0174
3	69	NYSY	16.4	0.0211
3	70	ILOP	12.2	0.0117
3	71	ACRU	11.5	0.0104
3	72	PIST	9.8	0.0075
3	73	NYSY	29.7	0.0693
3	74	NYSY	11.1	0.0097

3	75	PIST	7.9	0.0049
3	76	PIVI	23.8	0.0445
3	79	PIST	8.5	0.0057
3	80	QUMO	18.6	0.0272
3	81	PIST	8.8	0.0061
3	82	PIEC	53.9	0.2282
3	83	NYSY	12.5	0.0123
3	84	NYSY	9.8	0.0075
3	85	ILOP	6.3	0.0031
3	86	QURU	59	0.2734
3	87	ACRU	17.5	0.0241
3	88	PIST	27.2	0.0581
3	89	PIST	15.9	0.0199
3	90	QUCO	31.8	0.0794
3	91	ACRU	8.8	0.0061
4	92	PIST	16.7	0.0219
4	93	PIST	12.6	0.0125
4	94	PIST	19.2	0.0290
4	95	NYSY	7.7	0.0047
4	96	QUMO	24.6	0.0475
4	97	ACRU	6.9	0.0037
4	98	PIRI	45.2	0.1605
4	99	PIRI	23.7	0.0441
4	100	ILOP	5.4	0.0023
4	101	NYSY	6.8	0.0036
4	102	PIRI	33.8	0.0897
4	103	NYSY	10	0.0079
4	104	ILOP	11.3	0.0100
4	105	ILOP	7	0.0038
4	106	PIVI	23	0.0415
4	107	PIRI	45.3	0.1612
4	108	MAFR	5.7	0.0026
4	109	PIST	12.6	0.0125
4	110	PIST	49.4	0.1917
4	111	NYSY	12.8	0.0129
4	112	QUCO	41.2	0.1333
4	113	ILOP	11.7	0.0108
4	114	NYSY	12	0.0113

APPENDIX A2. *Continued*

5	115	PIST	18.7	0.0275
5	116	PIST	25.3	0.0503
5	117	PIST	14.5	0.0165
5	118	PIST	21	0.0346
5	119	PIST	9.7	0.0074
5	120	PIST	14.5	0.0165
5	121	PIST	34.6	0.0940
5	122	PIST	22.6	0.0401
5	123	PIST	12.6	0.0125
5	124	PIST	24.6	0.0475
5	125	PIRI	43.1	0.1459
5	126	PIST	17.7	0.0246
5	127	PIRI	38.8	0.1182
5	128	PIRI	38.3	0.1152
5	129	PIRI	14	0.0154
5	130	PIRI	31.4	0.0774
5	131	PIRI	40.9	0.1314
5	132	PIRI	19.4	0.0296

APPENDIX A3. Survey information and age structure information from CRXB.

Plot	Sample #	Species Code	DBH (cm)	BA (m^2)	Outer year (A)	Inner year (A)	Outer year (B)	Inner year (B)	Age
1	133	PIST	32.8	0.0845	2008	N/A	2008	N/A	N/A
1	134	PIST	9.0	0.0064	2008	N/A	2008	N/A	N/A
1	135	PIST	13.1	0.0135	2008	1950	2008	1950	58
1	136	PIRI	39.2	0.1207	2008	1897	2008	1897	111
1	137	PIST	38.6	0.1170	2008	1929	2008	N/A	79
1	138	PIST	32.3	0.0819	2008	1921	2008	1921	87
1	139	PIST	11.1	0.0097	2008	N/A	2008	N/A	N/A
1	140	ACRU	7.0	0.0038	2008	1981	2008	1981	27
1	141	PIST	11.8	0.0109	2008	1962	2008	1962	46
1	142	PIST	22.4	0.0394	2008	N/A	2008	N/A	N/A
1	143	PIST	20.0	0.0314	2008	1945	2008	1945	63
1	144	PIST	8.0	0.0050	2008	1943	2008	1943	65
1	145	ACRU	6.7	0.0035	2008	1974	2008	1974	34
1	146	PIST	41.9	0.1379	2008	1909	2008	N/A	99
1	147	OXAR	21.2	0.0353	2008	1916	2008	1916	92
1	148	PIST	17.9	0.0252	2008	1922	2008	1922	86
1	149	PIST	10.7	0.0090	2008	1968	2008	1968	40
1	150	PIST	9.2	0.0066	2008	1949	2008	1949	59
1	151	PIST	9.5	0.0071	2008	1963	2008	1963	45
1	152	PIST	20.0	0.0314	2008	1918	2008	N/A	90
1	153	ACRU	6.8	0.0036	2008	N/A	2008	N/A	N/A
1	154	PIST	51.6	0.2091	2008	1929	2008	N/A	79
1	155	ACRU	22.6	0.0401	2008	1936	2008	N/A	72
1	156	QUAL	21.0	0.0346	2008	1914	2008	N/A	94
1	157	PIVI	16.2	0.0206	2008	1922	2008	1922	86
1	158	ACRU	6.0	0.0028	2008	1967	2008	1967	41
1	159	NYSY	7.9	0.0049	2008	1917	2008	1917	91
1	160	OXAR	9.8	0.0075	2008	1936	2008	1936	72
1	161	PIST	29.5	0.0683	2008	1940	2008	1940	68
2	162	PIST	10.8	0.0092	2008	1955	2008	1955	53
2	163	ACRU	9.2	0.0066	2008	1958	2008	1958	50
2	164	SAAL	11.7	0.0108	2008	N/A	2008	N/A	N/A
2	165	ACRU	27.3	0.0585	2008	1972	2008	N/A	36
2	166	OXAR	19.1	0.0287	2008	1913	2008	1913	95
2	167	PIRI	44.3	0.1541	2008	1870	2008	N/A	138
2	168	PIST	14.5	0.0165	2008	1945	2008	1945	63

2	169	PIST	23.0	0.0415	2008	N/A	2008	N/A	N/A
2	170	OXAR	11.9	0.0111	2008	1934	2008	1934	74
2	171	PIST	34.4	0.0929	2008	1930	2008	N/A	78
2	172	ACRU	12.1	0.0115	2008	N/A	2008	N/A	N/A
2	173	ACRU	7.0	0.0038	2008	1966	2008	1966	42
2	174	PIST	41.5	0.1353	2008	1918	2008	N/A	90
2	175	ACRU	8.6	0.0058	2008	1963	2008	1963	45
2	176	PIST	19.8	0.0308	2008	N/A	2008	N/A	N/A
2	177	PIST	11.7	0.0108	2008	1954	2008	1954	54
2	178	TSCA	19.2	0.0290	2008	1960	2008	N/A	48
2	179	PIST	40.5	0.1288	2008	1936	2008	N/A	72
2	180	PIST	14.2	0.0158	2008	1938	2008	1938	70
2	181	ACRU	8.3	0.0054	2008	1962	2008	1962	46
2	182	PIST	18.6	0.0272	2008	1934	2008	N/A	74
3	183	TSCA	10.8	0.0092	2008	1977	2008	1977	31
3	184	PIST	32	0.0804	2008	1939	2008	N/A	69
3	185	PIST	36.8	0.1064	2008	1933	2008	N/A	75
3	186	PIST	44.3	0.1541	2008	1953	2008	N/A	55
3	187	TSCA	5.8	0.0026	2008	1983	2008	1983	25
3	188	PIST	37.6	0.1110	2008	1938	2008	N/A	70
3	189	NYSY	20.6	0.0333	2008	N/A	2008	N/A	N/A
3	190	PIST	23.5	0.0434	2008	1952	2008	N/A	56
3	191	MAFR	5.6	0.0025	2008	1980	2008	1980	28
3	192	PIST	12	0.0113	2008	1946	2008	1946	62
3	193	SAAL	6.5	0.0033	2008	1970	2008	1970	38
3	194	ACRU	13.6	0.0145	2008	1938	2008	1938	70
3	195	PIST	17.7	0.0246	2008	N/A	2008	N/A	N/A
3	196	PIST	32.1	0.0809	2008	N/A	2008	N/A	N/A
3	197	PIVI	23.5	0.0434	2008	1890	2008	N/A	118
3	198	ACRU	6	0.0028	2008	1967	2008	1967	41
3	199	ACRU	8	0.0050	2008	1965	2008	1965	43
3	200	PIST	10.2	0.0082	2008	1977	2008	1977	31
3	201	TSCA	25.7	0.0519	2008	1956	2008	1956	52
3	202	QUCO	24.5	0.0471	2008	1930	2008	N/A	78
3	203	ILOP	10.5	0.0087	2008	1963	2008	1963	45
3	204	PIST	21	0.0346	2008	1930	2008	N/A	78
3	205	PIRI	21.5	0.0363	2008	1891	2008	1891	117
3	206	PIST	27.2	0.0581	2008	1927	2008	N/A	81

APPENDIX A3. *Continued*

3	207	PIST	29.3	0.0674	2008	1910	2008	1910	98
3	208	ILOP	6.6	0.0034	2008	1973	2008	1973	35
3	209	PIST	9.1	0.0065	2008	1940	2008	1940	68
3	210	PIVI	38	0.1134	2008	1878	2008	N/A	130
4	211	PIST	16.3	0.0209	2008	N/A	2008	N/A	N/A
4	212	PIST	33.5	0.0881	2008	1921	2008	N/A	87
4	213	PIRI	38.5	0.1164	2008	1880	2008	N/A	128
4	214	PIST	30	0.0707	2008	N/A	2008	N/A	N/A
4	215	NYSY	6.6	0.0034	2008	1931	2008	1931	77
4	216	QUMO	27.3	0.0585	2008	1930	2008	N/A	78
4	217	PIST	42.2	0.1399	2008	1917	2008	N/A	91
4	218	NYSY	14.7	0.0170	2008	1903	2008	1903	105
4	219	ACRU	7.7	0.0047	2008	1975	2008	1975	33
4	220	PIST	7.7	0.0047	2008	1942	2008	1942	66
4	221	ACRU	10.8	0.0092	2008	1960	2008	N/A	48
4	222	OXAR	18.2	0.0260	2008	N/A	2008	N/A	N/A
4	223	PIST	27.8	0.0607	2008	N/A	2008	N/A	N/A
4	224	ACRU	27	0.0573	2008	1936	2008	N/A	72
4	225	ILOP	5.5	0.0024	2008	1960	2008	1960	48
4	226	PIST	6	0.0028	2008	N/A	2008	N/A	N/A
5	227	PIST	26.6	0.0556	2008	N/A	2008	N/A	N/A
5	228	ILOP	7.3	0.0042	2008	1966	2008	1966	42
5	229	SAAL	6	0.0028	2008	1961	2008	1961	47
5	230	QUMO	35.1	0.0968	2008	1927	2008	N/A	81
5	231	PIST	33	0.0855	2008	N/A	2008	N/A	N/A
5	232	NYSY	10	0.0079	2008	1940	2008	1940	68
5	233	PIST	16.5	0.0214	2008	1937	2008	1937	71
5	234	QUAL	36.8	0.1064	2008	1813	2008	N/A	195
5	235	ACRU	33.4	0.0876	2008	1904	2008	N/A	104
5	236	PIST	11.5	0.0104	2008	1935	2008	1935	73
5	237	PIST	35.2	0.0973	2008	1932	2008	N/A	76
5	238	PIST	12.8	0.0129	2008	1937	2008	1937	71
5	239	ACRU	21.7	0.0370	2008	1901	2008	N/A	107
5	240	PIST	19.2	0.0290	2008	1940	2008	N/A	68
5	241	PIST	34.3	0.0924	2008	1929	2008	N/A	79
5	242	PIST	21.7	0.0370	2008	1918	2008	1918	90

N/A = increment core not available due to extensive rot

APPENDIX A4. Survey information from study plot CRTA.

Plot	Sample #	Species Code	DBH (cm)	BA (m^2)
1	1	ACRU	17.5	0.0241
1	2	PIST	35.5	0.0990
1	3	PIRI	29.5	0.0683
1	4	PIST	34.0	0.0908
1	5	CATO	11.0	0.0095
1	6	ACRU	6.0	0.0028
1	7	ACRU	10.5	0.0087
1	8	PIRI	34.5	0.0935
1	9	ACRU	7.7	0.0047
1	10	ACRU	10.0	0.0079
1	11	QUCO	16.5	0.0214
1	12	ACRU	7.0	0.0038
1	13	ACRU	5.6	0.0025
1	14	ACRU	9.6	0.0072
1	15	PIST	6.0	0.0028
1	16	ACRU	6.7	0.0035
1	17	ACRU	7.1	0.0040
1	18	ACRU	10.8	0.0092
1	19	ACRU	13.0	0.0133
1	20	ACRU	8.5	0.0057
1	21	ACRU	10.0	0.0079
1	22	TSCA	6.8	0.0036
1	23	ACRU	17.0	0.0227
1	24	PIRI	25.8	0.0523
1	25	PIST	6.5	0.0033
1	26	ACRU	22.7	0.0405
1	27	ACRU	18.5	0.0269
1	28	PIST	7.7	0.0047
1	29	QUCO	26.6	0.0556
1	30	ACRU	10.9	0.0093
1	31	PIST	9.9	0.0077
1	32	PIST	22.2	0.0387
1	33	PIST	13.9	0.0152
2	34	PIVI	24.9	0.0487
2	35	PIVI	24.8	0.0483
2	36	PIVI	29.5	0.0683

