CHANGES IN FIRE REGIMES AND THE SUCCESSIONAL STATUS OF TABLE MOUNTAIN PINE (*Pinus pungens* Lamb.) IN THE SOUTHERN APPALACHIANS, USA

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DEDICATION

This thesis is dedicated to my wife
Tracey Reed-Armbrister
for her love, loyalty, and friendship.

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ABSTRACT

Table Mountain pine is a tree species endemic to the southern Appalachians that is heavily dependent on repeated surface fires for successful regeneration. Since the implementation of fire suppression as a forest management tool in the early 1900s, the fire frequency in Great Smoky Mountains National Park and surrounding National Forests has been dramatically altered. Without fire, Table Mountain pine will not persist in the southern Appalachian Mountains. I used dendrochronology to analyze the fire history and current age structure of Table Mountain pine populations. This approach provided baseline information on the current successional status of Table Mountain pine stands and their relationships with past fire. Cores were collected from a minimum of 75 trees at each of five study sites in Great Smoky Mountains National Park. Additionally, samples were taken from fire-scarred snags, stumps, and downed logs. Results indicated that the age structure of Table Mountain pine populations in the park exhibits a generally J-shaped distribution with the last major recruitment event occurring around 70 years ago. Fire history analysis indicated that the pre-park Weibull Median Fire Interval was 6.8 years, while the Maximum Hazard Interval, the longest fire-free period that can occur before burning is highly probable, was 80.6 years. These results indicate that the pre-park fire regime was characterized by frequent fires. Because the post-park fire interval has been dramatically increased by approximately 70 years of fire suppression, Table Mountain pine is being slowly extirpated from the southern Appalachian landscape. Data provided by the dendrochronological techniques used in this study are essential for the successful reintroduction of fire to regenerate Table Mountain pine in the region.

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1. INTRODUCTION

1.1 Background

Table Mountain pine (*Pinus pungens* Lamb.) is a genetically diverse species endemic to the Appalachian Mountains. The geographic range of Table Mountain pine extends from Pennsylvania to northern Georgia, while the elevational range varies between 305 and 1,220m (1,000 to 4,000 ft) (Della-Bianca 1990). *P. pungens* has medium to thick bark, serotinous cones, self-pruning limbs, a deep rooting habit, and is pitch producing, all of which are characteristics of trees adapted to repeated occurrences of surface fires (Della-Bianca 1990; Sutherland *et al.* 1995; Keeley and Zedler 1998). This tree is a secondary pioneer species that establishes quickly on sites that have been disturbed, especially by fire. Thus, Table Mountain pine plays a major role in the regeneration of mountain forests after major fire occurrences (Zobel 1969; Williams and Johnson 1990).

At the same time, Table Mountain pine has a lifespan of *ca.* 200 years (Zobel 1969), suggesting that the species not only helps to regenerate the forest after fire, but also becomes an integral member of the forest community. *P. pungens* provides a unique habitat for many animal species, such as white-tailed deer, wild turkey, scarlet tanagers, and ruffed grouse. The seeds of the tree provide food for many birds and small mammals; the mountain pine coneworm feeds only on the cones of this pine. Additionally, the serotinous cones of Table Mountain pine provide a food source that is available even when seed crops from other conifer species fail (Williams 1992).

Previous studies have shown Table Mountain pine to be a fire-dependent species (Zobel 1969; Williams *et al.* 1990; Williams and Johnson 1990; Sutherland *et al.* 1995; Waldrop and Brose 1999). Without fire, the reproductive success of Table Mountain pine is greatly reduced. The forest gradually changes from a pine-dominated stand into a forest of hardwood species. Due to this adjustment in forest composition and structure, Table Mountain pine may lose dominance, and perhaps be eliminated from the forest altogether. Hence, the existence of *P. pungens* in late successional stands may be jeopardized by recent human alterations of the natural fire regime.

A fire regime is a description of fire incidence over time and space, commonly characterized by fire type, fire frequency, spatial extent, and seasonality (Christensen 1993; Morino 1996). Fire can be defined as three general types: ground fires that smolder within the organic soil layer; surface fires that burn litter and fuels on the forest floor; and crown fires that burn in the crowns of trees (Wright and Bailey 1982; Morino 1996). Fire frequency is the number of fires that occur within a given area and time period (Christensen 1993; Morino 1996). Fire seasonality refers to the actual season in which a fire occurs.

In Great Smoky Mountains National Park (GSMNP), the fire regime of mid-elevation pine stands has been heavily influenced by humans (Harmon 1982; Davis 2000; Pierce 2000). Native Americans and European settlers used fire for hunting and to clear land for agriculture (Harmon, 1982; Delcourt and Delcourt 1997; Turrill *et al.* 1997; Turrill 1998; Davis 2000; Pierce 2000). During the late 1800s, widespread fires burned throughout the landscape of the Great Smoky Mountains as a result of logging practices and arson (Turrill 1998; Davis 2000; Pierce 2000). After the official creation of GSMNP

in 1934, forest managers removed fire as a major disturbance through the practice of fire suppression (Turrill 1998; Pierce 2000).

Although Table Mountain pine is a fire-dependent species, the site-specific fire history associated with this species remains unknown. It is imperative that forest managers understand the history of fire (including frequency, seasonality, and areal extent) in Table Mountain pine stands within GSMNP and surrounding areas to help ensure the survivability of the species (Mutch 1970).

1.2 Objectives

The purpose of this study was to provide baseline information on the successional status of Table Mountain pine stands within GSMNP and the fire history within those stands. I combined information from dendroecological investigations of fire history with information on the current age structure of *P. pungens* stands. This dual-natured process provided a detailed summary of the current age structure of Table Mountain pine populations, their relationships with past fire, and their prognosis for survival under the new human-altered fire regime. Additionally, I collected information on forest composition and structure that will be valuable to managers as they continue to prescribe fire as a management tool in areas of GSMNP and surrounding national forests.

My study was retrospective in that I intended to establish reference conditions of forest dynamics as they existed prior to the period of fire suppression. I had three primary objectives: (1) to evaluate the current age structure of Table Mountain pine stands; (2) to identify and characterize historical fire regimes (including wildfire frequency, seasonality, and areal extent) in selected Table Mountain pine stands; and

(3) to combine this information to assess the current successional status of mid-elevation Table Mountain pine stands. Addressing these primary objectives will provide critical ecological information that will assist managers when reintroducing fire to forests where Table Mountain pine exists.

2. BIOGEOGRAPHY OF TABLE MOUNTAIN PINE

Table Mountain pine was first collected by Michaux *ca.*1794 near Tablerock Mountain in Burke County, North Carolina, and was later described by Lambert in 1803 (Zobel 1969; Sanders 1992). Most commonly referred to as Table Mountain pine, this species is also known as poverty pine, hickory pine, southern mountain pine, black pine, ridge pine and prickly pine (Della-Bianca 1990; Sanders 1992; Williams 1992; Sutherland *et al.* 1995). This pine is an Appalachian endemic found in small, dense, unevenly distributed stands throughout its range, which extends from Pennsylvania down the Appalachian Mountains to eastern Tennessee and northern Georgia (Della-Bianca 1990).

In its range, *P. pungens* occupies xeric, south and southwest facing slopes, often on sites considered by foresters to be unfavorable for tree growth (Zobel 1969; Della-Bianca 1990; Sanders 1992; Sutherland *et al.* 1995; Turrill 1998). The range of Table Mountain pine falls exclusively within the ranges of two other yellow pines, pitch pine (*Pinus rigida* Mill.) and Virginia pine (*Pinus virginiana* Mill.). Table Mountain pine is by far less common than the other two (Zobel 1969; Sanders 1992; Sutherland *et al.* 1995).

The altitudinal range of *P. pungens* is rather wide, from approximately 305 to 1,220 meters (1,001 to 3,937 ft), with a few stands in Tennessee and North Carolina existing above 1,220 meters (3,937 ft). Stands of trees are most commonly found on steep, well-drained slopes and narrow ridges. This pine grows on shallow, undeveloped soils that tend to be strongly acidic and highly infertile (Zobel 1969). Table Mountain

pine is commonly associated with pitch pine and chestnut oak (*Quercus prinus* L.) (Williams and Johnson 1990).