2	37	ACRU	12.1	0.0115
2	38	PIST	7.6	0.0045
2	39	TSCA	6.3	0.0031
2	40	ACRU	7.0	0.0038
2	41	ACRU	13.0	0.0133
2	42	OXAR	11.2	0.0099
2	43	QUCO	33.9	0.0903
2	44	ACRU	6.8	0.0036
2	45	PIVI	38.5	0.1164
2	46	ACRU	9.8	0.0075
2	47	QUCO	26.4	0.0547
2	48	PIST	7	0.0038
2	49	ACRU	7.8	0.0048
2	50	ACRU	8.8	0.0061
2	51	QUCO	39	0.1195
2	52	QUCO	41.5	0.1353
2	53	NYSY	9.1	0.0065
2	54	QUCO	20.5	0.0330
2	55	OXAR	17	0.0227
2	56	ACRU	6.3	0.0031
2	57	TSCA	6.4	0.0032
2	58	PIVI	26.1	0.0535
2	59	ACRU	9	0.0064
2	60	ACRU	10.5	0.0087
2	61	ACRU	7.5	0.0044
2	62	ACRU	9.3	0.0068
2	63	ACRU	12.5	0.0123
2	64	PIST	16	0.0201
3	65	PIVI	20.2	0.0320
3	66	ACRU	8.6	0.0058
3	67	ACRU	10.5	0.0087
3	68	QUMO	12	0.0113
3	69	ACRU	7.5	0.0044
3	70	PIST	10.4	0.0085
3	71	ACRU	16.6	0.0216
3	72	ACRU	8	0.0050
3	73	PIST	50.7	0.2019
3	74	ACRU	7.5	0.0044

APPENDIX A4. *Continued*

3	75	ACRU	18.5	0.0269
3	76	ACRU	8.4	0.0055
3	80	QUMO	16.9	0.0224
3	81	ACRU	6.8	0.0036
3	82	TSCA	7.5	0.0044
3	83	ACRU	10.7	0.0090
3	84	QUMO	20.6	0.0333
3	85	ACRU	17.8	0.0249
3	86	ACRU	9.6	0.0072
3	87	ACRU	18	0.0254
3	88	ACRU	7.9	0.0049
3	89	ACRU	8.5	0.0057
3	90	ACRU	12.2	0.0117
4	91	OXAR	16.4	0.0211
4	92	QUCO	38	0.1134
4	93	TSCA	9.5	0.0071
4	94	ACRU	17.1	0.0230
4	95	QUCO	19.9	0.0311
4	96	ACRU	7.7	0.0047
4	97	QUCO	23.6	0.0437
4	98	NYSY	7.5	0.0044
4	99	PIST	19.6	0.0302
4	100	NYSY	7.9	0.0049
4	101	TSCA	8.4	0.0055
4	102	OXAR	8.9	0.0062
4	103	QUCO	15	0.0177
4	104	ACRU	14.2	0.0158
4	105	ACRU	12.3	0.0119
4	106	ACRU	13.9	0.0152
4	107	ACRU	8.2	0.0053
4	108	TSCA	8.3	0.0054
4	109	PIST	8.2	0.0053
4	110	QUCO	33	0.0855
4	111	PIST	19.6	0.0302
4	112	ACRU	8.7	0.0059
4	113	ACRU	6.5	0.0033
4	114	ACRU	22.8	0.0408
4	115	ACRU	8.3	0.0054

APPENDIX A4. *Continued*

4	116	ACRU	12	0.0113
4	117	PIST	6.8	0.0036
4	118	QUCO	45.5	0.1626
4	119	ACRU	8.7	0.0059
4	120	ACRU	9.7	0.0074
4	121	QUCO	15.6	0.0191
4	122	ACRU	10.9	0.0093
4	123	ACRU	11.3	0.0100
4	124	ACRU	13.6	0.0145
4	125	ACRU	14.6	0.0167
5	126	PIVI	20.4	0.0327
5	127	PIST	51.5	0.2083
5	128	ACRU	8.1	0.0052
5	129	OXAR	16.3	0.0209
5	130	QUCO	23.1	0.0419
5	131	TSCA	12.6	0.0125
5	132	PIST	8	0.0050
5	133	ACRU	14.5	0.0165
5	134	ACRU	21.3	0.0356
5	135	ACRU	10.1	0.0080
5	136	PIVI	24	0.0452
5	137	ACRU	12.4	0.0121
5	138	QUCO	64.6	0.3278
5	139	NYSY	12.5	0.0123
5	140	ACRU	11.6	0.0106
5	141	TSCA	8.5	0.0057
5	142	ACRU	12	0.0113
5	143	TSCA	6.5	0.0033
5	144	PIVI	14.3	0.0161
5	145	PIVI	17.7	0.0246
5	146	QUMO	14.7	0.0170
5	147	PIVI	14.5	0.0165
5	148	PIST	9.4	0.0069

APPENDIX A5. Survey information and age structure information from the study plot CRTB.

Plot	Sample #	Species Code	DBH (cm)	BA (m^2)	Outer year (A)	Inner year (A)	Outer year (B)	Inner year (B)	Age
1	149	PIVI	28.1	0.0620	2008	1934	2008	1934	74
1	150	NYSY	14.6	0.0167	2008	1932	2008	1932	76
1	151	PIVI	20.0	0.0314	2008	1932	2008	1932	76
1	152	NYSY	6.9	0.0037	2008	1964	2008	1964	44
1	153	PIVI	20.4	0.0327	2008	1936	2008	1936	72
1	154	OXAR	14.2	0.0158	2008	1944	2008	1944	64
1	155	NYSY	9.6	0.0072	2008	1953	2008	1953	55
1	156	NYSY	12.3	0.0119	2008	1938	2008	1938	70
1	157	QUCO	29.0	0.0661	2008	1927	2008	1927	81
1	158	PIVI	24.0	0.0452	2008	1933	2008	1933	75
1	159	ACRU	13.3	0.0139	2008	N/A	2008	N/A	N/A
1	160	PIVI	17.0	0.0227	2008	1937	2008	1937	71
1	161	PIST	12.5	0.0123	2008	1942	2008	1942	66
1	162	ACRU	11.6	0.0106	2008	1933	2008	1933	75
1	163	PIRI	44.4	0.1548	2008	1902	2008	1902	106
1	164	ACRU	7.0	0.0038	2008	1966	2008	1966	42
1	165	QUCO	23.5	0.0434	2008	1935	2008	1935	73
1	166	PIVI	17.1	0.0230	2008	1958	2008	1958	50
1	167	ACRU	26.8	0.0564	2008	1919	2008	1919	89
1	168	ACRU	12.9	0.0131	2008	N/A	2008	N/A	N/A
1	169	ACRU	11.9	0.0111	2008	1924	2008	1924	84
1	170	ACRU	11.6	0.0106	2008	1933	2008	1933	75
1	171	PIST	8.0	0.0050	2008	1953	2008	N/A	55
2	172	ACRU	20.1	0.0317	2008	1959	2008	N/A	49
2	173	PIST	7.7	0.0047	2008	1953	2008	1953	55
2	174	PIST	28.2	0.0625	2008	1955	2008	1955	53
2	175	PIST	46.1	0.1669	2008	1955	2008	N/A	53
2	176	ACRU	13.3	0.0139	2008	1933	2008	1933	75
2	177	ACRU	14.6	0.0167	2008	1937	2008	1937	71
2	178	PIVI	36.2	0.1029	2008	N/A	2008	N/A	N/A
2	179	TSCA	8.2	0.0053	2008	1983	2008	1983	25
2	180	NYSY	21.9	0.0377	2008	1918	2008	N/A	90
2	181	PIVI	18.4	0.0266	2008	1937	2008	1937	71
2	182	ACRU	10.4	0.0085	2008	N/A	2008	N/A	N/A
2	183	PIVI	17.0	0.0227	2008	1947	2008	1947	61
2	184	PIVI	39.4	0.1219	2008	1947	2008	1947	61

2	185	NYSY	10.6	0.0088	2008	1940	2008	1940	68
2	186	PIST	9.0	0.0064	2008	1975	2008	1975	33
2	187	PIVI	25.1	0.0495	2008	1933	2008	1933	75
2	188	PIVI	20.7	0.0337	2008	1942	2008	1942	66
2	189	TSCA	7.2	0.0041	2008	1983	2008	1983	25
2	190	NYSY	18.8	0.0278	2008	1929	2008	1929	79
2	191	PIVI	21.2	0.0353	2008	1941	2008	1941	67
2	192	PIVI	22.2	0.0387	2008	N/A	2008	N/A	N/A
2	193	PIVI	25.5	0.0511	2008	1943	2008	1943	65
2	194	PIST	7.2	0.0041	2008	1983	2008	1983	25
2	195	PIST	7.2	0.0041	2008	1984	2008	1984	24
2	196	PIST	8.3	0.0054	2008	1984	2008	1984	24
3	197	PIVI	18.5	0.0269	2008	1948	2008	1948	60
3	198	PIST	6.1	0.0029	2008	1980	2008	1980	28
3	199	NYSY	11.2	0.0099	2008	1931	2008	1931	77
3	200	OXAR	18.3	0.0263	2008	1950	2008	1950	58
3	201	TSCA	7.4	0.0043	2008	1981	2008	1981	27
3	202	OXAR	11.6	0.0106	2008	1945	2008	1945	63
3	203	PIVI	20.3	0.0324	2008	1937	2008	1937	71
3	204	QUCO	26.4	0.0547	2008	N/A	2008	N/A	N/A
3	205	NYSY	12.2	0.0117	2008	1931	2008	1931	77
3	206	PIST	19.1	0.0287	2008	1957	2008	N/A	51
3	207	ACRU	13.1	0.0135	2008	1940	2008	1940	68
3	208	PIVI	18.5	0.0269	2008	1940	2008	1940	68
3	209	NYSY	13	0.0133	2008	1933	2008	N/A	75
3	210	PIVI	27.5	0.0594	2008	1949	2008	1949	59
3	211	PIVI	13.7	0.0147	2008	1935	2008	1935	73
3	212	NYSY	16	0.0201	2008	1946	2008	1946	62
3	213	PIVI	27	0.0573	2008	1944	2008	1944	64
3	214	PIVI	14.5	0.0165	2008	1948	2008	1948	60
3	215	PIVI	10.9	0.0093	2008	1943	2008	1943	65
3	216	PIVI	17.8	0.0249	2008	1947	2008	1947	61
3	217	NYSY	14	0.0154	2008	1927	2008	1927	81
3	218	PIVI	18.4	0.0266	2008	1941	2008	1941	67
3	219	NYSY	10.2	0.0082	2008	1942	2008	1942	66
3	220	PIST	9.3	0.0068	2008	1963	2008	1963	45
3	221	ACRU	12.5	0.0123	2008	1949	2008	1949	59
3	222	NYSY	11.7	0.0108	2008	1924	2008	1924	84

3	223	PIVI	23.5	0.0434	2008	1945	2008	1945	63
3	224	PIVI	29.7	0.0693	2008	1936	2008	N/A	72
3	225	ACRU	12.1	0.0115	2008	N/A	2008	N/A	N/A
3	226	NYSY	6.8	0.0036	2008	1941	2008	1941	67
3	227	PIRI	21.6	0.0366	2008	N/A	2008	N/A	N/A
3	228	QUCO	24.5	0.0471	2008	1924	2008	N/A	84
3	229	PIVI	24	0.0452	2008	1954	2008	1954	54
3	230	NYSY	8.1	0.0052	2008	1939	2008	1939	69
3	231	NYSY	8.5	0.0057	2008	1947	2008	1947	61
4	232	PIST	19.2	0.0290	2008	1949	2008	N/A	59
4	233	QUCO	16.2	0.0206	2008	1926	2008	1926	82
4	234	PIVI	19.8	0.0308	2008	1936	2008	1936	72
4	235	ACRU	9.6	0.0072	2008	1939	2008	1939	69
4	236	TSCA	10.5	0.0087	2008	1961	2008	1961	47
4	237	PIST	9	0.0064	2008	N/A	2008	N/A	N/A
4	238	NYSY	9	0.0064	2008	1933	2008	NA	75
4	239	PIVI	23.4	0.0430	2008	1935	2008	NA	73
4	240	PIVI	19	0.0284	2008	1933	2008	1933	75
4	241	PIVI	17.3	0.0235	2008	1942	2008	1942	66
4	242	PIST	6.5	0.0033	2008	1980	2008	1980	28
4	243	QUCO	30.1	0.0712	2008	1933	2008	N/A	75
4	244	PIVI	24.8	0.0483	2008	1946	2008	N/A	62
4	245	TSCA	11.6	0.0106	2008	1972	2008	1972	36
4	246	QUCO	22.7	0.0405	2008	N/A	2008	N/A	N/A
4	247	ACRU	19.7	0.0305	2008	1922	2008	1922	86
4	248	PIST	7.4	0.0043	2008	1980	2008	1980	28
4	249	PIVI	17	0.0227	2008	1941	2008	N/A	67
4	250	PIVI	18.2	0.0260	2008	1949	2008	N/A	59
4	251	PIST	17.5	0.0241	2008	N/A	2008	N/A	N/A
4	252	PIST	7.8	0.0048	2008	1978	2008	1978	30
4	253	QUCO	13.8	0.0150	2008	1947	2008	1947	61
4	254	PIVI	18.9	0.0281	2008	1954	2008	1954	54
4	255	ACRU	9.9	0.0077	2008	N/A	2008	N/A	N/A
4	256	PIST	10.2	0.0082	2008	1978	2008	N/A	30
4	257	PIST	11.1	0.0097	2008	1964	2008	1946	62
4	258	PIST	11.7	0.0108	2008	1953	2008	1953	55
4	259	ACRU	20.5	0.0330	2008	1941	2008	N/A	67
4	260	ACRU	29.9	0.0702	2008	1947	2008	N/A	61

APPENDIX A5. *Continued*

4	261	PIST	8	0.0050	2008	1977	2008	1977	31
4	262	PIST	12.6	0.0125	2008	1972	2008	1972	36
5	265	TSCA	15.5	0.0189	2008	1956	2008	1956	52
5	266	ACRU	13.6	0.0145	2008	1931	2008	1931	77
5	267	ACRU	23.4	0.0430	2008	1928	2008	N/A	80
5	268	PIST	7.8	0.0048	2008	1979	2008	1979	29
5	269	PIST	8	0.0050	2008	1976	2008	1976	32
5	270	PIST	19.5	0.0299	2008	N/A	2008	N/A	N/A
5	271	PIST	7.5	0.0044	2008	1974	2008	N/A	34
5	272	ACRU	13.2	0.0137	2008	1952	2008	N/A	56
5	273	PIST	9	0.0064	2008	1975	2008	1975	33
5	274	OXAR	21.8	0.0373	2008	1947	2008	1947	61
5	275	PIST	7.5	0.0044	2008	1982	2008	N/A	26
5	276	PIVI	24.1	0.0456	2008	1948	2008	N/A	60
5	277	NYSY	8.5	0.0057	2008	1923	2008	1923	85
5	278	NYSY	6.5	0.0033	2008	1950	2008	N/A	58
5	279	PIST	8.5	0.0057	2008	1982	2008	1982	26
5	280	PIVI	29.9	0.0702	2008	1940	2008	N/A	68
5	281	NYSY	12.6	0.0125	2008	1948	2008	N/A	60
5	282	ACRU	15	0.0177	2008	1962	2008	1962	46
5	283	NYSY	9.9	0.0077	2008	1937	2008	1937	71
5	284	PIVI	22.1	0.0384	2008	N/A	2008	N/A	N/A
5	285	ACRU	24.3	0.0464	2008	1946	2008	N/A	62
5	286	PIVI	29.6	0.0688	2008	1933	2008	1933	75
5	287	NYSY	10.4	0.0085	2008	1933	2008	1933	75
5	288	PIVI	17.3	0.0235	2008	1939	2008	N/A	69
5	289	PIVI	16.1	0.0204	2008	1940	2008	1940	68
5	290	PIST	12.5	0.0123	2008	1974	2008	1974	34
5	291	PIVI	25.1	0.0495	2008	1936	2008	N/A	72
5	292	PIVI	19.3	0.0293	2008	1939	2008	N/A	69
5	293	PIVI	21	0.0346	2008	1954	2008	N/A	54

N/A = increment core not available due to extensive rot

APPENDIX A6. CRX Fire History Summary Information.