2.1 Biology and Fire Adaptations

Table Mountain pine is a shade-intolerant secondary pioneer species that is often small in stature and poor in form (Figure 2-1) (Sutherland *et al.* 1995; Della-Bianca 1990). The species has medium-thick bark, extremely long branches, and deep roots. The long branches protect the typically thin soil from solar radiation that can quickly evaporate soil moisture, and the deep rooting habit anchors the pine firmly to the bedrock, while absorbing water and nutrients (Della-Bianca 1990). In addition, Table Mountain pine is a species adapted to both long- and short-interval fire regimes (Sutherland *et al.* 1995). The medium-thick bark helps insulate the tree from the heat of surface fires, and the limbs are self-pruning (Della-Bianca 1990; Sutherland *et al.* 1995; Keeley and Zedler 1998). The pine is also pitch-producing, which helps the tree compartmentalize injuries caused by fires (Sutherland *et al.* 1995; Keeley and Zedler 1998). Furthermore, the seeds of *P. pungens* are larger than those of other fire-adapted tree species. This characteristic allows the species to more efficiently establish larger seedlings after a fire (Zobel 1969).

Table Mountain pine is also a fire-dependent species, meaning it requires fire for successful regeneration. The cones of this pine are serotinous, an adaptation of many pine species to repeated fire (Zobel 1969). Serotinous cones are sealed with resin and remain on the tree for one or more years after the seeds mature (Keeley and Zedler 1998). The cones open and release seeds when heated during a fire. Table Mountain pine seeds

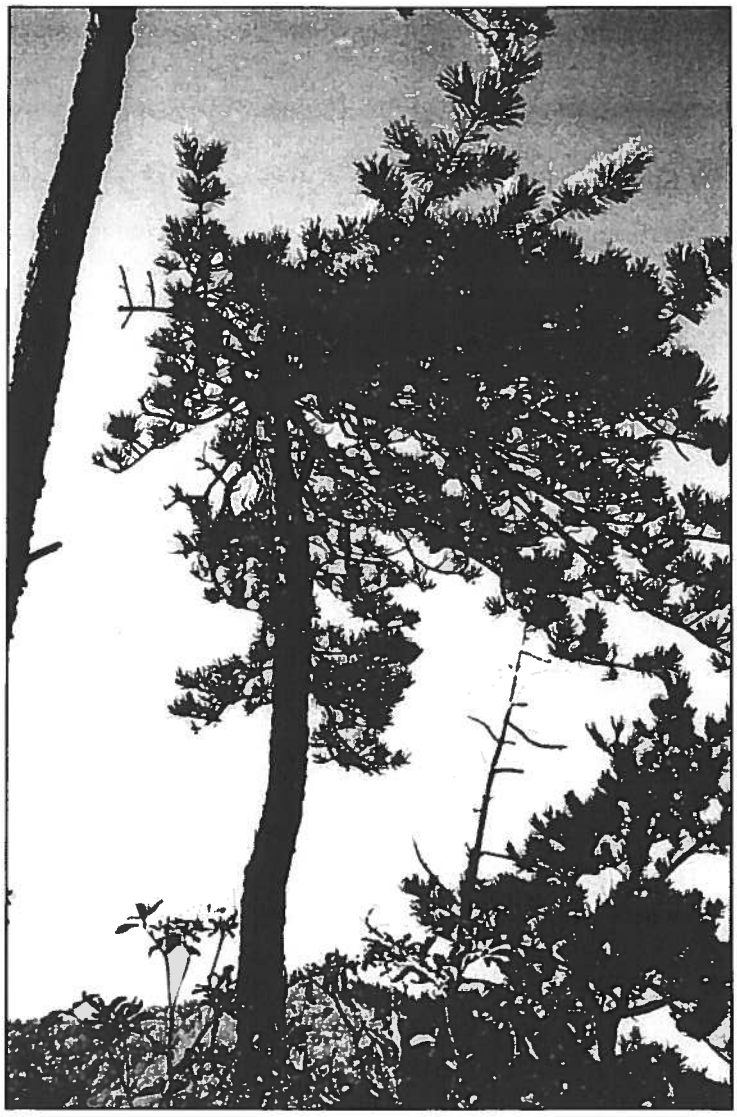


Figure 2-1. A Table Mountain pine at the Bull Head study site.

can remain viable for up to 11 years within the cone, although Barden (1978) found that approximately 40% of two-year-old seeds were released each year. In the same study, Barden (1978) suggests that the opening of Table Mountain pine cones is delayed a minimum of two minutes while being heated, thus allowing the hottest flames of a forest fire to pass before the seeds are dispersed. In addition to serotinous cones, the pine can reproduce vegetatively after fire from basal sprouts (Keeley and Zedler 1998).

Serotinous cones are beneficial, because they help maintain genetic diversity in Table Mountain pine populations. Gibson and Hamrick (1991a) found that the genetic record of past individuals is effectively preserved in the pine's serotinous cones. The seed pool in Table Mountain pine stands contains the products of several mating events between multiple trees over a period of many years. During fire, the serotinous cones will open and release the seed pool to reestablish the population. This strategy maintains genetic diversity by limiting the possibility that the population will experience a genetic bottleneck. In a similar study, Gibson and Hamrick (1991b) evaluated the genetic diversity of *P. pungens* and found that not only does fire promote the persistence of the pine, but it also perpetuates regular population turnover. Thus, fire would prevent the loss of individual genotypes due to stand senescence and would maintain a majority of the intrapopulational genetic variation in living individuals (Gibson and Hamrick 1991b).

3. LITERATURE REVIEW

3.1 Southern Appalachian Fire Regimes

Fire has heavily influenced forest structure and composition in the southern Appalachian region. Both lightning and anthropogenic fires have reinforced the fire-adapted traits of tree species that colonized the area after the most recent glaciation (Turrill *et al.* 1997). However, due to high levels of precipitation commonly associated with lightning strikes, natural lightning fires were infrequent. Barden and Woods (1976), Harmon (1982), and Abrams (1992) have all suggested that prehistoric Native American use of fire must have contributed significantly to the past fire regime in the southern Appalachians.

3.1.1 Natural Fire Regimes

Lightning was an important ignition source for forest fires in the southeastern United States for millions of years before the arrival of humans. Natural lightning fires had a greater impact on the pine-grasslands of the Piedmont area than the adjacent mountainous southern Appalachian region (Turrill 1998). The relatively low flammability of the southern Appalachians was due largely to its mesic broad-leaf deciduous forests. These forests were humid areas where fuels were not prone to dry quickly. It has been hypothesized that the fire regime probably consisted of low-intensity fires occurring at irregular intervals with occasional high-severity fires in the more xeric habitats (Turrill *et al.* 1997; Turrill 1998).

The significance of lightning in the prehistoric fire regime of the southern Appalachians is not fully understood. After the arrival of humans to the region around 12,000 BP (Before Present), the total area covered by fire-adapted southern pine species increased by as much as 14% (Delcourt and Delcourt 1987; Turrill 1998). This increase in fire-adapted pine species and other disturbance-initiated species has been attributed to anthropogenic and lightning-ignited fire (Turrill *et al.* 1997, Turrill 1998).

3.1.2 Anthropogenic Fire Regimes

The Cherokee were the largest of the pre-Columbian tribes to occupy the southern Appalachians. Studies have indicated that their use of fire for clearing of agricultural plots and hunting increased the heterogeneity of the forests and created a mosaic of open grasslands, woodlands, and closed-canopy forests (Harmon 1982; Delcourt and Delcourt 1997; Turrill *et al.* 1997; Turrill 1998). By incorporating archaeological records with analyses of pollen and charcoal collected from peat bogs, Delcourt and Delcourt (1997, 1998) have documented the association between early humans and fire in the southern Appalachians. Their results are consistent with the interpretation that anthropogenic fire has altered the forest composition of the region; however, they add that additional research is needed on a more regional scale for a complete understanding of Native American impacts on the prehistoric fire regime (Delcourt and Delcourt 1998).

During the late 1700s, Europeans migrated into the southern Appalachian Mountains (Pierce 2000). As they settled the region, they were introduced to the Native American burning practices, which they quickly adopted and incorporated into their own burning practices. Early farming and hunting in both the low elevation stream valleys

and higher elevation forests ensured the maintenance of southern Appalachian forests through fire (Turrill *et al.* 1997; Turrill 1998).

The introduction of European diseases led to a vast reduction in Native American populations in the southern Appalachians. The Cherokee Indians alone lost over 10,000 people to small pox epidemics (Turrill 1998). As the number of Native Americans decreased, so did the impact of cultural fire on the landscape. This decline in fire frequency led to the development of a more dense, closed canopy forest, while the shade-intolerant, fire-adapted species, like the yellow pines, slowly retreated to the extremely xeric, south-facing slopes and ridge tops.

With the construction of railroads through the southern Appalachians around 1880, logging became an important industry for the region (Davis 2000; Pierce 2000). As loggers began to harvest the rich timber resources found in the dense oak-hickory forests, they left behind piles of highly flammable slash (Turrill 1998; Davis 2000; Pierce 2000). Because pines were often the sole seed source available after logging, pine forests began reestablishing on logged sites (Turrill 1998). Delcourt and Delcourt (1997) found evidence of this pine regeneration in a palynological study that indicated an increase in pine pollen and charcoal around 1882.

Fire was being used as a tool for clearing land in the early 1900s; however, the national attitude towards forest fires was beginning to change (Turrill 1998). Forest managers, along with the general public, began to envision fire as a destructive force that wastefully eliminated natural resources (Turrill 1998; Pierce 2000). As the federal government began acquiring and managing lands across the United States, the policy of

eliminating all forest fires was established (Turrill 1998). This practice of fire suppression had a significant impact on southern Appalachians forests.

From its establishment in 1934 until 1996, fire suppression was practiced by forest managers in GSMNP. The forests of the southern Appalachian Mountains are more susceptible to fire during the fall to spring months, when deciduous trees have dropped their leaves, thus adding new fuel to the forest floor (Sanders 1992). Very few fires have occurred in the Park after the 1930s, and those that did were primarily human-caused fires (Sanders 1992; Turrill 1998). The interval between fire recurrences was increased dramatically by the federal practice of fire suppression (Turrill 1998), thus impacting the reproductive ability of fire-dependent species, such as Table Mountain pine.

While fire was not completely eliminated from the landscape during the period of fire suppression, the fires that did occur were primarily human-caused accidental fires or arson. These fires were typically small in size and found on ridge tops, rarely impacting more than 40 hectares (98.8 acres) (Turrill 1998). The overall fire rotation interval for the forests of GSMNP during the period of fire suppression was estimated to be over 2000 years (Harmon 1982).

In 1996, the National Park Service (NPS) began to change the way fire was handled on public lands. In an attempt to prevent unintentional fires, prescribed (or controlled) burning was introduced to GSMNP to eliminate the over-abundance of fuel that had collected on the forest floor. Controlled burning not only prevents hazardous stand-eliminating fires by reducing fuel loads, but also aids those species that depend upon fire for reproduction (National Park Service 2000).

The United States Forest Service defines prescribed burning as "fire applied in a knowledgeable manner to forest fuels on a specific land area under selected weather conditions to accomplish predetermined, well-defined management objectives" (USDA Forest Service 1989). Prescribed burns, however, are used more as a management tool in the surrounding national forests than in GSMNP. In 2000, controlled fires burned less than 405 hectares (1,000 acres) of forests in GSMNP, while personnel in Cherokee National Forest alone burned approximately 8,500 hectares (21,000 acres) (Jenkins 2001).

The application of this management technique is difficult, because prescribed burns require specific ("prescribed") environmental conditions to ensure public safety. Additionally, managers must be able to support the application of fire as a management tool to ensure that the goals of a prescribed burn are valid and can be achieved (Turrill 1998). Much of the research on fire and vegetation interactions within the southern Appalachian region has been concluded to increase the amount of knowledge and support for the reintroduction of fire.

3.1.3 Lightning Fires vs. Anthropogenic Fires

The humid climate of the southern Appalachian Mountains limits the amount of fuel in the region's forests. Even though there might be a large quantity of woody debris on the forest floor, this debris is often too wet to burn. Lightning and humans are two major ignition sources in these forests. While both lightning fires and anthropogenic fires are components of the current human-altered fire regime, a number of differences exist between the two types of ignition sources.

The optimal season for lightning fires occurs in May before thunderstorms reach their greatest frequency in the summer months. Barden (1974) documented that 90% of all lightning fires in the southern Appalachians occur between April and August, with 40% of those fires occurring in May alone. On the other hand, the anthropogenic fire season has two peaks, March through May and October through November. These two peaks in fire correspond to the two driest periods, when the litter and fuel on the forest floor dries out. While anthropogenic fire is important during both seasons, it is more severe during the spring months (Barden 1974). Over 60% of all anthropogenic fires occur between March and May, accounting for 80% of the total area burned each year (Barden 1974). The October to November peak in human-caused fire accounted for only 25% of fires and 13% of the total area burned (Barden 1974).

In the same study, Barden (1974) found that lightning was responsible for igniting 15% of the fires in GSMNP from 1940 to 1969. In the adjacent Cherokee National Forest, lightning started only 5% of all fires between 1960 and 1969. Barden (1974) attributed the lower frequency of lightning fires in the Cherokee National Forest to human activities, such as logging and land clearing. More recently, the National Park Service (1997) found that, on average, lightning ignites only 10% of all the fires in the Park, with the remaining 90% caused by humans. Forty-one percent of all the fires in the Park between the years of 1931 and 1991 were the result of arson.

Lightning fires and anthropogenic fires within GSMNP had the same median size, 0.8 hectares (2 acres); however, lightning fires occurred primarily on ridge tops, while anthropogenic fires occurred at lower slope positions (Barden 1974). Barden's results indicated no lightning fires on record in the park were classified as crown fires. Human-

caused fires were found to be more severe: 7% of human-caused fires in the Cherokee National Forest were classified as crown fires.

Barden and Woods (1976) stated that lightning fires in GSMNP were of such a low average severity that very little pine regeneration would occur if park managers set in motion a "let-burn" policy. If lightning fires were allowed to burn in the park, they would most likely create "hotspots" of pine reproduction. These hotspots would consist only of small stands located on "steep southerly slopes where excessive drainage and high insolation encourage severe fires" (Barden and Woods 1976).

3.2 Status of Table Mountain Pine in the Southern Appalachian Mountains

3.2.1 Decline of Table Mountain Pine Populations

Research has shown that fire suppression will prevent Table Mountain pine persistence by facilitating the establishment of shade-tolerant deciduous species due to the accumulation of a thick detritus layer and high concentrations of nutrients and moisture in the soil (Williams *et al.* 1990; Groeschl *et al.* 1993). Williams *et al.* (1990) found that thick leaf litter prevents Table Mountain pine seeds from settling into the soil and creates a barrier to root growth. Additionally, deciduous seedlings, benefiting from increased nutrients and soil moisture retained in the leaf litter, out-compete Table Mountain pine by reducing the amount of sunlight in the understory (Williams *et al.* 1990).

These factors have all played an integral part in the decline of *P. pungens* in the forests of the southern Appalachian Mountains. Documented evidence of Table

Mountain pine population decline has been the driving factor for much of the research concerning the species (Gray 2001; SAMAB 1996). Table Mountain pine – pitch pine forests have been designated as one of the 31 rare communities in the southern Appalachians by the Southern Appalachian Assessment (SAMAB 1996). The majority of the research points to the removal of fire from Table Mountain pine stands as a primary cause of the pine's decline from the landscape (Harman 1982; Turrill 1998; Waldrop and Brose 1999; Brose and Waldrop 2000).

3.2.2 Fire and the Forest Floor

Certain species, such as Table Mountain pine, rely upon fire to provide the optimum conditions for seed germination on the forest floor. In general, fire burns away the organic layer and exposes mineral soil, conditions essential for some trees to establish. Additionally, fire will thin out the understory, thus reducing competition for nutrients, moisture, and especially light.

In 1990, Williams *et al.* published a study that analyzed the impact of fire suppression on Table Mountain pine stands by evaluating the influence of leaf litter and soil moisture on Table Mountain pine establishment. Their results indicated that leaf litter plays a significant role in reducing Table Mountain pine seedling establishment and growth. Williams *et al.* (1990) found a "direct, negative effect of oak litter on emergence of Table Mountain pine seedlings" and attributed the association to mechanical or physical factors, not a chemical influence.

Oak litter provides very few areas where seeds and seedling roots can access moist soil, especially when compared to pine litter. Seedlings tend to establish in small

clumps where the oak litter is not as thick, thus increasing competition for resources. After seedlings establish in the oak litter, they are more prone to death from desiccation as the litter dries out. Williams *et al.* (1990) concluded that, although leaf litter can inhibit the establishment of Table Mountain pine seedlings, a thin layer of pine litter can increase the probability that the seedlings will survive after establishment. Survival is likely because a thin leaf layer will allow the seed to reach the soil, while also providing protection for the seedling.