Fire Interval Analyses, All Scarred, 1749–1934

Summary Information

Year	Total Scars	Recorder Trees	% Scarred	Fire Interval
1749	2	2	100	.
1754	1	3	33	5
1757	2	4	50	3
1765	1	4	25	8
1766	1	4	25	1
1768	1	4	25	2
1772	1	4	25	4
1777	3	6	50	5
1780	1	6	17	3
1787	2	6	33	7
1796	1	6	17	9
1806	1	3	33	10
1809	1	3	33	3
1813	1	2	50	4
1830	1	2	50	17
1833	1	2	50	3
1839	2	3	67	6
1847	1	2	50	8
1853	1	2	50	6
1857	2	2	100	4
1865	1	2	50	8
1870	2	2	100	5
1873	1	2	50	3
1878	1	2	50	5
1898	2	3	67	20
1902	2	5	40	4
1906	2	5	40	4
1916	3	5	60	10

Summary Statistics

Total Intervals	27
Mean Fire Interval	6.19
Median Fire Interval	5.00
Fire Frequency	0.16
Weibull Modal Interval	3.82
Weibull Median Interval	5.55
Weibull Fire Frequency	0.18
Standard Deviation	4.30
Coefficient of Variation	0.69
Skewness	1.75
Kurtosis	2.90
Scale parameter	6.96
Shape parameter	1.61
Minimum Fire Interval	1.00
Maximum Fire Interval	20.00
Lower Exceedance Interval	2.00
Upper Exceedance Interval	10.96
Maximum Hazard Interval	24.41

APPENDIX A7. CRT Fire History Summary Information.

Fire Interval Analyses, All Scarred, 1678–2008

Summary Information

Year	Total Scars	Recorder Trees	% Scarred	Fire Interval
1720	1	1	100	.
1740	1	2	50	20
1777	1	1	100	37
1786	1	2	50	9
1814	1	2	50	28
1818	1	3	33	4
1828	1	4	25	10
1835	1	4	25	7
1838	1	4	25	3
1843	1	4	25	5
1847	1	3	33	4
1848	1	3	33	1
1849	1	4	25	1
1850	1	4	25	1
1854	1	4	25	4
1856	2	5	40	2
1858	1	5	20	2
1861	1	5	20	3
1862	1	5	20	1
1863	1	5	20	1
1871	1	5	20	8
1872	1	6	17	1
1874	1	6	17	2
1884	1	4	25	10
1888	3	6	50	4
1889	1	6	17	1
1896	3	6	50	7
1900	2	6	33	4
1902	4	7	57	2
1906	2	8	25	4
1909	4	8	50	3
1912	2	9	22	3
1914	1	10	10	2
1916	3	10	30	2
1920	2	9	22	4
1922	2	8	25	2
1923	1	8	13	1

APPENDIX A7. *continued*

1926	1	8	13	3
1930	1	8	13	4
1934	2	5	40	4
1945	1	5	20	11

Summary Statistics

Total Intervals	35
Mean Fire Interval	3.43
Median Fire Interval	3.00
Fire Frequency	0.29
Weibull Modal Interval	1.95
Weibull Median Interval	3.03
Weibull Fire Frequency	0.33
Standard Deviation	2.43
Coefficient of Variation	0.71
Skewness	1.28
Kurtosis	1.06
Scale parameter	3.84
Shape parameter	1.54
Minimum Fire Interval	1.00
Maximum Fire Interval	10.00
Lower Exceedance Interval	1.04
Upper Exceedance Interval	6.17
Maximum Hazard Interval	5.74

APPENDIX A8. COFECHA dating adjustments for fire-scarred samples at CRX.

PART 8: ADJUSTMENTS FOR UNDATED SERIES: CRX 15:46 Mon 09 Nov 2009 Page 2

Time span 1684 2006 323 years, best matches for 40-year segments lagged 5 years
Listed in order from highest correlation

Series	Counted Segment		Add	Corr # 1	Add	Corr # 2	Add	Corr # 3	Add	Corr # 4	Add	Corr # 5	Add	Corr # 6	Add	Corr # 7	Add	Corr # 8	Add	Corr # 9	Add	Corr #10	Add	Corr #11
CRX323A	1844	1883	27	.42	-152	.40	-42	.38	0	.36	-12	.34	74	.34	120	.34	6	.33	-119	.33	68	.31	-92	.31
CRX323A	1849	1888	0	.43	27	.41	64	.36	68	.35	-42	.35	-152	.35	55	.33	6	.33	-74	.33	-94	.32	-119	.30
CRX323A	1854	1893	-42	.44	-152	.42	68	.40	27	.39	64	.39	0	.37	-126	.35	-170	.34	-137	.34	55	.33	-74	.33
CRX323A	1859	1898	27	.50	-74	.47	-152	.41	68	.39	-94	.39	-42	.38	0	.37	-171	.36	64	.35	59	.35	-170	.33
CRX323A	1864	1903	27	.46	68	.45	-74	.44	-171	.39	-126	.38	-94	.36	-42	.36	-152	.35	0	.35	88	.34	64	.34
CRX323A	1869	1908	27	.45	0	.45	-74	.41	-125	.40	-100	.38	68	.37	-126	.36	-34	.35	4	.35	55	.33	69	.31
CRX323A	1874	1913	-51	.41	4	.40	-125	.38	-74	.38	-161	.36	55	.35	59	.34	-34	.34	-144	.32	-42	.31	88	.31
CRX323A	1879	1918	-61	.52	68	.52	-171	.44	-145	.43	-74	.42	-34	.42	46	.41	-125	.39	0	.37	88	.33	-71	.32
CRX323A	1884	1923	-61	.53	-171	.51	13	.43	-34	.39	68	.38	-98	.37	-145	.35	-71	.35	-74	.34	46	.34	23	.34
CRX323A	1889	1928	-171	.60	-61	.50	46	.48	-34	.40	68	.36	-26	.35	-71	.35	13	.33	0	.33	-145	.31	-183	.30
CRX323A	1894	1933	-171	.56	0	.45	-97	.43	-51	.41	46	.38	-26	.37	-61	.37	-125	.35	-145	.31	-153	.31	19	.31
CRX323A	1899	1938	-171	.54	0	.50	-153	.45	-26	.42	-51	.41	-74	.35	-145	.35	46	.31	4	.31	17	.31	13	.29
CRX323A	1904	1943	-171	.58	0	.51	-26	.39	-153	.37	17	.35	-51	.35	-71	.33	-74	.30	19	.30	-45	.30	-207	.30
CRX323A	1909	1948	-171	.54	0	.53	-26	.42	19	.37	-93	.37	58	.35	-71	.35	-51	.33	42	.32	-45	.32	-32	.32
CRX323A	1914	1953	0	.49	-171	.45	-87	.38	42	.36	19	.35	-114	.33	-45	.33	-13	.32	-53	.31	-71	.31	-26	.31
CRX323A	1919	1958	-53	.44	42	.44	-87	.43	0	.42	-171	.39	-80	.36	-189	.33	-42	.32	-223	.30	26	.28	-172	.28
CRX323A	1924	1963	-53	.44	0	.43	-87	.40	-80	.38	42	.36	-171	.36	-172	.34	-198	.32	-32	.31	-153	.30	-106	.30
CRX323A	1929	1968	-80	.48	0	.42	-117	.39	-172	.35	-53	.33	-164	.33	-190	.31	-87	.31	23	.31	-139	.31	-45	.30
CRX323A	1934	1973	-80	.45	0	.41	-248	.40	-87	.39	-53	.39	-164	.34	-139	.32	-71	.32	-41	.30	-168	.30	-152	.29
CRX323A	1939	1978	-87	.43	0	.40	-180	.37	1	.37	-168	.34	-155	.34	-248	.33	11	.32	-53	.32	-152	.29	-251	.29
CRX323A	1944	1983	-129	.45	0	.44	-180	.44	-155	.40	-142	.38	-251	.36	-53	.35	1	.35	-238	.33	-80	.33	-168	.32
CRX323A	1949	1988	0	.46	-251	.45	-1	.44	-168	.39	-239	.37	1	.36	-180	.35	-142	.35	-214	.34	-153	.33	-252	.32
CRX323A	1954	1993	0	.59	-213	.45	-251	.44	-1	.44	-239	.40	-214	.38	-130	.37	-168	.36	-250	.35	-142	.33	-94	.33
CRX323A	1959	1998	0	.71	-239	.50	-95	.48	-1	.42	-130	.37	-24	.37	-168	.36	-251	.34	-214	.34	-94	.32	-165	.31
CRX323A	1964	2003	0	.65	-239	.54	-95	.46	-1	.41	-94	.40	-240	.39	-213	.37	-214	.37	-181	.35	-132	.34	-122	.33
CRX323A	1968	2007	-94	.48	-239	.48	-95	.45	-181	.37	-1	.36	-122	.36	-240	.35	-280	.35	-214	.33	-213	.32	-114	.31

26 segments

Number of segments

Add	No	R_av	Add	No	R_av	Add	No	R_av	Add	No	R_av	Add	No	R_av	Add	No	R_av	Add	No	R_av	Add	No	R_av
+0	23	.45	-171	12	.48	-74	10	.38	+68	9	.39	-152	7	.36	-94	7	.37	-71	7	.33	-53	7	.37
-42	7	.36	-87	6	.39	-168	6	.34	-26	6	.38	+27	6	.44	-80	5	.40	-214	5	.35	-239	5	.46
-145	5	.35	-51	5	.38	-153	5	.35	-34	5	.38	-1	5	.41	-251	5	.38	+46	5	.38	-45	4	.31
-61	4	.48	+19	4	.33	+42	4	.37	-125	4	.38	+55	4	.34	+64	4	.36	+4	3	.35	+13	3	.35
-172	3	.32	-126	3	.36	-142	3	.35	-95	3	.46	-180	3	.39	+1	3	.36	-213	3	.38	+88	3	.33

Chronological order

Add	No	Add	No	Add	No	Add	No	Add	No	Add	No	Add	No	Add	No	Add	No	Add	No	Add	No	Add	No	Add	No	Add	No
-251	5	-239	5	-214	5	-213	3	-180	3	-172	3	-171	12	-168	6	-153	5	-152	7	-145	5	-142	3	-126	3	-125	4

Add	No	Add	No	Add	No	Add	No	Add	No	Add	No	Add	No	Add	No	Add	No	Add	No	Add	No	Add	No	Add	No	Add	No
-95	3	-94	7	-87	6	-80	5	-74	10	-71	7	-61	4	-53	7	-51	5	-45	4	-42	7	-34	5	-26	6	-1	5
+0	23	+1	3	+4	3	+13	3	+19	4	+27	6	+42	4	+46	5	+55	4	+64	4	+68	9	+88	3				

Series	Counted Segment	Add	Corr # 1	Add	Corr # 2	Add	Corr # 3	Add	Corr # 4	Add	Corr # 5	Add	Corr # 6	Add	Corr # 7	Add	Corr # 8	Add	Corr # 9	Add	Corr #10	Add	Corr #11
CRX327A	1865 1904	34	.47	-93	.47	-164	.42	49	.39	0	.38	-81	.36	-151	.35	-55	.35	-21	.34	-165	.32	86	.32
CRX327A	1870 1909	-164	.45	-183	.44	0	.43	-21	.41	-25	.35	-177	.34	49	.33	-165	.32	-74	.31	85	.31	-67	.30
CRX327A	1875 1914	0	.45	-164	.39	-21	.39	-141	.38	-67	.37	-183	.32	-74	.31	-163	.30	53	.30	49	.29	-127	.28
CRX327A	1880 1919	0	.50	-78	.37	49	.37	-67	.37	-173	.35	-87	.34	-101	.32	-2	.30	-21	.30	-141	.30	-74	.29
CRX327A	1885 1924	0	.51	-199	.42	-67	.39	-87	.38	-184	.38	-196	.34	30	.33	-78	.32	-118	.31	49	.31	-41	.30

5 segments

Number of segments

Add	No	R_av	Add	No	R_av	Add	No	R_av	Add	No	R_av	Add	No	R_av	Add	No	R_av	Add	No	R_av	Add	No	R_av
+0	5	.45	+49	5	.34	-67	4	.36	-21	4	.36	-164	3	.42	-74	3	.31						

Chronological order

Add	No	Add	No	Add	No	Add	No	Add	No	Add	No	Add	No	Add	No	Add	No	Add	No	Add	No	Add	No	Add	No	Add	No
-164	3	-74	3	-67	4	-21	4	+0	5	+49	5																

Series	Counted Segment	Add	Corr # 1	Add	Corr # 2	Add	Corr # 3	Add	Corr # 4	Add	Corr # 5	Add	Corr # 6	Add	Corr # 7	Add	Corr # 8	Add	Corr # 9	Add	Corr #10	Add	Corr #11
CRX331A	1819 1858	-87	.40	-97	.39	39	.39	-123	.36	62	.35	-109	.35	0	.34	111	.33	-83	.31	61	.31	-61	.31
CRX331A	1824 1863	0	.40	61	.39	-65	.38	62	.37	-137	.35	-24	.34	-61	.33	-9	.32	130	.31	129	.30	-83	.30
CRX331A	1829 1868	0	.46	62	.39	-65	.38	-9	.34	-137	.33	129	.33	61	.30	-36	.30	-79	.30	29	.30	-61	.29
CRX331A	1834 1873	-65	.42	0	.42	-39	.33	-38	.32	-137	.32	62	.30	-9	.30	-14	.29	25	.29	92	.29	61	.27
CRX331A	1839 1878	-116	.49	29	.40	0	.38	-93	.36	-90	.33	-39	.31	78	.30	-38	.30	-19	.29	-36	.28	-9	.27
CRX331A	1844 1883	-116	.50	29	.38	-93	.37	-90	.35	-125	.32	0	.31	-38	.29	-19	.27	-36	.27	-24	.27	78	.27
CRX331A	1847 1886	-116	.50	-90	.38	-125	.34	-93	.34	0	.34	-36	.33	-9	.31	62	.30	29	.30	78	.29	95	.29

7 segments

Number of segments

Add	No	R_av	Add	No	R_av	Add	No	R_av	Add	No	R_av	Add	No	R_av	Add	No	R_av	Add	No	R_av	Add	No	R_av
+0	7	.38	-9	5	.31	+62	5	.34	-36	4	.30	+29	4	.34	+61	4	.32	-38	3	.30	-90	3	.35
-116	3	.49	-137	3	.33	-65	3	.39	-61	3	.31	-93	3	.35	+78	3	.29						

Chronological order

Add	No	Add	No	Add	No	Add	No	Add	No	Add	No	Add	No	Add	No	Add	No	Add	No	Add	No	Add	No	Add	No	Add	No
-137	3	-116	3	-93	3	-90	3	-65	3	-61	3	-38	3	-36	4	-9	5	+0	7	+29	4	+61	4	+62	5	+78	3

Series	Counted Segment	Add	Corr # 1	Add	Corr # 2	Add	Corr # 3	Add	Corr # 4	Add	Corr # 5	Add	Corr # 6	Add	Corr # 7	Add	Corr # 8	Add	Corr # 9	Add	Corr #10	Add	Corr #11
CRX331B	1685 1724	18	.60	267	.51	76	.50	203	.49	-1	.48	160	.45	5	.45	101	.39	0	.37	58	.32	130	.30

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 CRX331B  1690 1729    18 .59   267 .49    76 .44   160 .43    -1 .41    88 .38     0 .38     5 .38   203 .38   101 .37   199 .34
 CRX331B  1695 1734    18 .54    76 .46   267 .43   199 .43     0 .43    88 .40     5 .39    -1 .38   203 .38   160 .37   216 .34
 CRX331B  1700 1739   185 .45   216 .40    63 .39   -13 .36   205 .35     0 .34   118 .34   174 .33    29 .32    26 .32    44 .31
 CRX331B  1705 1744     0 .50   185 .41    63 .40    44 .37    99 .34    26 .34    64 .33   216 .33   129 .33   174 .32   215 .31
 CRX331B  1710 1749    44 .49     0 .45    99 .42   174 .41   136 .39   118 .37   129 .35    36 .34    63 .32   152 .32   216 .32
 CRX331B  1715 1754    44 .44   174 .40   152 .37   129 .35     0 .34   118 .34   240 .33   136 .33   206 .32    71 .32   -25 .31
 CRX331B  1720 1759   174 .45   152 .37   247 .37   129 .36    85 .35    44 .34     0 .33   118 .33   215 .32    98 .32    11 .32
 CRX331B  1725 1764    11 .40    85 .39   152 .36   240 .35   174 .33    36 .33   -11 .33   133 .33   206 .31   215 .30   129 .28
      9 segments  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
 Number of segments
       Add  No R_av    Add  No R_av    Add  No R_av    Add  No R_av    Add  No R_av    Add  No R_av    Add  No R_av    Add  No R_av
        +0   8  .39   +174   6  .37    +44   5  .39   +129   5  .34   +118   4  .34   +152   4  .36   +216   4  .35     +5   3  .40
       +18   3  .58    +63   3  .37   +160   3  .42     -1   3  .42   +203   3  .42   +215   3  .31    +76   3  .47   +267   3  .47
 Chronological order
       Add  No     Add  No     Add  No     Add  No     Add  No     Add  No     Add  No     Add  No     Add  No     Add  No     Add  No     Add  No     Add  No     Add  No
        -1   3      +0   8      +5   3     +18   3     +44   5     +63   3     +76   3    +118   4    +129   5    +152   4    +160   3    +174   6    +203   3    +215   3
      +216   4    +267   3

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          Counted       Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr
 Series   Segment   Add  # 1  Add  # 2  Add  # 3  Add  # 4  Add  # 5  Add  # 6  Add  # 7  Add  # 8  Add  # 9  Add  #10  Add  #11
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 CRX333B  1800 1839   -37 .49    51 .40    90 .37  -109 .35   131 .35    74 .35   -97 .32     0 .30   125 .29   -13 .28     4 .28
 CRX333B  1805 1844   -37 .48  -109 .39    74 .35    51 .35   125 .35   142 .33    90 .32   -13 .30   -62 .29   -97 .27    -8 .26
 CRX333B  1810 1849    22 .45   128 .39   -85 .36   151 .33   -37 .32     0 .32    13 .31    14 .31   111 .30   -62 .29    56 .29
 CRX333B  1815 1854   128 .41   -85 .37    56 .36    14 .36    22 .35   -37 .35   120 .33   -24 .32    65 .31   151 .30  -121 .30
 CRX333B  1820 1859  -120 .41    56 .39    37 .38     0 .37   129 .36   -84 .36   -83 .35   -37 .31   106 .30   -88 .30  -106 .30
 CRX333B  1825 1864   129 .41   -84 .40     0 .37    38 .37  -121 .34    37 .34    56 .34  -120 .33  -139 .32   -51 .31    57 .30
 CRX333B  1830 1869     0 .39    38 .39    29 .35  -120 .35   129 .34   128 .33   -84 .31   -43 .30    78 .30  -139 .28   120 .27
 CRX333B  1835 1874     0 .49   -84 .40   -59 .38     7 .37  -129 .37   -83 .36   -30 .36   120 .34    38 .32   -92 .30   -10 .30
      8 segments  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
 Number of segments
       Add  No R_av    Add  No R_av    Add  No R_av    Add  No R_av    Add  No R_av    Add  No R_av    Add  No R_av    Add  No R_av
        +0   6  .37    -37   5  .39    -84   4  .37    +56   4  .34    +38   3  .36   -120   3  .36   +120   3  .31   +128   3  .38
      +129   3  .37
 Chronological order
       Add  No     Add  No     Add  No     Add  No     Add  No     Add  No     Add  No     Add  No     Add  No     Add  No     Add  No     Add  No     Add  No     Add  No
      -120   3     -84   4     -37   5      +0   6     +38   3     +56   4    +120   3    +128   3    +129   3

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          Counted       Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr
 Series   Segment   Add  # 1  Add  # 2  Add  # 3  Add  # 4  Add  # 5  Add  # 6  Add  # 7  Add  # 8  Add  # 9  Add  #10  Add  #11
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 CRX338A  1932 1971     0 .65   -41 .42  -162 .40   -10 .38  -108 .36  -196 .35  -220 .34  -188 .31  -168 .30   -47 .30  -205 .29
 CRX338A  1937 1976     0 .52  -251 .44   -47 .38  -168 .36  -188 .36  -214 .35  -213 .34   -98 .31  -215 .31  -154 .30   -27 .29
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CRX338A  1942 1981     0 .49  -251 .49  -188 .40  -154 .37  -179 .36  -128 .34    25 .34  -213 .34  -196 .33   -95 .33   -47 .31
CRX338A  1947 1986     0 .48  -179 .48  -188 .46  -128 .42  -214 .41   -95 .41  -213 .38  -171 .34   -52 .32  -251 .30  -114 .29
CRX338A  1952 1991     0 .53  -188 .48  -214 .45    15 .41  -213 .41   -69 .36  -114 .35  -212 .34    -1 .33   -52 .32  -115 .31
CRX338A  1957 1996     0 .51  -213 .49  -188 .47  -214 .42  -268 .38  -114 .36   -69 .34    -1 .31     8 .30  -231 .30  -115 .28
CRX338A  1962 2001  -213 .54  -187 .47     0 .43  -268 .41  -114 .41  -214 .39  -233 .35    -1 .32  -115 .32   -72 .32  -188 .31
CRX338A  1967 2006  -231 .56  -187 .42   -18 .40   -73 .39  -213 .36  -233 .36  -131 .36  -214 .34  -257 .34     0 .33  -141 .33
CRX338A  1968 2007  Lag from prior segment   1 years; insufficient
     8 segments  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
Number of segments
      Add No R_av   Add No R_av   Add No R_av   Add No R_av   Add No R_av   Add No R_av   Add No R_av   Add No R_av

    +0  8  .49  -213  7  .41  -188  7  .40  -214  6  .39  -114  4  .35  -115  3  .31   -47  3  .33    -1  3  .32
     -251  3  .41
Chronological order
      Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No
     -251  3  -214  6  -213  7  -188  7  -115  3  -114  4   -47  3    -1  3    +0  8
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        Counted         Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr
Series  Segment     Add  # 1  Add  # 2  Add  # 3  Add  # 4  Add  # 5  Add  # 6  Add  # 7  Add  # 8  Add  # 9  Add  #10  Add  #11
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CRX339A  1772 1811   166 .54   -83 .46   -13 .42   -47 .38   -50 .35   -85 .34   114 .33    59 .32   116 .30   -51 .29    13 .29
CRX339A  1777 1816   166 .47   -47 .44   -83 .42     0 .35   -84 .35   -13 .35   181 .34   114 .31    59 .30   -71 .30   -33 .30
CRX339A  1782 1821   181 .40     0 .39   -13 .34   -83 .33   -46 .33   -71 .33   166 .32    38 .31    59 .30    25 .29   114 .29
CRX339A  1787 1826     0 .46   -13 .42   166 .40   -71 .36    -2 .35    59 .33    76 .32   -29 .32   114 .31    12 .30   -46 .30
CRX339A  1792 1831     0 .47    -2 .38   166 .36    72 .35    59 .35   -13 .35   -54 .33    46 .32    30 .32   123 .32   -71 .31
CRX339A  1797 1836     0 .49   -54 .37    72 .36   166 .36   -13 .36    -2 .35     2 .34   -72 .32   -29 .31    46 .30    68 .30
CRX339A  1802 1841    -2 .42   -53 .38   -54 .37    99 .34    30 .34   -72 .32     0 .32   140 .32   -71 .30    72 .30     2 .30
CRX339A  1807 1846  -123 .39   -71 .37    93 .36     0 .34   -53 .33   123 .32   -54 .32   -15 .31    99 .30   -27 .30   -97 .30
CRX339A  1808 1847  Lag from prior segment   1 years; insufficient
     8 segments  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
Number of segments
      Add No R_av   Add No R_av   Add No R_av   Add No R_av   Add No R_av   Add No R_av   Add No R_av   Add No R_av
       +0  7  .40   -71  6  .33   -13  6  .37  +166  6  .41   +59  5  .32    -2  4  .38  +114  4  .31   -54  4  .35
      -83  3  .40   +72  3  .34
Chronological order
      Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No
      -83  3   -71  6   -54  4   -13  6    -2  4    +0  7   +59  5   +72  3  +114  4  +166  6

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        Counted         Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr
Series  Segment     Add  # 1  Add  # 2  Add  # 3  Add  # 4  Add  # 5  Add  # 6  Add  # 7  Add  # 8  Add  # 9  Add  #10  Add  #11
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CRX340A  1734 1773     0 .54    19 .45    44 .43   -40 .42    71 .42   141 .35   213 .35   211 .33   -18 .31   210 .31    20 .30
CRX340A  1739 1778     0 .54    44 .45   139 .39    19 .39   -18 .36    71 .35   -40 .35   -39 .34   -41 .33   -26 .33   141 .33
CRX340A  1744 1783     0 .48    19 .46   -58 .45    44 .45   -41 .42   -39 .37    84 .37    71 .36   119 .36   139 .35   -18 .35
CRX340A  1749 1788   -58 .44     0 .43   -39 .43    19 .42   139 .41    71 .41   -18 .40   119 .39    44 .38   -17 .34   -40 .32
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APPENDIX A8. *continued*

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CRX340A  1754 1793   -18 .55     0 .45   139 .42   207 .34   100 .33   -40 .32    56 .32    19 .31   -41 .30   -59 .30    17 .29
CRX340A  1759 1798   -18 .45   100 .44   -22 .36   127 .35    78 .35    56 .33   207 .31     0 .29   -40 .28   -36 .28   -44 .26
CRX340A  1760 1799  Lag from prior segment   1 years; insufficient
     6 segments  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -

Number of segments
       Add No R_av   Add No R_av   Add No R_av   Add No R_av   Add No R_av   Add No R_av   Add No R_av   Add No R_av
       -18  6  .40    +0  6  .45   -40  5  .34   +19  5  .41   +44  4  .43   +71  4  .38  +139  4  .39   -41  3  .35
       -39  3  .38
 Chronological order
       Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No
       -41  3    -40  5    -39  3    -18  6     +0  6    +19  5    +44  4    +71  4   +139  4

          Counted        Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr
 Series    Segment   Add  # 1  Add  # 2  Add  # 3  Add  # 4  Add  # 5  Add  # 6  Add  # 7  Add  # 8  Add  # 9  Add  #10  Add  #11
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 CRX341A  1730 1769    27 .37   116 .35   126 .34   -17 .33    26 .33   128 .32    28 .30   198 .29   119 .29     1 .27   -42 .27
 CRX341A  1735 1774     0 .47   -17 .43   162 .42   100 .40   119 .36     1 .31   230 .30    27 .28   128 .28   222 .27   -18 .27
 CRX341A  1740 1779   100 .46     0 .43   -17 .40     1 .35   -43 .33   164 .32   162 .32   222 .31   181 .30   206 .29   119 .29
 CRX341A  1745 1784   100 .48     0 .45   -17 .39     1 .34   222 .33   -58 .33   191 .32   123 .32   -43 .31   162 .30    84 .30
 CRX341A  1750 1789     0 .43   100 .39    84 .38   191 .36   -17 .36   -43 .34   206 .34   179 .31    54 .30   -58 .30    27 .30
 CRX341A  1755 1794     0 .50   -17 .38    84 .37   100 .35   123 .34   -43 .34   191 .33   179 .32   -25 .31     1 .30   -36 .30
 CRX341A  1757 1796     0 .48   100 .40    84 .39   -17 .39   -25 .36   123 .36   -43 .35   -36 .31    35 .31   162 .29    12 .28
     7 segments  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
 Number of segments
       Add No R_av   Add No R_av   Add No R_av   Add No R_av   Add No R_av   Add No R_av   Add No R_av   Add No R_av
       -17  7  .38    +0  6  .46  +100  6  .41    +1  5  .31   -43  5  .33   +84  4  .36  +162  4  .33  +119  3  .31
      +123  3  .34   +27  3  .31  +191  3  .34  +222  3  .31
 Chronological order
       Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No
       -43  5    -17  7     +0  6     +1  5    +27  3    +84  4   +100  6   +119  3   +123  3   +162  4   +191  3   +222  3

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           Counted       Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr
 Series    Segment   Add  # 1  Add  # 2  Add  # 3  Add  # 4  Add  # 5  Add  # 6  Add  # 7  Add  # 8  Add  # 9  Add  #10  Add  #11
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 CRX346A  1740 1779   -34 .53    26 .51    24 .45    51 .42    63 .42     0 .42   188 .39   137 .39    -8 .35   108 .34   205 .32
 CRX346A  1745 1784    26 .51   -34 .51    51 .47    24 .45     0 .44   -48 .41   188 .40    49 .39   137 .38   108 .38   193 .37
 CRX346A  1750 1789     0 .52   213 .36   170 .35    51 .34   -36 .32    81 .32   118 .31   189 .31   119 .30   -59 .28    10 .28
 CRX346A  1755 1794   -36 .43    82 .39   121 .37     0 .36   152 .32   119 .30   191 .30    22 .30   -26 .29   188 .28   189 .28
 CRX346A  1760 1799    82 .45   152 .41   -36 .40   -19 .38   188 .37     0 .35   204 .35   121 .34   -20 .29   205 .28    36 .28
 CRX346A  1763 1802   188 .49   -36 .39     0 .37   -19 .36   121 .35   -20 .34    82 .34   194 .33   204 .31   120 .31   152 .29
     6 segments  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
 Number of segments
       Add No R_av   Add No R_av   Add No R_av   Add No R_av   Add No R_av   Add No R_av   Add No R_av   Add No R_av
        +0  6  .41  +188  5  .39   -36  4  .39   +82  3  .39  +121  3  .35  +152  3  .34   +51  3  .41
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Chronological order
      Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No
      -36  4     +0  6    +51  3    +82  3   +121  3   +152  3   +188  5

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         Counted        Corr       Corr       Corr       Corr       Corr       Corr       Corr       Corr       Corr       Corr       Corr
 Series  Segment   Add  # 1  Add  # 2  Add  # 3  Add  # 4  Add  # 5  Add  # 6  Add  # 7  Add  # 8  Add  # 9  Add  #10  Add  #11
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 CRX348A  1765 1804    0 .53  152 .34  -58 .34   -8 .34  186 .34   51 .30  169 .30  -46 .30  -22 .29  -36 .29  -77 .29
 CRX348A  1770 1809    0 .49  -22 .41   51 .34  -58 .34  152 .34   -8 .33  186 .33  -77 .31   41 .29  171 .29  119 .29
 CRX348A  1772 1811    0 .48  -22 .42  -58 .36   41 .34  162 .33  171 .32  186 .32   51 .31   -8 .30  -77 .30  128 .29
      3 segments  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
 Number of segments
      Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av
      -77  3  .30    -58  3  .35    -22  3  .37     -8  3  .32     +0  3  .50    +51  3  .32   +186  3  .33

Chronological order
      Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No
      -77  3    -58  3    -22  3     -8  3     +0  3    +51  3   +186  3

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         Counted        Corr       Corr       Corr       Corr       Corr       Corr       Corr       Corr       Corr       Corr       Corr
 Series  Segment   Add  # 1  Add  # 2  Add  # 3  Add  # 4  Add  # 5  Add  # 6  Add  # 7  Add  # 8  Add  # 9  Add  #10  Add  #11
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 CRX349A  1745 1784    0 .42  -34 .42  169 .41  179 .37   72 .33   84 .32  111 .31  118 .31    7 .30  222 .30  215 .30
 CRX349A  1750 1789    0 .52  -18 .41  169 .38  107 .35  111 .33  179 .33  118 .32   72 .32  100 .32  101 .29  -58 .28
 CRX349A  1755 1794    0 .53  -36 .44  107 .40  179 .37  -18 .36  -70 .36  -58 .34  181 .33  191 .31  169 .30  152 .29
 CRX349A  1760 1799  -36 .45    0 .44  107 .40  -70 .39  -58 .38  152 .38  -18 .36  195 .35  179 .33  111 .32  100 .31
 CRX349A  1765 1804    0 .47  -36 .43    8 .39  127 .38  -70 .37  -18 .36  -58 .35  195 .34  100 .34  107 .34  160 .34
      5 segments  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
 Number of segments
      Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av
       +0  5  .48    -58  4  .34    -18  4  .37   +107  4  .37   +179  4  .35   +100  3  .32    -36  3  .44   +111  3  .32
     +169  3  .36    -70  3  .37
 Chronological order
      Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No
      -70  3    -58  4    -36  3    -18  4     +0  5   +100  3   +107  4   +111  3   +169  3   +179  4

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         Counted        Corr       Corr       Corr       Corr       Corr       Corr       Corr       Corr       Corr       Corr       Corr
 Series  Segment   Add  # 1  Add  # 2  Add  # 3  Add  # 4  Add  # 5  Add  # 6  Add  # 7  Add  # 8  Add  # 9  Add  #10  Add  #11
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 CRX350A  1761 1800  -70 .44   27 .42  107 .40    0 .39   88 .38   97 .37   29 .33  126 .32  145 .31  -19 .30  195 .29
 CRX350A  1766 1805    0 .42   27 .39   29 .37  -70 .36   88 .35  -22 .34    8 .33   80 .32   96 .32  -12 .31   37 .30
 CRX350A  1771 1810   27 .51    0 .42  -22 .36   37 .35  -70 .34  107 .34    8 .33   29 .32   59 .32   80 .30   96 .29
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 CRX350A  1776 1815    29 .35   -22 .35   -59 .34   107 .34    59 .33   -60 .33    27 .32    12 .30     0 .29    80 .29    81 .28
 CRX350A  1781 1820   -59 .44   -96 .44    59 .43     0 .43    12 .40   -60 .39    29 .38   -42 .34    81 .34    42 .33   -70 .32
      5 segments  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
 Number of segments
       Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av
        +0  5  .39    +29  5  .35    -70  4  .36    +27  4  .41    -22  3  .35    +59  3  .36    +80  3  .30   +107  3  .36

Chronological order
       Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No
       -70  4    -22  3     +0  5    +27  4    +29  5    +59  3    +80  3   +107  3

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           Counted      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr
 Series    Segment  Add  # 1  Add  # 2  Add  # 3  Add  # 4  Add  # 5  Add  # 6  Add  # 7  Add  # 8  Add  # 9  Add  #10  Add  #11
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 CRX351A  1889 1928    0 .56 -127 .55   -43 .49 -185 .37 -102 .37    43 .31    26 .31    77 .29 -173 .28   -29 .27   -86 .27
 CRX351A  1894 1933 -127 .52    0 .48   -43 .47 -185 .38 -152 .35 -102 .34 -115 .32 -198 .31 -186 .31 -174 .30    26 .30
=================== ======== ======== ======== ======== ======== ======== ======== ======== ======== ======== ========
           Counted      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr
 Series    Segment  Add  # 1  Add  # 2  Add  # 3  Add  # 4  Add  # 5  Add  # 6  Add  # 7  Add  # 8  Add  # 9  Add  #10  Add  #11

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 CRX352A  1892 1931    0 .43    64 .37 -185 .37 -127 .33 -173 .32   -43 .29 -102 .29 -115 .28   -51 .28    31 .28 -125 .28
 CRX352A  1896 1935    0 .46 -173 .39 -127 .37 -185 .32    64 .31   -43 .30   -64 .30    65 .29 -115 .28 -102 .26   -26 .26
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APPENDIX A9. COFECHA dating adjustments for fire-scarred samples at CRT.

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PART 8:  ADJUSTMENTS FOR UNDATED SERIES: CRT                                                        15:58  Mon 09 Nov 2009  Page   2

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 Time span  1684  2006   323 years, best matches for  40-year segments lagged   5 years
 Listed in order from highest correlation

           Counted        Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr
 Series    Segment    Add  # 1  Add  # 2  Add  # 3  Add  # 4  Add  # 5  Add  # 6  Add  # 7  Add  # 8  Add  # 9  Add  #10  Add  #11
 -------- ---------  --------  --------  --------  --------  --------  --------  --------  --------  --------  --------  --------
 CRT304A  1834 1873   -16 .50   -49 .44     0 .42  -125 .40    52 .38    68 .36    23 .36    91 .34    27 .33    95 .32    90 .31
 CRT304A  1839 1878     0 .45    27 .44   -49 .42  -125 .41   -16 .39    95 .38  -100 .36    74 .35    91 .35     4 .33    52 .33
 CRT304A  1844 1883   -49 .50     0 .49    27 .44   -16 .42  -100 .39     4 .37  -158 .37    68 .36    90 .34  -125 .33    21 .32
 CRT304A  1849 1888   -49 .53     0 .52    27 .43   -76 .39   -16 .38  -100 .37    21 .36     4 .36  -158 .34   -59 .31    23 .31
 CRT304A  1854 1893     0 .55   -49 .52    27 .48  -158 .40  -100 .38  -122 .36    23 .36   -76 .35   -59 .33    91 .32    68 .31
 CRT304A  1859 1898     0 .55  -100 .47   -49 .46  -158 .45    27 .38    91 .38    81 .36  -122 .36   -59 .36    72 .34   -99 .34
 CRT304A  1864 1903     0 .51  -100 .46  -158 .45    81 .41   -88 .36    91 .36  -177 .35   -99 .35   -49 .35    23 .34  -159 .34
 CRT304A  1869 1908  -100 .48     0 .48    91 .38   -75 .38  -158 .37  -177 .35    23 .34   -88 .34   -29 .33   -99 .33    27 .33
 CRT304A  1874 1913  -129 .35  -187 .34    84 .34    53 .33  -127 .31     4 .31   -38 .30    -2 .29    67 .29  -145 .29  -146 .28
 CRT304A  1875 1914  Lag from prior segment   1 years; insufficient
      9 segments  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
 Number of segments
       Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av
        +0  8  .50   -100  7  .42    -49  7  .46    +27  7  .41   -158  6  .40    +91  6  .35    +23  5  .34     +4  4  .34
       -16  4  .42    -59  3  .33    -99  3  .34    +68  3  .35   -125  3  .38
 Chronological order
       Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No
      -158  6   -125  3   -100  7    -99  3    -59  3    -49  7    -16  4     +0  8     +4  4    +23  5    +27  7    +68  3    +91  6