Groeschl *et al.* (1993) evaluated the effect of differing levels of fire intensity on the forest floor. They found that when fire is suppressed, conditions in pine forests become more favorable for deciduous species, especially oaks. Groeschl *et al.* (1993) discovered that severe fires completely eliminate accumulated litter and greatly reduce the amount of carbon and nitrogen stored in the forest floor. Nevertheless, their results indicated an increase in pH and higher levels of phosphorus, calcium, and magnesium associated with the thick ash layer created by the fire. After two years, litter fall remained low due to high overstory mortality and little regrowth. Overall, Groeschl *et al.* (1993) concluded that conditions after severe fire events are more conducive to pine emergence, a conclusion similar to that made by Turrill *et al.* (1997), Elliot *et al.* (1999), and Welch *et al.* (2000).

Williams and Johnson (1992) discovered that Table Mountain pine could not establish on sites with unsuitable microhabitat. They found an abundance of seeds in areas where fire had not occurred. The presence of a thick litter layer (>4 cm or 1.6 in), however, allowed very few seeds to establish. In areas where fire had occurred, specific

microhabitat characteristics (litter layer of 4 cm (1.6 in) or less) favored the establishment of Table Mountain pine.

While analyzing fire intensity levels for Table Mountain pine stand replacement, Waldrop and Brose (1999) discovered that Table Mountain pine seedlings did emerge and survive on a duff layer twice as thick as the 4 cm (1.6 in) maximum described by Williams and Johnson (1992). This result indicates that the thickness of the organic layer may not play as important a role in the establishment of pine species as previous studies have shown. These conflicting studies demonstrate that more research must be undertaken to fully understand the relationship between pine emergence and conditions on the forest floor.

3.2.3 Table Mountain Pine and Fire

In 1996, the use of fire as a management tool in the forests of the southern Appalachian Mountains was initiated (Turrill 1998). The majority of research completed before 1996 was focused on the association between fire and plant biology. As early as the 1930s, scientists in the Southeast began formulating the idea that fire was not the prodigal disturbance it was considered to be earlier in the century (Wright and Bailey 1982). By the early 1970s, this led to a surge in research focused on fire history and the natural role of fire in the southern Appalachians. Eventually, scientists and forest managers determined that fire was a natural disturbance and began contemplating the problem of reintroducing fire to the landscape.

In 1984, Harmon completed one of the first studies concerned with returning GSMNP to pre-suppression forest structure. His study sites were located in areas of the

park known to have had low-severity fires only two years before he began the study. Harmon's primary conclusion was that the reinitiation of the pre-park fire interval would not be enough to return the GSMNP to pre-suppression forest structure. He arrived at this conclusion by examining the association between the thickness of a tree's bark and its ability to survive low-intensity fires.

Fire susceptibility is commonly determined by bark thickness, among other characteristics; however, Harmon (1984) determined bark thickness by itself is not a good qualifier, unless a range of sizes is specified. For example, a thin-barked tree with a high dbh can actually have thicker bark than a characteristically thick-barked tree with a low dbh. He also found that both the presence of a bark collar and the amount of taper in the bark from the base of the stem to breast height can increase the ability of a tree to survive low-intensity fires.

Using fire-scarred pines, Harmon (1982) described the pre-suppression fire interval in the western portion of the park as ranging from two years to as long as 49 years on south facing slopes in GSMNP. In his 1984 study, Harmon stated that this fire interval allowed some thin-barked tree species to reach a size and bark thickness capable of protecting them from low-intensity fires; nevertheless, sites with short fire return intervals would be colonized by fire-adapted species with thick bark. The roughly 60-year fire suppression period in GSMNP has eliminated the original heterogeneous forest composition created by the varying pre-park fire interval. Hence, the period required for a return to pre-suppression forest structure would be extremely long.

More recently, scientists have been addressing the direct effect of prescribed burns on the forests of the southern Appalachians. Turrill (1998) analyzed prescribed fire

as a tool to regenerate populations of three pine species in the southern Appalachian Mountains. She did not rely on natural fire occurrences, but rather applied controlled fire to her study sites to analyze pre-burn and post-burn forest composition. Turrill found that the deep litter and duff layers on the forest floor that have accumulated over the decades of fire suppression are not commonly removed by one controlled burn. Additionally, she witnessed post-fire yellow pine regeneration and a thinning of the understory at only one of her study sites.

The results found by Turrill (1998) supported those found in a study by Sanders (1992) at Bote Mountain in GSMNP. In his study, Sanders observed a 96% emergence of Table Mountain pine seedlings after both high-intensity and moderate-intensity burns. In prescribed burns of those intensities, the forest canopy was thinned and the mineral soil was exposed. Turrill (1998) concluded in her study that if a prescribed burn is not intense and severe enough to generate the site characteristics observed by Sanders (1992), then the burn will possibly encourage succession towards a hardwood-dominated forest by increasing the number of hardwood sprouts in the understory.

Waldrop and Brose (1999) compared the fire intensity levels required to regenerate Table Mountain pine populations in the southern Appalachians. Like Turrill (1998), they also applied controlled burns to their study site with similar results. Waldrop and Brose (1999) concluded that medium- to high-intensity fires will provide the optimum site factors necessary for Table Mountain pine seedling emergence. At this intensity, overstory mortality was close to 100%, while insolation to the forest floor was high and seedling density was sufficient. Medium-intensity fires are safer than high-

intensity fires and can be achieved during a wider burning window (Waldrop and Brose 1999).

3.2.4 Population Studies of Table Mountain Pine

Many scientists have effectively used dendroecological techniques to analyze age structure and forest dynamics in the eastern United States (Henry and Swan 1974; Platt *et al.* 1988; Stephenson and Adams 1989; Abrams *et al.* 1995; Pederson *et al.* 1997). Three major studies that focused on the population dynamics of Table Mountain pine provide the foundation for my research. The primary objective of these studies was to identify any successional trends present in Table Mountain pine populations of the southern Appalachian Mountains. Based on a suggestion by Whittaker (1956) that populations of drought resistant pine species (such as Table Mountain pine) will sustain themselves without fire on xeric south-facing slopes, Barden (1977) began a long-term study of Table Mountain pine populations on Looking Glass Rock in North Carolina. Because of fire suppression and the rare occurrence of lightning-caused fires in the southern Appalachians, Barden theorized that Whittaker's statement of pine persistence without fire must be true. Dendroecological techniques were used to determine the age structure of the Table Mountain pine populations on Looking Glass Rock. The results indicated continuous reproduction with a mortality rate of 50% since the last fire, which occurred in 1889 (Barden 1977).

Barden revisited the Looking Glass Rock study site in 1996, 20 years after his original study. He used the same techniques from the 1977 investigation; however, he arrived at different results. After 20 years, the populations of Table Mountain pine on his

study site had a peak in the middle age classes, with only a small percentage of trees in the younger age-classes. According to Barden (2000), this type of age structure is representative of aging or declining populations. He attributed this change to the droughts that occurred during the 1980s, with a possibility that an increase in global temperature might also have impacted the reproduction of Table Mountain pine (Barden 2000).

Williams and Johnson (1990) describe age distributions similar to that of the Table Mountain pine stands on Looking Glass Rock as typical of disturbance-dependent shade-intolerant pine species. Similar to that of Barden (1977), the purpose of their study at Brush Mountain, Virginia was to test the suggestion by Whittaker (1959) that Table Mountain pine populations growing on xeric, south-facing sites can persist without fire. They also incorporated dendroecological techniques in their study of age structure. The age distributions of Table Mountain pine on three study sites differed from those on the sites studied by Barden (1977, 2000), because they found a bimodal distribution, with major peaks in the 45-55 and 70-80 year age-classes. Smaller peaks occurred for the 5-15 year age-classes at all sites. Their results indicate that Table Mountain pine stands on Brush Mountain do not have an adequate percentage of young trees to promote persistence without the introduction of recurring fires (Williams and Johnson 1990).

During the Fourth Annual Dendroecological Fieldweek, Sutherland *et al.* (1995) carried out a pilot project on the fire history of a stand of Table Mountain pines also on Brush Mountain, Virginia. Though preliminary, this study demonstrated that dendrochronological study of wedges and sections from fire-scarred trees can be used to establish a local record of fires. In addition to studying fire scars, the team of scientists

extracted cores from Table Mountain pine to determine stand age structure, and made observations on the size structure of other trees in the stand. Results suggested a bimodal age distribution similar to that described by Williams and Johnson (1990) for other stands on Brush Mountain, with two major recruitment events apparently linked to two major fire events at the site. Thus, the pilot project by Sutherland *et al.* (1995) was also significant in providing the first evidence that recruitment phases postulated by others to be linked to fire were indeed temporally associated with past fires.

4. STUDY AREA

4.1 Southern Appalachian Mountains

The southern Appalachians consist of a number of mountain chains, including the Great Smokies, Blue Ridge, Chilhowee, Stone, Bald, and Iron Mountains. The region is approximately 480 km (300 mi) long and encompasses parts of West Virginia, southwestern Virginia, eastern Tennessee, western North Carolina, northwestern South Carolina, and northern Georgia (Figure 4-1) (Barden 1974; Abrams *et al.* 1995). A number of national forests (such as the Pisgah and Cherokee) and GSMNP are found in the region. The southern Appalachian Mountains are ecologically important due to their high level of biodiversity. Between 100 and 135 native tree species are found in GSMNP, more species of native trees than in any other North American National Park (Clebsch and DeFoe 1993).

Together, the southern most portions of both the Ridge and Valley and Blue Ridge Provinces make up the southern Appalachians. The Ridge and Valley Province is approximately 2,000 km (1,243 mi) in length and varies in width from 40 to 120 km (25 to 75 mi). It is composed of southwest-northeast trending folded and faulted mountains and broad flat valleys. The Blue Ridge Province is a ridge system that ranges in elevation from 750 to 1,950 m (2,461 to 6,398 ft), spans approximately 900 km (560 mi) in length, and varies from 8 to 80 km (5 to 50 mi) wide (Brouillet and Whetstone 1993).

Precambrian-aged sandstone, shale, and limestone, along with granitic and metamorphic formations found in the Blue Ridge Province, make up the bedrock of the

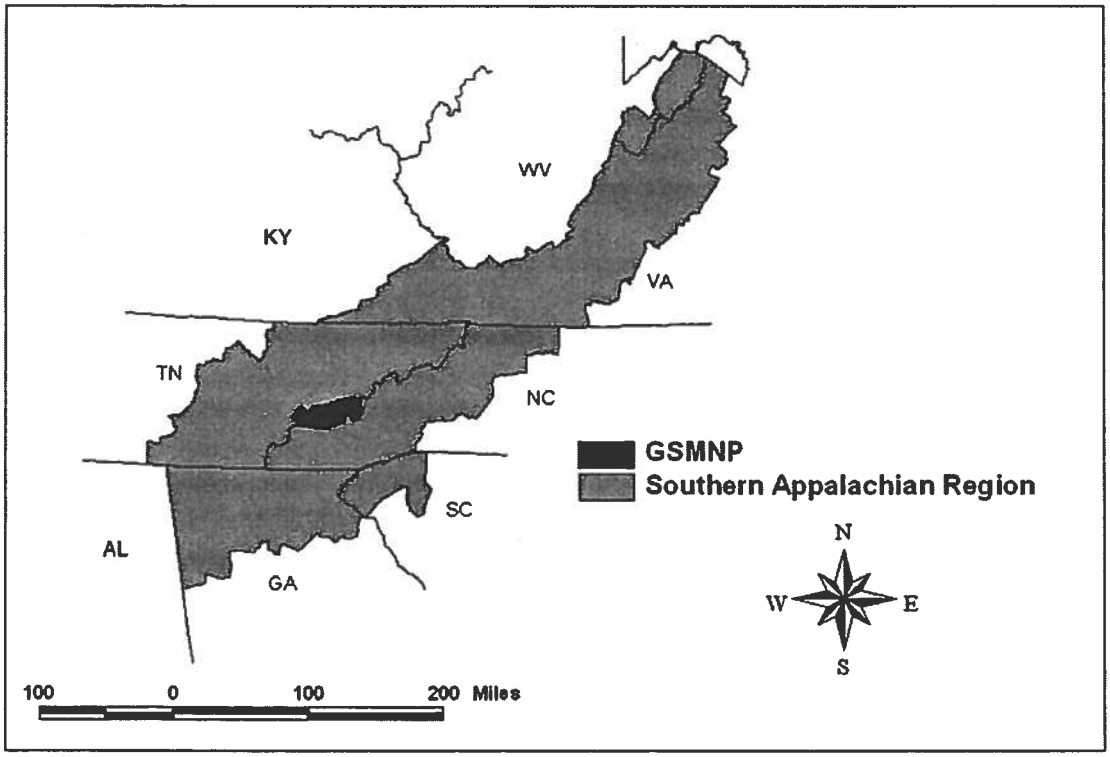


Figure 4-1. The southern Appalachian region and Great Smoky Mountains National Park. This map was created using data from the Southern Appalachian Assessment Online GIS Database managed by SAMAB (SAMAB 2002).

southern Appalachians. The erosion of the sedimentary bedrock has produced the characteristic features of the Ridge and Valley Province (Brouillet and Whetstone 1993). Soils are primarily ultisols and inceptisols. These soils are highly acidic and low in fertility (Harmon 1984; Harrod *et al.* 1998).

4.2 Great Smoky Mountains National Park

The United States Congress established Great Smoky Mountains National Park on June 15, 1934 (Campbell 1960). The land within the park was placed under the jurisdiction of the NPS, with the goal of duplicating the success of the national parks in the western United States. The park is located near the most southern tip of the range of Table Mountain pine in eastern Tennessee and western North Carolina (Figure 4-1). The park consists of 2,032 square kilometers (785 mi^2), or 203,200 hectares (502,100 acres), of land, of which 95% is forested. GSMNP is world-renowned for its high species diversity, and was visited by over 10 million people in 1999. It is one of the largest protected areas in the eastern United States and has been declared an International Biosphere Reserve by the United Nations (National Park Service 2002).

4.2.1 Geology

The Great Smoky Mountains were created during the Appalachian orogeny approximately 200 million years ago. They are one of the largest mountain groups in the Blue Ridge province. The bedrock found in GSMNP can be classified into three basic

groups. The first bedrock class consists of metamorphic Precambrian basement complex, specifically gneisses, schists, and granitic rocks that are more than one billion years old (Moore 1988; King *et al.* 1968).

The majority of the bedrock found in GSMNP falls into the second class – metamorphosed, sedimentary, late Precambrian rocks of the Ocoee Supergroup. This group contains metamorphosed phyllites, schists, and quartzites, slates, shales, sandstones and metasiltstones that are 500 million to one billion years old. Three main groups make up the Ocoee Supergroup: the Snowbird, Great Smoky, and Walden Creek Groups. Seventeen formations make up the Ocoee Supergroup (Moore 1988; King *et al.* 1968).

The third class of bedrock found in GSMNP contains the youngest rocks in the park, the sedimentary rocks of the Ridge and Valley Province. These rocks are found in the western portion of GSMNP and are between 300 and 500 million years old. The rock types that make up this class include limestones, dolostones, shales, and sandstones (Moore 1988; King *et al.* 1968).

4.2.2 Climate

Though the local climate within GSMNP varies with aspect and altitude, the average climate for the southeastern United States is humid subtropical. The mean precipitation in GSMNP exceeds 2,030 millimeters (80 in). The average annual temperature ranges from 15 to 20° C (59 to 68 ° F) in July to 2 to 5° C (36 to 41 ° F) in January, with the average number of frost-free days ranging from 170 to 180 (Della-Bianca 1990). Late spring and early fall tend to be the driest periods of the year, while winter and July are the wettest. Gatlinburg, Tennessee, with an elevation of 445 m

(1,460 ft), has an average annual temperature of 13.8° C (56.9 ° F) and an average annual precipitation of 1,374 mm (54.1 in) (National Park Service 2002). Clingman's Dome (2,024 m or 6,642 ft elevation) has an average annual temperature of 5.9° C (42.7 ° F) and an average annual precipitation of 2,085 mm (91 in) (National Park Service 2002). According to Thornthwaite's climate classification system, Gatlinburg is classified as a humid mesothermal climate, while Clingman's Dome, having colder temperatures and lower evapotranspiration, is classified as a perhumid microthermal climate (Barden 1974).

4.2.3 Vegetation Types

Forest composition, like climate, varies dramatically with elevation. While many characteristics, such as streams and slope angles, can influence the forest structure at any given site, the vegetation of the southern Appalachians can be characterized according to an elevation-moisture gradient. White basswood (*Tilia americana* L.), sugar maple (*Acer saccharum* Marsh.), yellow birch (*Betula alleghaniensis* Britton), American beech (*Fagus grandifolia* Ehrh.), and yellow poplar (*Liriodendron tulipifera* L.) are major components of low-elevation mesic sites (Whittaker 1956; Barden 1974; Greller 1988).

Oak-hickory forests are supported on submesic and subxeric sites at lower and middle elevations. This forest type is dominated by northern red oak (*Quercus rubra* L.), white oak (*Q. alba* L.), chestnut oak (*Q. prinus* L.), pignut hickory (*Carya glabra* Mill.), and mockernut hickory (*C. tomentosa* Poir.) (Whittaker 1956; Barden 1974). The American chestnut (*Castanea dentata* Marsh.) was a dominant tree species of these sites

until it was virtually eliminated by the chestnut blight in the early 1940s (Barden 1974; Greller 1988).