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           Counted        Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr
 Series    Segment    Add  # 1  Add  # 2  Add  # 3  Add  # 4  Add  # 5  Add  # 6  Add  # 7  Add  # 8  Add  # 9  Add  #10  Add  #11
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 CRT307A  1868 1907    79 .45   -12 .41  -141 .40  -148 .38  -170 .35    36 .34  -104 .34  -114 .33  -150 .32   -85 .32  -112 .31
 CRT307A  1873 1912    79 .56   -14 .40  -170 .37  -112 .37  -141 .36    16 .35    48 .32  -159 .32   -53 .31   -61 .30  -150 .30
 CRT307A  1878 1917    79 .66  -159 .53  -141 .41    48 .39  -116 .37   -16 .33   -41 .32   -15 .32   -14 .31  -112 .29   -59 .28
 CRT307A  1883 1922    79 .53  -159 .50  -141 .45  -116 .38   -59 .38   -22 .38    15 .35   -15 .34   -71 .34   -89 .34    11 .34
 CRT307A  1888 1927  -141 .57  -159 .49   -59 .44    79 .43  -116 .40   -89 .35  -133 .34   -22 .33   -16 .31   -53 .31   -14 .29
 CRT307A  1893 1932  -141 .58   -22 .41   -59 .39  -112 .35    54 .35    15 .35  -161 .34  -195 .34   -53 .33  -201 .32  -159 .29
 CRT307A  1898 1937     0 .56  -162 .41   -22 .39   -43 .37    15 .36   -51 .34  -125 .33   -41 .32   -53 .30    19 .29   -78 .29
 CRT307A  1903 1942     0 .59  -162 .43   -78 .40   -22 .39    19 .36    51 .33   -41 .31   -51 .30   -53 .30    15 .29    63 .27
 CRT307A  1908 1947     0 .62   -78 .43    19 .38  -162 .36    51 .33   -10 .33  -106 .31   -22 .30    10 .29   -49 .29  -220 .29
 CRT307A  1913 1952     0 .72   -78 .46    19 .41    51 .40  -162 .37   -17 .37   -10 .31   -41 .31  -118 .29  -108 .29   -88 .28
 CRT307A  1918 1957     0 .73  -162 .49   -17 .48   -78 .46    19 .39   -10 .35   -88 .34    41 .34   -49 .33  -101 .32  -133 .31
 CRT307A  1923 1962     0 .65  -162 .51  -222 .41   -49 .37    19 .34   -97 .34   -10 .34   -17 .33   -78 .32  -133 .29   -74 .29
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 CRT307A  1928 1967     0 .58  -162 .55  -222 .45   -97 .40   -49 .37   -10 .33    19 .32  -152 .31   -78 .30   -88 .30   -74 .28
 CRT307A  1933 1972     0 .47  -162 .42   -49 .41  -198 .35   -97 .35  -222 .34   -17 .33  -127 .33   -10 .31  -114 .27  -152 .27
 CRT307A  1938 1977  -160 .43  -215 .38   -97 .38   -49 .36   -60 .34  -127 .32    -7 .31   -17 .31  -187 .31  -144 .30  -147 .30

CRT307A  1939 1978  Lag from prior segment   1 years; insufficient
     15 segments  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
 Number of segments
       Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av
      -162  8  .44     +0  8  .61    -78  7  .38    +19  7  .36    -49  6  .35    -22  6  .36    -10  6  .33  -141  6  .46
      -159  5  .43    -53  5  .31    -17  5  .36    +79  5  .53    -41  4  .31    -59  4  .37  -112  4  .33   +15  4  .34
       -97  4  .37  -116  3  .38  -222  3  .40  -133  3  .31    -14  3  .33    +51  3  .35    -88  3  .31
 Chronological order
       Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No
      -222  3  -162  8  -159  5  -141  6  -133  3  -116  3  -112  4   -97  4   -88  3   -78  7   -59  4   -53  5   -49  6   -41  4
       -22  6   -17  5   -14  3   -10  6    +0  8   +15  4   +19  7   +51  3   +79  5

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          Counted        Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr
 Series   Segment    Add  # 1  Add  # 2  Add  # 3  Add  # 4  Add  # 5  Add  # 6  Add  # 7  Add  # 8  Add  # 9  Add  #10  Add  #11
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 CRT308A  1823 1862   132 .44    68 .43  -119 .41   -59 .39    23 .37    29 .35   -84 .34    80 .33   -30 .33   -65 .32   -36 .30
 CRT308A  1828 1867    68 .44     0 .42   -59 .41  -119 .38   132 .37    -8 .36    23 .35   -65 .34    29 .34   -84 .32   123 .31
 CRT308A  1833 1872     0 .52  -119 .40   130 .39   -36 .38   -30 .35   -65 .33    97 .33   107 .33    78 .33   -59 .32  -118 .32
 CRT308A  1838 1877     0 .49    68 .44   -73 .37   -30 .36    78 .34    48 .33   -19 .32  -118 .31  -110 .31  -119 .31    38 .31
 CRT308A  1843 1882     0 .46    68 .43   -30 .40   -73 .38    89 .34    78 .34   -92 .34   123 .33  -127 .33   -65 .32   -90 .29
 CRT308A  1848 1887  -161 .54     0 .45   -90 .41    37 .38    68 .36    89 .33   -92 .31   -30 .31    78 .31   -84 .31  -127 .29
 CRT308A  1853 1892     0 .45  -161 .45   -84 .36    68 .34    37 .34  -101 .33   -90 .32  -102 .30    -6 .30   -30 .30  -110 .29
 CRT308A  1858 1897   -39 .50    68 .38    26 .38     0 .35   -52 .35  -149 .33    49 .33   -90 .32    37 .31  -115 .30  -148 .30
      8 segments  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
 Number of segments
       Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av
        +0  7  .45    +68  7  .40    -30  6  .34    -65  4  .33    -84  4  .33  -119  4  .37    -90  4  .34    +78  4  .33
       -59  3  .38    +37  3  .34
 Chronological order
       Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No
      -119  4   -90  4   -84  4   -65  4   -59  3   -30  6    +0  7   +37  3   +68  7   +78  4
===================  ========  ========  ========  ========  ========  ========  ========  ========  ========  ========  ========
          Counted        Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr
 Series   Segment    Add  # 1  Add  # 2  Add  # 3  Add  # 4  Add  # 5  Add  # 6  Add  # 7  Add  # 8  Add  # 9  Add  #10  Add  #11
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 CRT312A  1780 1819   -10 .54     0 .40   -96 .35    89 .34   -56 .34    41 .33    17 .32   154 .32   142 .32    15 .31   101 .30
 CRT312A  1785 1824     0 .47    89 .46   -41 .37   -78 .37   -59 .33    60 .32   -76 .30    17 .30   -96 .29    82 .29   123 .29
 CRT312A  1790 1829     0 .46    89 .39   -78 .36   -41 .35   -59 .33   -76 .31    17 .29    60 .29    43 .29   123 .28    82 .27
 CRT312A  1795 1834    63 .42     0 .41   -41 .38   -59 .37    89 .37   -95 .36   -33 .35   -58 .32   131 .31    60 .31    41 .29
 CRT312A  1800 1839     0 .49   -41 .44    86 .41   -59 .39   -58 .37    -6 .37    63 .36   -33 .32   -95 .31    82 .30   -55 .30
 CRT312A  1805 1844   -29 .48     0 .46   -58 .44   -41 .41   -59 .37    82 .35    86 .33   -92 .31   133 .31   154 .31   -33 .30
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CRT312A  1807 1846   -29 .52     0 .47   -58 .46   -41 .42    82 .38   -59 .38   -84 .37   104 .33   154 .32    86 .31    30 .31
      7 segments  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
 Number of segments
       Add  No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av
        +0   7  .45    -41   6  .39    -59  6  .36    +82  5  .32    -58  4  .40    +89  4  .39    +60  3  .31    -33  3  .32
       +86   3  .35    +17   3  .30  +154  3  .31

Chronological order
       Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No
       -59  6   -58  4   -41  6   -33  3    +0  7   +17  3   +60  3   +82  5   +86  3   +89  4  +154  3
=================== ======== ======== ======== ======== ======== ======== ======== ======== ======== ======== ========
         Counted       Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr
 Series  Segment   Add  # 1  Add  # 2  Add  # 3  Add  # 4  Add  # 5  Add  # 6  Add  # 7  Add  # 8  Add  # 9  Add  #10  Add  #11
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 CRT314A  1678 1717   142 .46    58 .45   180 .38   110 .37    24 .36    32 .35   273 .31    78 .28   249 .28   129 .28    51 .28
 CRT314A  1683 1722    58 .46   142 .46   274 .39   159 .39   240 .37    24 .36   110 .36    50 .32   210 .31   136 .30    32 .29
 CRT314A  1688 1727    58 .47   159 .45   142 .43     0 .41   210 .40   136 .40   130 .36    24 .34   249 .34   110 .33   274 .32
 CRT314A  1693 1732   249 .47    58 .45     0 .42   159 .41   136 .39   250 .38    83 .35   143 .35   106 .34   274 .34   110 .34
 CRT314A  1698 1737     0 .52   249 .50   159 .41   250 .40    83 .40   143 .37   136 .35    70 .34    58 .34   106 .34    11 .33
 CRT314A  1703 1742     0 .70    70 .54   249 .46    83 .43   136 .43   143 .40   159 .39   110 .35    97 .35   106 .32    26 .31
 CRT314A  1708 1747     0 .69   136 .47    83 .41   249 .40   143 .39    70 .39    97 .38   -19 .36    58 .35   159 .33   240 .30
      7 segments  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
 Number of segments
       Add  No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av
       +58   6  .42   +136   6  .39   +159  6  .40   +249  6  .41   +110  5  .35     +0  5  .55    +83  4  .40   +143  4  .38
      +142   3  .45    +24   3  .35   +106  3  .34    +70  3  .42   +274  3  .35
 Chronological order
       Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No
        +0  5   +24  3   +58  6   +70  3   +83  4  +106  3  +110  5  +136  6  +142  3  +143  4  +159  6  +249  6  +274  3