Low and middle elevation xeric sites with a southern aspect support a combination of pine and hardwood species. Table Mountain pine, Virginia pine, pitch pine, and shortleaf pine (*P. echinata* Mill.) are all found on these sites. Virginia pine is found only at the lower elevations, while Table Mountain pine is more common at the middle elevations. Pitch pine exists throughout this elevational range. Dominant hardwood trees include chestnut oak, scarlet oak (*Q. coccinea* Muenchh.), red maple (*A. rubrum* L.), and blackgum (*Nyssa sylvatica* Marsh.) (Whittaker 1956; Barden 1974). These are the forests most commonly impacted by fire.

High elevation forests in the southern Appalachians are dominated by red spruce (*Picea rubens* Sarg.) and Fraser fir (*Abies fraseri* Pursh.). In addition to spruce-fir forests, the vegetation communities in the higher elevations include heath balds and grassy balds. These communities exist on exposed ridges with the main taxa being mountain laurel (*Kalmia latifolia* L.) and various *Rhododendron* species in heath balds and *Danthonia compressa* Aust. in grassy balds (Whittaker 1956; Barden 1974; Greller 1988).

4.2.4 History

The GSMNP landscape seen today has been influenced by the presence of humans. Prehistoric Indians first moved into what is today GSMNP approximately 8,000 years ago (Pierce 2000). These early Native Americans were hunter-gatherers who migrated from site to site collecting and hunting for food sources. They took advantage

of the plethora of seasonal opportunities provided by the mountainous landscape of the southern Appalachians. The fall was a season of bounty, when Indian groups would move to ridge tops and summits to hunt deer and collect nuts and mast for the winter months (Pierce 2000).

With the introduction of horticulture and agriculture, Indian groups began establishing settlements in stream valleys and floodplains (Pierce 2000). Though not to the same extent, the Cherokee, like their prehistoric ancestors, continued to utilize the diversity of the Great Smoky Mountains for hunting and gathering. For 8,000 years, Native Americans altered the landscape of the Great Smoky Mountains, especially through the use of fire. Fire was used as a tool primarily for clearing land for agriculture and driving game (Van Lear and Waldrop 1989; DeVivo 1991; Pierce 2000).

European settlers began moving into the southern Appalachian region by the mid-1700s; however, the first settlements in the Great Smoky Mountains were not established until the 1790s (Van Lear and Waldrop 1989; Pierce 2000). Originally, these settlements were small in size and clustered along major streams. A primary reason for this settlement pattern was that the Cherokee Indians retained much of the land in the Great Smoky Mountains for hunting until they were relocated in the 1830s (Pierce 2000). As the Cherokee were relocated to the western United States, all of the land in the Great Smoky Mountains was opened for European settlement.

The European settlers had agricultural practices similar to those of the Native Americans; however, they introduced another practice that dramatically altered the landscape of the Great Smoky Mountains – livestock grazing (Pierce 2000). Fire was used to improve the habitat for livestock on slopes and ridges, a practice referred to

regionally as "greening the grass." This process fostered the growth of grasses and shoots for livestock consumption, while removing the underbrush that hindered livestock movement (Pierce 2000).

In the mid-1800s, two major commercial opportunities were burgeoning in the Great Smoky Mountains region, mining and logging. Many hoped that major deposits of gold and silver would be found in the mountains, but the miners that came flooding into the region in search of wealth eventually left empty-handed (Pierce 2000). Logging, on the other hand, had been practiced on a small scale throughout the 18th and 19th centuries. The first major logging operation in the Great Smoky Mountains, however, was not initiated until the 1880s (Turrill 1998; Davis 2000; Pierce 2000). Roads, railroads, logging camps, and small towns were built almost overnight to facilitate the booming new industry. Eventually, however, the price of lumber decreased and logging companies began practicing "cut and run" techniques that left the mountain landscape devastated (Davis 2000; Pierce 2000).

In 1916, President Woodrow Wilson officially created the National Park Service. The first national parks (Yellowstone, Yosemite, and Grand Canyon) were extremely popular, and people from all parts of the country demanded the establishment of national parks in their regions (Pierce 2000). The federal government began purchasing land in the southern Appalachians in the early 1900s, a process that culminated in the creation of GSMNP on June 15, 1934 (National Park Service 2000; Campbell 1960). From its establishment by the United States Congress, GSMNP was managed to be a pristine public attraction where fire played no role (Pierce 2000).

4.3 Study Sites

4.3.1 Selection Criteria

In June, 2001, I obtained from the NPS office at Twin Creeks Resource Center in Gatlinburg, Tennessee, NPS records concerning Table Mountain pine stands within GSMNP. These records were the result of an extensive Table Mountain pine stand mapping project that began in 1992. They contained stand specific data, including stand location, percentage Table Mountain pine, presence of fire-scarred Table Mountain pines, southern pine beetle (*Dendroctonus frontalis* Zimm.) (SPB) infestations, elevation, and other information I deemed critical for site selection.

I selected 10 stands that I considered to be optimal for this study. To be considered, the site had to be classified by the NPS as being at least 70% Table Mountain pine. Furthermore, stands had to have fire-scarred snags or stumps. Stands described by the NPS as having heavy SPB infestation or no signs of regeneration when data were collected in 1992 did not qualify as optimal study sites. I worked with NPS personnel to ensure the selected sites provided adequate spatial resolution to infer the broad-scale effects of fire and fire suppression on Table Mountain pine. After field reconnaissance, I narrowed my study sites to five specific stands that formed a transect from the Cherokee Orchard Loop to Cades Cove (Figure 4-2). The stand characteristics of the selected study sites differed somewhat from the 1992 NPS records. SPB had altered stand composition and structure to varying degrees at all sites. The range in elevation and stand

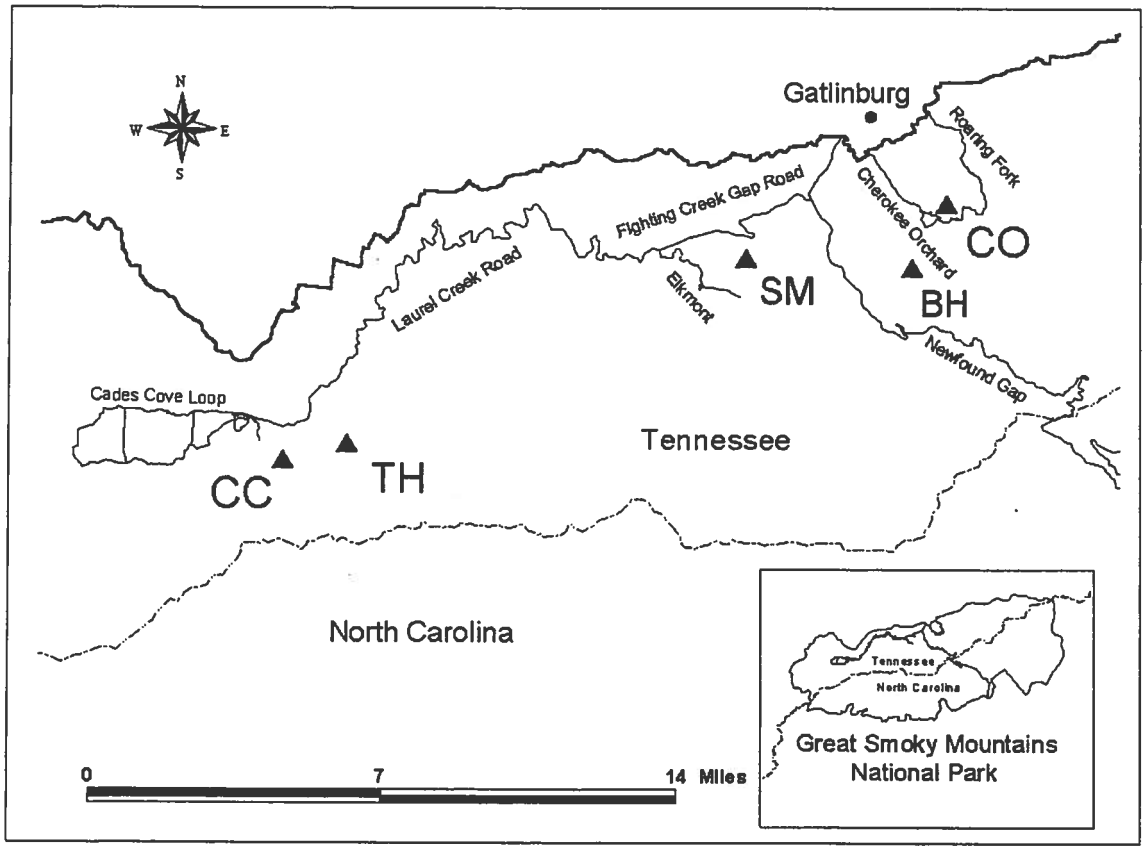


Figure 4-2. Study sites in Great Smoky Mountains National Park. Locations of study sites are indicated by triangles and the corresponding site identification code: Cherokee Orchard (CO), Bull Head (BH), Sugarland Mountain (SM), Thunderhead (TH), and Cades Cove (CC). This map was created using data from the Southern Appalachian Assessment Online GIS Database managed by SAMAB (SAMAB 2002).

characteristics between the selected study sites allowed me to make inferences regarding Table Mountain pine stands throughout its range in the southern Appalachians.

4.3.2 Stand Descriptions

4.3.2.1 Cherokee Orchard (CO)

The Cherokee Orchard site (35° 40.75' N, 83° 28.67' W) is located just north of the intersection of Roaring Fork Motor Trail and Cherokee Orchard Road on the Baskins Creek Trail (Figure 4-3). The elevation ranges from 822 to 883 m (2,700 to 2,900 ft) with an aspect of 210°. Approximately 85% of the canopy is Table Mountain pine. Other canopy species include red maple, pitch pine, and chestnut oak. This stand has an open canopy with a very thick midstory. The Table Mountain pines located at the top of the ridge have been dramatically thinned by SPB infestation since the 1992 NPS survey. The fuel load is heavy in this stand and includes both fine fuels and numerous downed pines. Red maple has started invading from the bottom of the stand.

4.3.2.2 Bull Head (BH)

The Bull Head site (35° 39.67' N, 83° 29.38' W) is located southwest of the Cherokee Orchard site on the southwestern slope of Bull Head Mountain (Figure 4-4). The elevation ranges from 1,060 to 1,158 m (3,480 to 3,800 ft) with an aspect of 240°. The stand ranges from 30% Table Mountain pine down slope to 100% Table Mountain pine on the ridge top. Pitch pine, chestnut oak, scarlet oak, and blackgum are other canopy species in the stand. SPB appears to have caused some recent mortality at lower

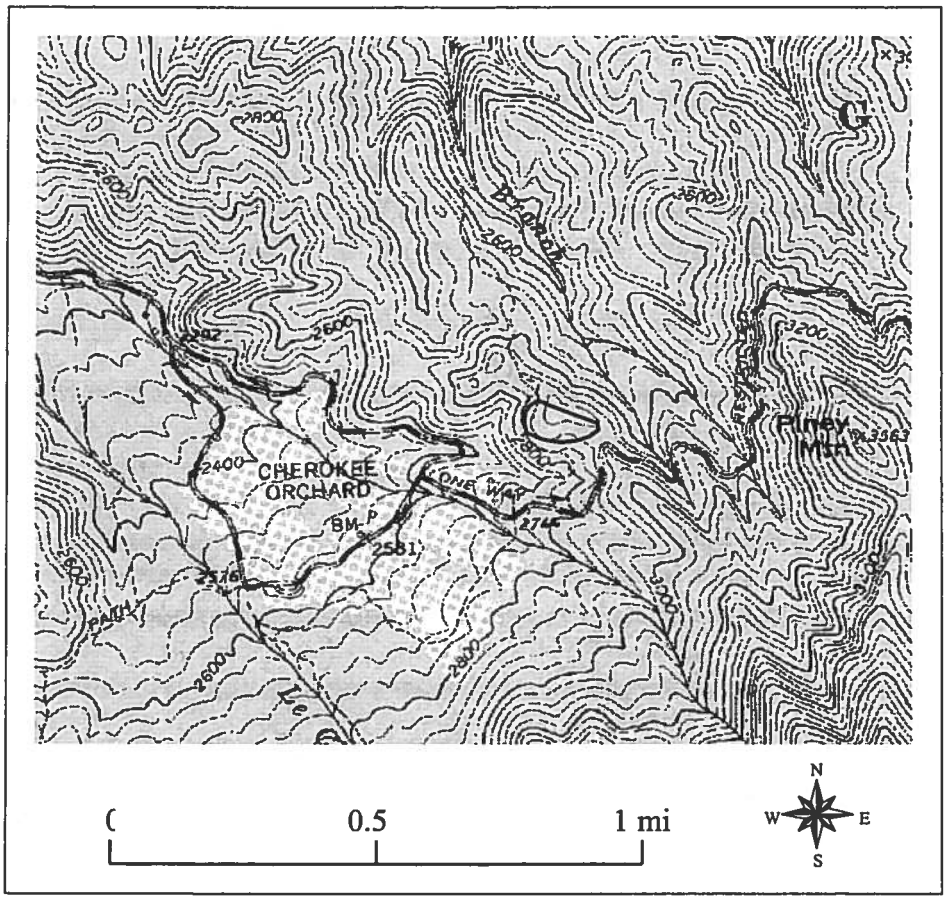


Figure 4-3. Map of the Cherokee Orchard study site. The site boundary is designated by a thick black line in the center of the map. This map was created using the Mount Le Conte, TN-NC USGS 7.5 minute topographic quadrangle.

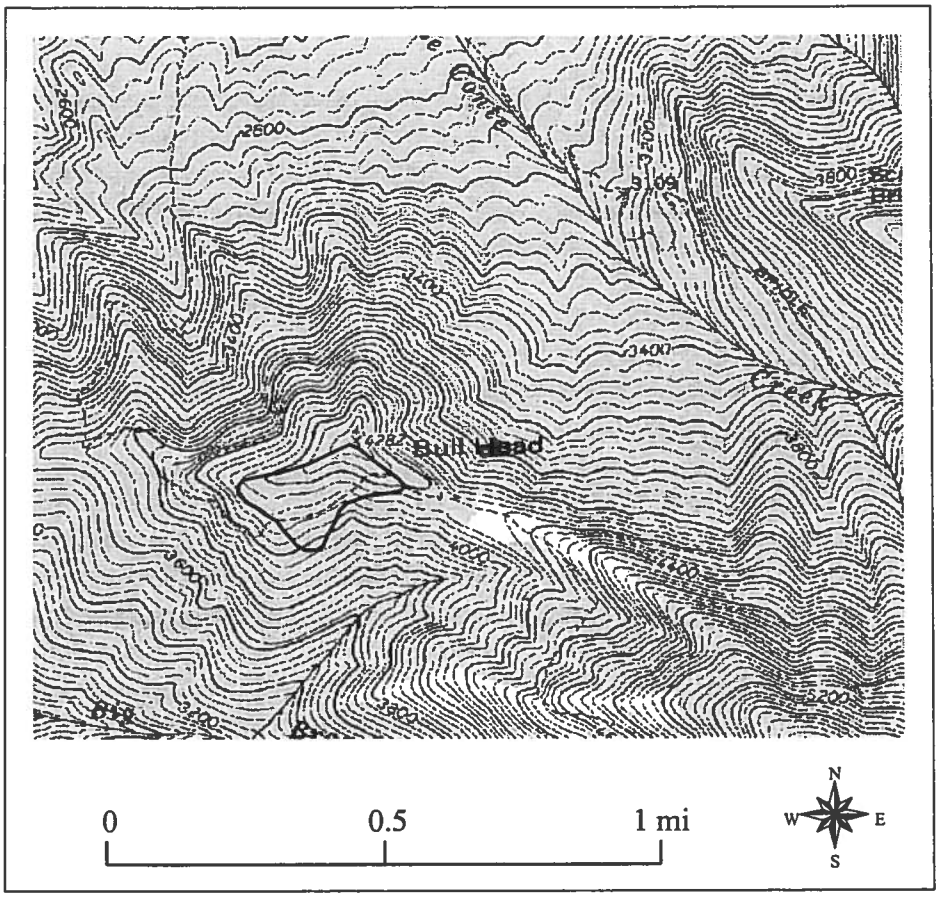


Figure 4-4. Map of the Bull Head study site. The site boundary is designated by a thick black line. This map was created using the Mount Le Conte, TN-NC USGS 7.5 minute topographic quadrangle.

elevations within the stand. This infestation has resulted in a heavy horizontal fuel load. Additionally, hardwood species are invading in those kill areas. I noted as many as six lightning-scarred pines, but found no indication that those lightning strikes resulted in surface fires. However, I did find other evidence of fire throughout this stand.