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         Counted       Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr
 Series  Segment   Add  # 1  Add  # 2  Add  # 3  Add  # 4  Add  # 5  Add  # 6  Add  # 7  Add  # 8  Add  # 9  Add  #10  Add  #11
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 CRT315A  1858 1897  -165 .41  -100 .40   -16 .40     0 .39    48 .37   106 .37   -68 .35   -88 .35   -53 .34  -146 .34   -23 .33
 CRT315A  1863 1902  -100 .53     0 .43  -126 .39   -16 .38   -23 .38   -89 .35    55 .33   -99 .33    82 .31  -107 .29  -145 .29
 CRT315A  1868 1907  -100 .44     0 .43    63 .37   -23 .37    82 .36  -107 .33   -99 .32  -183 .31   -89 .31  -126 .31  -177 .30
 CRT315A  1873 1912    63 .56    -5 .42  -107 .35   -89 .35   -23 .35   -99 .35  -167 .33   -70 .33  -148 .30    82 .29  -130 .29
 CRT315A  1878 1917    63 .50    -5 .48  -167 .40   -32 .35   -89 .33  -148 .33  -107 .31   -23 .30    48 .28    82 .27    29 .27
 CRT315A  1883 1922    -5 .44    63 .37   -32 .36    -4 .33   -89 .32    48 .30   -26 .30  -132 .29  -166 .26    58 .26  -148 .26
 CRT315A  1888 1927  -132 .46   -89 .41    -4 .40    -5 .36    63 .36   -22 .34    48 .34   -59 .33  -149 .33  -169 .31  -201 .30
 CRT315A  1893 1932  -132 .45  -158 .42    -5 .40  -201 .38   -92 .37    64 .37   -74 .37  -166 .36  -133 .34  -106 .34  -204 .34
 CRT315A  1898 1937  -166 .42   -74 .40  -106 .39     0 .39  -158 .39  -132 .39  -204 .38  -121 .37  -133 .36  -203 .35    63 .34
 CRT315A  1903 1942  -121 .41  -106 .41     0 .39  -132 .38  -158 .38  -133 .36  -203 .34  -216 .34   -22 .33  -204 .33   -68 .32
 CRT315A  1908 1947  -106 .47     0 .45  -133 .42  -118 .37  -204 .35  -121 .34  -152 .31    48 .30    19 .30   -10 .30  -178 .29
     11 segments  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
```

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Number of segments
       Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av
       -89  6  .35     +0  6  .41    +63  6  .42   -132  5  .39    -23  5  .35     -5  5  .42    +48  5  .32   -107  4  .32
      -106  4  .40   -204  4  .35   -133  4  .37    +82  4  .31    -99  3  .33   -148  3  .30   -166  3  .35   -121  3  .38
      -158  3  .40   -100  3  .46
 Chronological order
       Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No
      -204  4   -166  3   -158  3   -148  3   -133  4   -132  5   -121  3   -107  4   -106  4   -100  3    -99  3    -89  6    -23  5     -5  5
        +0  6    +48  5    +63  6    +82  4

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          Counted       Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr
 Series   Segment   Add  # 1  Add  # 2  Add  # 3  Add  # 4  Add  # 5  Add  # 6  Add  # 7  Add  # 8  Add  # 9  Add  #10  Add  #11
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 CRT316A  1857 1896    0 .45     8 .40    19 .37    39 .37  -145 .36   -99 .36   -76 .35   103 .35  -137 .35  -119 .34   -29 .34
 CRT316A  1862 1901 -145 .51     0 .49  -127 .46   -76 .37  -119 .35  -100 .34   -99 .33   -29 .32    45 .32    55 .32   -27 .31
 CRT316A  1867 1906    0 .53  -127 .48  -145 .45   -76 .38   -99 .36  -125 .36   -29 .33    45 .33    -6 .33  -107 .32  -159 .29
 CRT316A  1872 1911    0 .53  -127 .50  -145 .36    45 .36   -29 .35   -35 .32    80 .31   -43 .30    -6 .30  -107 .29   -27 .29
 CRT316A  1877 1916 -127 .56     0 .50    45 .41  -145 .39   -43 .34   -35 .33  -107 .31  -119 .30    87 .30   -27 .30  -133 .30
 CRT316A  1882 1921 -127 .54    -6 .45     0 .42  -145 .41    45 .40   -43 .35    -4 .34  -119 .32   -35 .31  -107 .31  -133 .30
 CRT316A  1887 1926 -127 .58  -203 .41    -6 .40  -107 .40     0 .39  -145 .36    45 .36   -43 .35  -170 .34    80 .32  -133 .32
 CRT316A  1892 1931 -204 .63  -127 .54  -133 .43    -5 .42    -6 .41  -203 .39  -107 .38     0 .36    64 .36  -152 .35   -43 .35
 CRT316A  1894 1933 -204 .62  -127 .54  -133 .42    -6 .42     0 .40    -5 .40  -203 .38  -107 .36   -43 .35    64 .34  -152 .34
      9 segments  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
 Number of segments
       Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av
        +0  9  .45   -127  8  .52   -145  7  .40   -107  7  .34    -43  6  .34     -6  6  .39    +45  6  .36   -133  5  .35
      -119  4  .33    -29  4  .34    -35  3  .32    -27  3  .30    -76  3  .37   -203  3  .39    -99  3  .35
 Chronological order
       Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No
      -203  3   -145  7   -133  5   -127  8   -119  4   -107  7    -99  3    -76  3    -43  6    -35  3    -29  4    -27  3     -6  6     +0  9
       +45  6

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          Counted       Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr
 Series   Segment   Add  # 1  Add  # 2  Add  # 3  Add  # 4  Add  # 5  Add  # 6  Add  # 7  Add  # 8  Add  # 9  Add  #10  Add  #11
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 CRT317A  1869 1908    0 .46    12 .42   -99 .39    53 .38    20 .38    -7 .38  -145 .38  -125 .36  -107 .33  -178 .33    42 .31
 CRT317A  1874 1913    0 .49    34 .46    53 .43  -118 .38    20 .35  -127 .32   -72 .31    44 .31    68 .31  -107 .29    -7 .29
 CRT317A  1879 1918 -118 .41    53 .41    34 .37   -72 .37  -164 .36     0 .35  -178 .33   -42 .33    20 .32    87 .31  -143 .30
 CRT317A  1882 1921 -118 .52    53 .43   -67 .42   -42 .37  -197 .36   -72 .33     0 .32  -126 .32  -178 .32  -143 .31  -103 .31
      4 segments  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
 Number of segments
       Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av
        +0  4  .40    +53  4  .41    -72  3  .34   -178  3  .33    +20  3  .35   -118  3  .44
 Chronological order
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Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No
     -178  3  -118  3   -72  3    +0  4   +20  3   +53  4

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          Counted       Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr
 Series   Segment   Add  # 1  Add  # 2  Add  # 3  Add  # 4  Add  # 5  Add  # 6  Add  # 7  Add  # 8  Add  # 9  Add  #10  Add  #11
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 CRT318A  1872 1911    0 .49  -99 .45 -111 .44 -183 .42  -35 .41  -84 .40 -145 .38   68 .38   53 .37    4 .32 -119 .31
 CRT318A  1877 1916 -111 .53    0 .50 -145 .42  -84 .41   53 .40  -99 .40 -183 .38   68 .35 -100 .34 -137 .33  -35 .32
 CRT318A  1882 1921 -111 .53 -196 .49    0 .43 -100 .43  -84 .42 -183 .41   53 .41  -99 .39  -35 .38 -197 .38   16 .35


 CRT318A  1887 1926 -196 .59 -100 .45    0 .43   68 .38  -41 .37    1 .34  -35 .33 -178 .33 -140 .33 -111 .32 -195 .32
 CRT318A  1892 1931    1 .41  -86 .36 -100 .35 -157 .35 -140 .34   34 .33  -16 .31  -64 .30   68 .29 -178 .27  -41 .27
 CRT318A  1894 1933    1 .49  -86 .36  -16 .35   34 .34 -113 .33 -100 .32 -161 .32   68 .31 -157 .30  -64 .29 -183 .29
      6 segments  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
 Number of segments
       Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av
      -100  5  .38    +68  5  .34   -183  4  .37    -35  4  .36     +0  4  .46   -111  4  .45    -84  3  .41     +1  3  .41
       +53  3  .39    -99  3  .41
 Chronological order
       Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No
      -183  4  -111  4  -100  5   -99  3   -84  3   -35  4    +0  4    +1  3   +53  3   +68  5

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          Counted       Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr
 Series   Segment   Add  # 1  Add  # 2  Add  # 3  Add  # 4  Add  # 5  Add  # 6  Add  # 7  Add  # 8  Add  # 9  Add  #10  Add  #11
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 CRT319A  1823 1862    0 .44  -84 .42   80 .41   37 .38    6 .33  129 .33  -59 .32 -136 .31   78 .30  -78 .30   35 .30
 CRT319A  1828 1867    0 .57   37 .41  -59 .38  107 .37  -84 .37 -142 .34 -106 .32   80 .32  -30 .30   78 .28  129 .28

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          Counted       Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr
 Series   Segment   Add  # 1  Add  # 2  Add  # 3  Add  # 4  Add  # 5  Add  # 6  Add  # 7  Add  # 8  Add  # 9  Add  #10  Add  #11
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 CRT319B  1839 1878 -155 .49   97 .41 -119 .40    0 .40  -13 .37   29 .35  -26 .35   80 .34   61 .34  -97 .33 -154 .33

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          Counted       Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr
 Series   Segment   Add  # 1  Add  # 2  Add  # 3  Add  # 4  Add  # 5  Add  # 6  Add  # 7  Add  # 8  Add  # 9  Add  #10  Add  #11
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 CRT401A  1870 1909    0 .53 -102 .52  -48 .42 -145 .36  -61 .36   -2 .33 -119 .33 -127 .33   60 .32 -148 .31 -179 .31
 CRT401A  1875 1914    0 .57   68 .39  -48 .37  -84 .34  -27 .33  -99 .30 -127 .30 -119 .29 -145 .29 -157 .29   41 .28
 CRT401A  1880 1919    0 .57   68 .47   84 .42 -145 .38  -45 .34  -61 .33 -127 .32 -147 .32  -27 .31  -99 .29   41 .29
 CRT401A  1885 1924    0 .54  -61 .40  -45 .36   68 .36  -38 .36 -127 .36 -181 .34   15 .32 -145 .32  -26 .30   32 .30
 CRT401A  1890 1929    0 .59  -61 .48  -38 .40 -203 .39   68 .37 -147 .35 -145 .33  -75 .33   15 .31 -127 .30  -45 .30
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 CRT401A  1895 1934     0 .54  -203 .40  -127 .36   -42 .36  -145 .35  -164 .34    68 .34   -61 .34   -86 .32  -149 .32    15 .31
 CRT401A  1900 1939  -164 .52    17 .50     0 .46  -138 .40   -42 .38  -112 .38   -38 .38    42 .36  -127 .33  -145 .32    43 .28
      7 segments  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
 Number of segments
       Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av
      -145  7  .34  -127  7  .33    +0  7  .54   -61  5  .38   +68  5  .39   -45  3  .34   +15  3  .31   -38  3  .38
 Chronological order
       Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No
      -145  7 -127  7   -61  5   -45  3   -38  3    +0  7   +15  3   +68  5

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          Counted       Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr
 Series   Segment    Add  # 1  Add  # 2  Add  # 3  Add  # 4  Add  # 5  Add  # 6  Add  # 7  Add  # 8  Add  # 9  Add  #10  Add  #11
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 CRT402A  1863 1902    90 .54  -175 .43  -123 .42    51 .37     4 .37   -63 .33  -160 .32   -39 .31    68 .31  -157 .31  -159 .31
 CRT402A  1868 1907  -169 .43    90 .43   -39 .38  -159 .37  -123 .37   -63 .35    25 .34     4 .32   -72 .32  -175 .31  -160 .31
 CRT402A  1873 1912   -51 .43  -123 .42     4 .42  -169 .42   -72 .39    36 .38  -159 .36    58 .34   -23 .33    90 .33    80 .32
 CRT402A  1878 1917     4 .48    36 .44  -169 .41   -51 .41  -193 .40    19 .38   -32 .35    58 .34   -23 .33  -159 .33  -141 .33
 CRT402A  1883 1922    19 .49     4 .45  -181 .42  -141 .39   -23 .38  -169 .38   -51 .37  -133 .36    58 .35   -32 .35    71 .35
 CRT402A  1888 1927  -141 .54    19 .46  -133 .45  -170 .43   -52 .35    29 .35    38 .31   -32 .30   -26 .30   -82 .29     4 .28
 CRT402A  1893 1932  -141 .50    19 .43  -170 .42  -133 .40    38 .37    29 .36   -52 .34   -26 .31  -178 .30   -82 .30   -34 .28
 CRT402A  1898 1937  -133 .47    19 .46  -141 .39  -170 .38     6 .36    38 .35   -82 .35  -178 .33   -51 .31   -34 .30   -26 .29
 CRT402A  1903 1942  -133 .45    19 .44     0 .39  -152 .35    38 .35   -26 .35  -141 .31  -153 .31  -170 .31     6 .30  -178 .30
 CRT402A  1908 1947  -133 .56     0 .50    19 .48  -152 .39  -118 .39    38 .31   -45 .30  -189 .30  -141 .28   -30 .28    58 .27
 CRT402A  1913 1952     0 .57  -133 .52    19 .41  -152 .35   -17 .34  -118 .33   -45 .31   -32 .31   -10 .31  -229 .31   -30 .29
 CRT402A  1918 1957     0 .60  -152 .42   -17 .41  -133 .38   -10 .37   -68 .34  -144 .30  -229 .30  -230 .29  -211 .29    19 .28
 CRT402A  1923 1962     0 .59  -152 .42  -133 .38   -68 .36   -17 .32   -10 .31  -230 .30  -190 .29  -144 .29   -32 .28  -170 .28
 CRT402A  1928 1967     0 .56  -215 .36  -116 .35  -190 .34  -194 .32   -97 .32    35 .32   -72 .31   -68 .31   -10 .31   -32 .30
 CRT402A  1933 1972     0 .59   -32 .45  -194 .38  -248 .38  -152 .35   -10 .35   -68 .33  -116 .33    26 .33  -144 .32   -74 .29
 CRT402A  1938 1977     0 .62   -32 .45   -68 .42    26 .40  -152 .38   -10 .34  -194 .33  -195 .31  -204 .30  -248 .29  -116 .29
 CRT402A  1943 1982     0 .54   -81 .39   -32 .37   -68 .34  -230 .34  -152 .33    19 .32  -195 .32  -103 .31  -248 .31  -196 .30
 CRT402A  1948 1987     0 .49   -68 .46  -195 .44   -32 .38  -142 .37  -251 .36   -13 .36  -103 .36  -152 .31  -196 .30   -81 .30
 CRT402A  1953 1992   -68 .46  -195 .45     0 .39   -55 .36  -196 .36  -142 .35   -13 .33  -222 .32   -96 .32  -239 .31   -81 .30
 CRT402A  1958 1997   -68 .44   -13 .44  -142 .42  -163 .37  -272 .36   -26 .35   -55 .34  -195 .33  -165 .31  -130 .30  -273 .28
 CRT402A  1963 2002   -68 .41   -26 .41  -195 .39  -169 .38  -272 .38  -163 .34  -130 .33  -239 .32   -24 .31   -55 .31     0 .29
 CRT402A  1968 2007  -195 .43   -68 .40   -26 .39  -169 .38  -142 .37  -163 .36  -273 .34   -55 .34  -196 .29   -77 .29   -96 .29
     22 segments  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
 Number of segments
       Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av
        +0 12  .51   -68 11  .39   -32 10  .35   +19 10  .41  -152  9  .37  -133  9  .44  -141  7  .39   -26  7  .34
      -195  7  .38  -169  6  .40   -10  6  .33    +4  6  .38  -170  5  .36   +38  5  .34   -55  4  .34   -51  4  .38
      -196  4  .31  -159  4  .34  -142  4  .38   +58  4  .32  -230  3  .31  -178  3  .31  -123  3  .40  -116  3  .32
       -82  3  .31   -23  3  .35   -17  3  .36   -13  3  .38  -194  3  .34  -248  3  .33  -144  3  .30  -163  3  .36
       -81  3  .33   -72  3  .34   +90  3  .43
 Chronological order
       Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No
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APPENDIX A9. *continued*

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     -248   3  -230   3  -196   4  -195   7  -194   3  -178   3  -170   5  -169   6  -163   3  -159   4  -152   9  -144   3  -142   4  -141   7
     -133   9  -123   3  -116   3   -82   3   -81   3   -72   3   -68  11   -55   4   -51   4   -32  10   -26   7   -23   3   -17   3   -13   3
      -10   6    +0  12    +4   6   +19  10   +38   5   +58   4   +90   3

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         Counted         Corr     Corr     Corr     Corr     Corr     Corr     Corr     Corr     Corr     Corr     Corr
 Series  Segment    Add  # 1 Add  # 2 Add  # 3 Add  # 4 Add  # 5 Add  # 6 Add  # 7 Add  # 8 Add  # 9 Add  #10 Add  #11
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 CRT403A  1792 1831   63 .40   88 .39 -107 .39   53 .38   23 .38  -39 .36   90 .35  151 .35  175 .33  -73 .32  -95 .32
 CRT403A  1797 1836   53 .44  -73 .33  -74 .32   61 .32   89 .32 -111 .31 -110 .29   87 .27   88 .27  -95 .27  -55 .27
 CRT403A  1802 1841    0 .45  -73 .38   53 .38   61 .38  155 .37 -110 .35  156 .34  -74 .33   87 .33  -55 .30  -40 .30
 CRT403A  1807 1846    0 .47  -73 .45   53 .40  156 .38   87 .38   61 .33  -95 .32  -40 .31  155 .30  -13 .29  -96 .29

 CRT403A  1812 1851   53 .41  -40 .39   87 .37   11 .37    0 .36 -124 .34  -73 .33   61 .31 -125 .30   98 .30   57 .28
 CRT403A  1817 1856    0 .58  -84 .47  -32 .38  120 .34  -59 .34   68 .33  -13 .32   80 .31   98 .31   57 .29  143 .29
 CRT403A  1822 1861    0 .54  -84 .41   80 .34  -59 .33  -32 .33   68 .32  -46 .31  143 .31  -13 .30   98 .30 -106 .29
 CRT403A  1827 1866 -142 .60    0 .52  -84 .43  -59 .34   68 .34   80 .33 -106 .32 -143 .30  -46 .30  -13 .30  -32 .28
 CRT403A  1832 1871 -142 .56    0 .56  -84 .45  -59 .43   68 .39  107 .37   -6 .36 -143 .36 -106 .31  -32 .31  -46 .30
 CRT403A  1837 1876    0 .58 -142 .48  -84 .45  -59 .43   68 .39  107 .36 -143 .34  -46 .33   -6 .32 -106 .31   56 .29
 CRT403A  1842 1881    0 .52  -84 .47   68 .47 -142 .44   43 .38  107 .38  -59 .34  -46 .33 -109 .33  123 .30 -143 .30
     11 segments  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
 Number of segments
       Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av
        +0  9  .51    -84  6  .45    -59  6  .37    +68  6  .37    -73  5  .36    -46  5  .32    +53  5  .40   -142  4  .52
       -32  4  .32    -13  4  .30   -143  4  .32   -106  4  .31    +61  4  .34    +87  4  .34    -95  3  .30    +80  3  .33
       -40  3  .33    +98  3  .30   +107  3  .37
 Chronological order
       Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No
      -143  4   -142  4   -106  4    -95  3    -84  6    -73  5    -59  6    -46  5    -40  3    -32  4    -13  4     +0  9    +53  5    +61  4
       +68  6    +80  3    +87  4    +98  3   +107  3

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         Counted         Corr     Corr     Corr     Corr     Corr     Corr     Corr     Corr     Corr     Corr     Corr
 Series  Segment    Add  # 1 Add  # 2 Add  # 3 Add  # 4 Add  # 5 Add  # 6 Add  # 7 Add  # 8 Add  # 9 Add  #10 Add  #11
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 CRT404A  1819 1858 -102 .40    0 .36   35 .35   44 .33  -92 .32  106 .32  -56 .31   64 .31   28 .31 -120 .30   37 .29
 CRT404A  1824 1863   28 .40   71 .36  -56 .36  -31 .33 -102 .33  -91 .31   35 .31    0 .30   44 .29 -109 .29   80 .27
 CRT404A  1829 1868    0 .41  129 .38 -109 .38   39 .37  -79 .34  107 .34   -7 .32  -84 .32   35 .31  136 .31  -91 .30
      3 segments  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
 Number of segments
       Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av
        +0  3  .35    +35  3  .32

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         Counted         Corr     Corr     Corr     Corr     Corr     Corr     Corr     Corr     Corr     Corr     Corr
 Series  Segment    Add  # 1 Add  # 2 Add  # 3 Add  # 4 Add  # 5 Add  # 6 Add  # 7 Add  # 8 Add  # 9 Add  #10 Add  #11
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 CRT406A  1850 1889   -53 .60   113 .51  -136 .47   -66 .44   -78 .40   -70 .40    49 .37    19 .37    45 .34    23 .34    74 .33
 CRT406A  1855 1894   -53 .52  -126 .40    19 .39   -66 .39  -125 .34    23 .32    -6 .31   -29 .31    68 .30  -107 .29  -165 .29
 CRT406A  1860 1899   -53 .47    68 .46     0 .38  -107 .36    19 .34  -126 .34    87 .34   -29 .33   -66 .33   -82 .32     4 .28
 CRT406A  1865 1904    68 .47   -53 .41   -23 .40     0 .37     4 .35   -82 .32    87 .32    19 .32  -178 .32  -126 .31    64 .30
 CRT406A  1870 1909    68 .37  -125 .37     4 .37     0 .34  -107 .31   -53 .30   -66 .30  -178 .29  -140 .28  -145 .27   -26 .27
 CRT406A  1875 1914  -141 .40  -178 .40    72 .37   -70 .36     0 .33     4 .32  -145 .31   -57 .30    73 .30    45 .29  -125 .29
 CRT406A  1880 1919   -57 .42    72 .40  -141 .40    49 .34   -22 .33   -70 .33  -140 .32    73 .32  -145 .31  -178 .31    17 .30
 CRT406A  1885 1924  -144 .43  -141 .43   -22 .40  -178 .37    27 .34     0 .33   -81 .33  -177 .32    17 .32     8 .32  -106 .28
 CRT406A  1890 1929  -141 .50   -22 .43    27 .40  -144 .37   -89 .36     0 .33  -159 .32   -70 .31   -81 .30  -177 .29   -40 .29
 CRT406A  1895 1934     0 .49  -162 .46   -22 .40   -62 .34  -199 .33    17 .33   -51 .32   -43 .32   -61 .31  -121 .31  -179 .30
 CRT406A  1900 1939  -162 .55     0 .47   -22 .43    27 .40   -43 .38  -199 .36    51 .35    17 .34   -62 .32   -51 .32   -40 .31
 CRT406A  1905 1944  -162 .54     0 .48   -22 .44    51 .38  -188 .37    27 .36  -199 .35   -51 .34   -78 .33   -43 .33    17 .32
 CRT406A  1910 1949     0 .58  -162 .49  -188 .41   -22 .39   -78 .39  -187 .39  -199 .35   -51 .35    52 .34    51 .33   -70 .33
     13 segments  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -

Number of segments
       Add No R_av   Add No R_av   Add No R_av   Add No R_av   Add No R_av   Add No R_av   Add No R_av   Add No R_av
        +0 10  .41   -22  7  .40   -70  5  .35   -53  5  .46  -178  5  .34   +17  5  .32  -162  4  .51   -66  4  .36
       -51  4  .33  -141  4  .43  -199  4  .35    +4  4  .33   +19  4  .35   +27  4  .38   +68  4  .40  -107  3  .32
      -145  3  .30  -126  3  .35   -78  3  .37   -43  3  .34   +51  3  .35  -125  3  .33
 Chronological order
       Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No
      -199  4  -178  5  -162  4  -145  3  -141  4  -126  3  -125  3  -107  3   -78  3   -70  5   -66  4   -53  5   -51  4   -43  3
       -22  7    +0 10    +4  4   +17  5   +19  4   +27  4   +51  3   +68  4

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           Counted       Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr      Corr
 Series    Segment   Add  # 1  Add  # 2  Add  # 3  Add  # 4  Add  # 5  Add  # 6  Add  # 7  Add  # 8  Add  # 9  Add  #10  Add  #11
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 CRT407A  1739 1778   119 .49   149 .40     0 .38   130 .37   181 .37   -35 .34    54 .34   101 .34    82 .31   -18 .30    23 .29
 CRT407A  1744 1783   119 .44     0 .38   181 .35   130 .34   155 .34   149 .34    54 .30   213 .30   179 .30   -35 .30   138 .29
 CRT407A  1749 1788   181 .39   155 .37     0 .36   119 .36   179 .35   -35 .35   191 .33    88 .30    52 .29   213 .29    71 .28
 CRT407A  1754 1793     0 .47   179 .43   191 .38   155 .36    88 .36   181 .34    25 .34    52 .32    71 .32    -2 .29    27 .28
 CRT407A  1759 1798     0 .46   191 .37   -58 .35    -2 .35   155 .35    52 .33    49 .32   127 .31   179 .30    -3 .30    88 .29
 CRT407A  1763 1802    38 .45   136 .41   -60 .37   -58 .36     0 .36   -46 .35    -3 .33    24 .33    26 .33   155 .33   -48 .30
      6 segments  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
 Number of segments
       Add No R_av   Add No R_av   Add No R_av   Add No R_av   Add No R_av   Add No R_av   Add No R_av   Add No R_av
        +0  6  .40  +155  5  .35  +179  4  .34  +181  4  .36  +119  3  .43   -35  3  .33   +52  3  .31   +88  3  .32
      +191  3  .36
 Chronological order
       Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No    Add No
       -35  3    +0  6   +52  3   +88  3  +119  3  +155  5  +179  4  +181  4  +191  3

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          Counted       Corr        Corr        Corr        Corr        Corr        Corr        Corr        Corr        Corr        Corr        Corr
Series    Segment    Add   # 1   Add   # 2   Add   # 3   Add   # 4   Add   # 5   Add   # 6   Add   # 7   Add   # 8   Add   # 9   Add   #10   Add   #11
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CRT407B  1833 1872   -92 .42   -109 .39   -100 .39      0 .37     74 .37    -83 .36     27 .34   -110 .33    -91 .33    -74 .32     48 .32
CRT407B  1838 1877   -92 .50   -109 .42    -63 .40      0 .37     74 .36     64 .36    -83 .35    -10 .33     27 .33   -100 .33    -66 .32
CRT407B  1843 1882   -92 .52    -63 .41     53 .41      0 .40     27 .37     68 .37   -109 .36    -23 .36     74 .35   -147 .35     38 .34
CRT407B  1848 1887     0 .47     68 .42    -29 .39     51 .37   -147 .35     70 .34    -23 .33     49 .33    -59 .31   -148 .30     27 .28
CRT407B  1853 1892     0 .49    -29 .45     68 .44     51 .39   -147 .37     49 .37    -23 .34    102 .33     70 .32   -148 .31    -53 .31
CRT407B  1858 1897   -29 .55      0 .47     68 .47     51 .46     19 .43   -111 .43     49 .41   -126 .35    -88 .32    102 .31   -171 .31
CRT407B  1863 1902   -29 .57   -130 .42     51 .42      0 .38     61 .37     19 .37     49 .37    -46 .36   -147 .35   -152 .33    -89 .33
CRT407B  1868 1907   -29 .61     51 .39    -76 .39   -147 .39      0 .39     49 .37     61 .37   -130 .37     19 .36    -46 .35    -89 .34
CRT407B  1873 1912    61 .47    -29 .44   -130 .40    -46 .40     49 .38     -7 .36    -76 .35   -147 .35      0 .33     51 .33     19 .31
     9 segments  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
Number of segments
      Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av
       +0  9  .41    -29  6  .50   -147  6  .36    +49  6  .37    +51  6  .39    +19  4  .37    +27  4  .33    +68  4  .42
     -130  3  .40    -23  3  .34    -92  3  .48    -46  3  .37    +61  3  .40   -109  3  .39    +74  3  .36
Chronological order

 Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No
     -147  6  -130  3  -109  3   -92  3   -46  3   -29  6   -23  3    +0  9   +19  4   +27  4   +49  6   +51  6   +61  3   +68  4
      +74  3

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          Counted       Corr        Corr        Corr        Corr        Corr        Corr        Corr        Corr        Corr        Corr        Corr
Series    Segment    Add   # 1   Add   # 2   Add   # 3   Add   # 4   Add   # 5   Add   # 6   Add   # 7   Add   # 8   Add   # 9   Add   #10   Add   #11
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CRT411A  1784 1823   -97 .54      0 .46     31 .41     61 .40    -78 .39    101 .37    138 .35    -39 .34     70 .33    118 .33    152 .32
CRT411A  1789 1828   -97 .50      0 .49    152 .45    -78 .36     61 .34    107 .33    116 .32    174 .32    101 .32    -39 .31     31 .30
CRT411A  1794 1833     0 .43    -39 .42    140 .39     61 .35    -77 .35    152 .33    -76 .33     49 .31    128 .31    102 .30    118 .29
CRT411A  1796 1835     0 .47    -39 .46    140 .45    128 .39    152 .38    -77 .36    118 .30    -76 .29     -2 .28     61 .28     97 .28
     4 segments  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
Number of segments
      Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av    Add No R_av
      -39  4  .38     +0  4  .46    +61  4  .34   +152  4  .37   +118  3  .31
Chronological order
      Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No
      -39  4    +0  4   +61  4  +118  3  +152  4

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          Counted       Corr        Corr        Corr        Corr        Corr        Corr        Corr        Corr        Corr        Corr        Corr
Series    Segment    Add   # 1   Add   # 2   Add   # 3   Add   # 4   Add   # 5   Add   # 6   Add   # 7   Add   # 8   Add   # 9   Add   #10   Add   #11
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CRT412A  1710 1749    37 .46      0 .44     12 .40    110 .39     92 .36    159 .36    208 .34    119 .34     41 .33     29 .32     66 .31
CRT412A  1715 1754     0 .47     37 .46    208 .36    167 .36     92 .35     29 .33    -17 .33     66 .33     80 .33    137 .33    129 .31
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CRT412A  1720 1759     0 .48   232 .44    37 .41    29 .39   100 .35    92 .34   208 .34   129 .34   110 .33   137 .33   159 .31
CRT412A  1725 1764   232 .49    29 .46     0 .38   100 .36   208 .36   129 .34   110 .33    37 .33   148 .32   137 .31   159 .31
CRT412A  1730 1769   232 .49   129 .48    29 .37     0 .36    37 .35   148 .34    57 .34   110 .32    80 .32   201 .32   220 .31
     5 segments  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
Number of segments
      Add No R_av   Add No R_av   Add No R_av   Add No R_av   Add No R_av   Add No R_av   Add No R_av   Add No R_av
       +0  5  .42   +29  5  .37   +37  5  .40  +110  4  .34  +129  4  .37  +208  4  .35  +137  3  .32  +159  3  .33
      +92  3  .35  +232  3  .47
Chronological order
      Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No   Add No
       +0  5   +29  5   +37  5   +92  3  +110  4  +129  4  +137  3  +159  3  +208  4  +232  3
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VITA

Ian Corbett Feathers grew up near Bristol, Tennessee and attended Sullivan East High School. Thereafter, he earned the Associate of Science degree with emphasis in secondary education from Northeast State Technical Community College in Blountville, Tennessee. He then transferred to the University of Tennessee, Knoxville, where he earned the Bachelor of Arts degree with a major in geography with minors in history and secondary education. He graduated with *Magna cum Laude* honors and received the *Outstanding Undergraduate in Geography* award for 2006–2007. He also served as a student assistant in the Map Library and served as a student intern in the Laboratory of Tree-Ring Science. Upon completion of his Bachelor's degree, Ian was awarded a graduate assistantship in the Department of Geography at the University of Tennessee, Knoxville to further support his geographic research interests. Ian received the *Outstanding Teaching Assistant* award in 2007–2008. In 2008–2009, he served as Head Graduate Teaching Assistant for the *Introduction to the Natural Environment I & II* courses. In May of 2010, Ian was awarded the Master of Science degree in Geography. In his time off, you'll find him travelling the land with a backpack, playing various genres of music, and searching for the best experiences in life.