4.3.2.3 Sugarland Mountain (SM)

The Sugarland Mountain site (35° 39.30' N, 83° 33.42' W) is located approximately 3.2 km (2 mi) south of Little River Road on Sugarland Mountain Trail at the intersection of the trail and Mids Branch (Figure 4-5). The elevation ranges from 822 to 883 m (2,700 to 2,900 ft) with an aspect of 230°. The western portion of the stand contains 60% Table Mountain pine, while the eastern portion contains 80%. Along the ridge top, Table Mountain pine makes up 95% to 100% of the canopy. Pitch pine, chestnut oak, and scarlet oak are the other canopy species at this stand. SPB infestation throughout the stand has caused an extremely heavy horizontal fuel load. I found charred stumps and snags in the southeastern portion of the stand (Figure 4-6).

4.3.2.4 Thunderhead (TH)

The Thunderhead site (35° 35.75' N, 83° 43.78' W) is located just north of the intersection of Lead Cove Trail and Bote Mountain Jeep Trail on the southern ridge of Bote Mountain (Figure 4-7). I selected this stand primarily for its proximity to the location of the 1986 Peachtree fires. The elevation ranges from 884 to 957 m (2,600 to 3,140 ft) with an aspect of 172°. The canopy is comprised of 85% Table Mountain pine

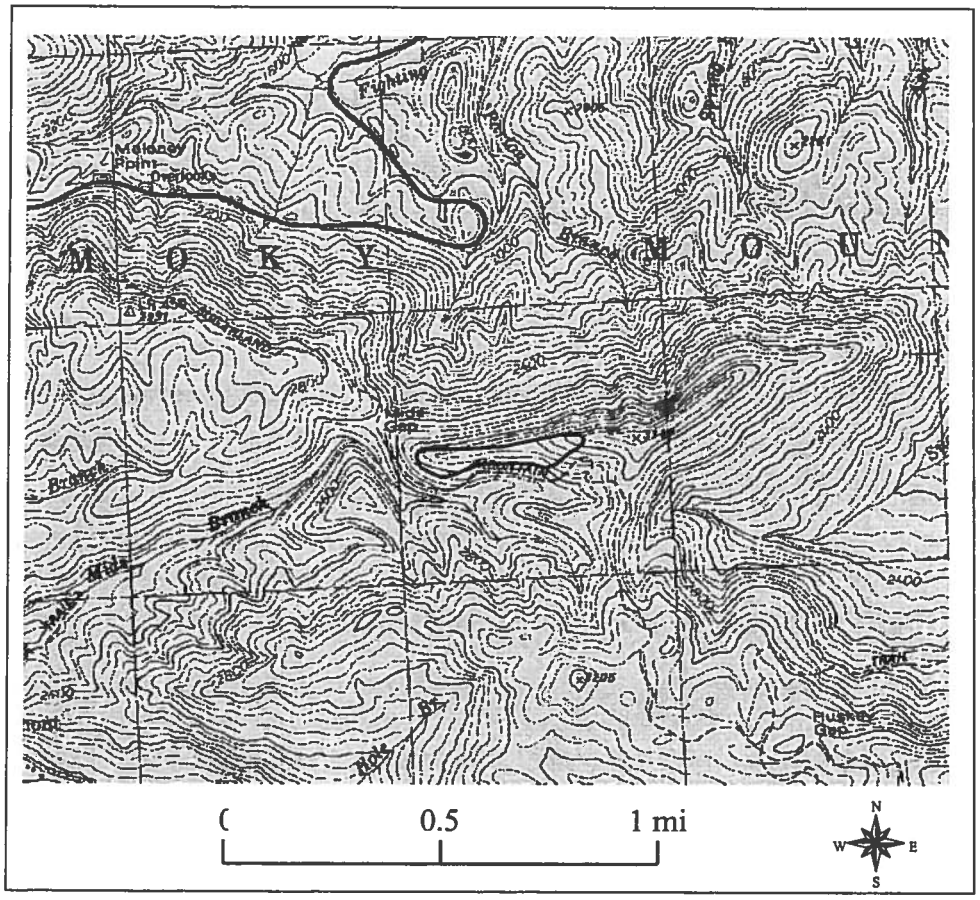


Figure 4-5. Map of the Sugarland Mountain study site. The site boundary is designated by a thick black line in the center of the map. This map was created using the Gatlinburg, TN USGS 7.5 minute topographic quadrangle.

Figure 4-6. Fire-scarred downed log at the Sugarland Mountain study site.

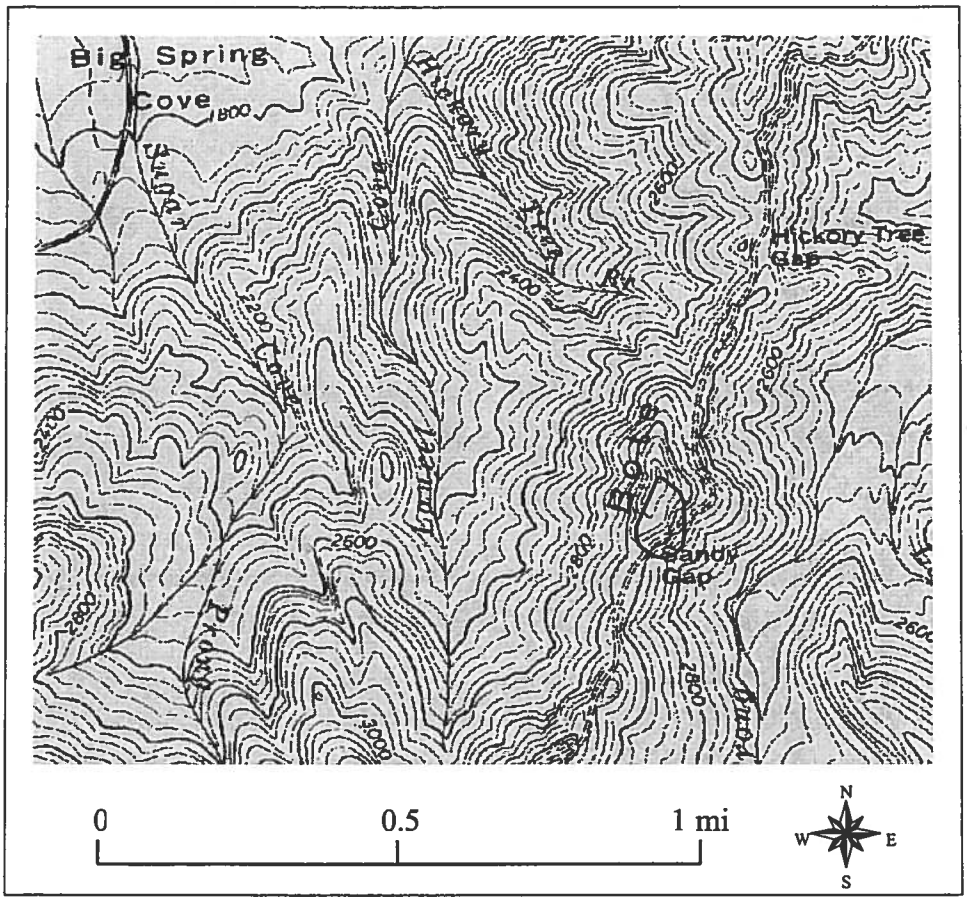


Figure 4-7. Map of the Thunderhead study site. The site boundary is designated by a thick black line. This map was created using the Thunderhead Mountain, NC-TN USGS 7.5 minute topographic quadrangle.

and 13% pitch pine. I found very little evidence of SPB infestation; however, there is a heavy horizontal fuel load on top of the ridge. The entire stand has a thick layer of fine fuels.

4.3.2.5 Cades Cove (CC)

The Cades Cove site (35° 35.42'N, 83° 45.17' W) is located 2 km (1.3 mi) up the Anthony Creek Trail from the Cades Cove picnic area on a south-facing slope of Allnight Ridge (Figure 4-8). The elevation ranges from 695 to 914 m (2,280 to 3,000 ft) with an aspect of 200°. This stand is the most unique stand in my study because it is very moist. Anthony Creek is approximately 10 m (30 ft) down slope of the Table Mountain pine stand. The canopy is comprised of approximately 70% Table Mountain pine, 15% pitch pine, and 15% hardwood species. The midstory is thick with eastern hemlock (*Tsuga canadensis* L.) to the middle of the stand where white pine (*Pinus strobus* L.) becomes the dominant midstory species. Hardwood species, such as red maple and scarlet oak, are also present. I found no evidence of SPB infestation in the stand. Fine and heavy fuels were present.

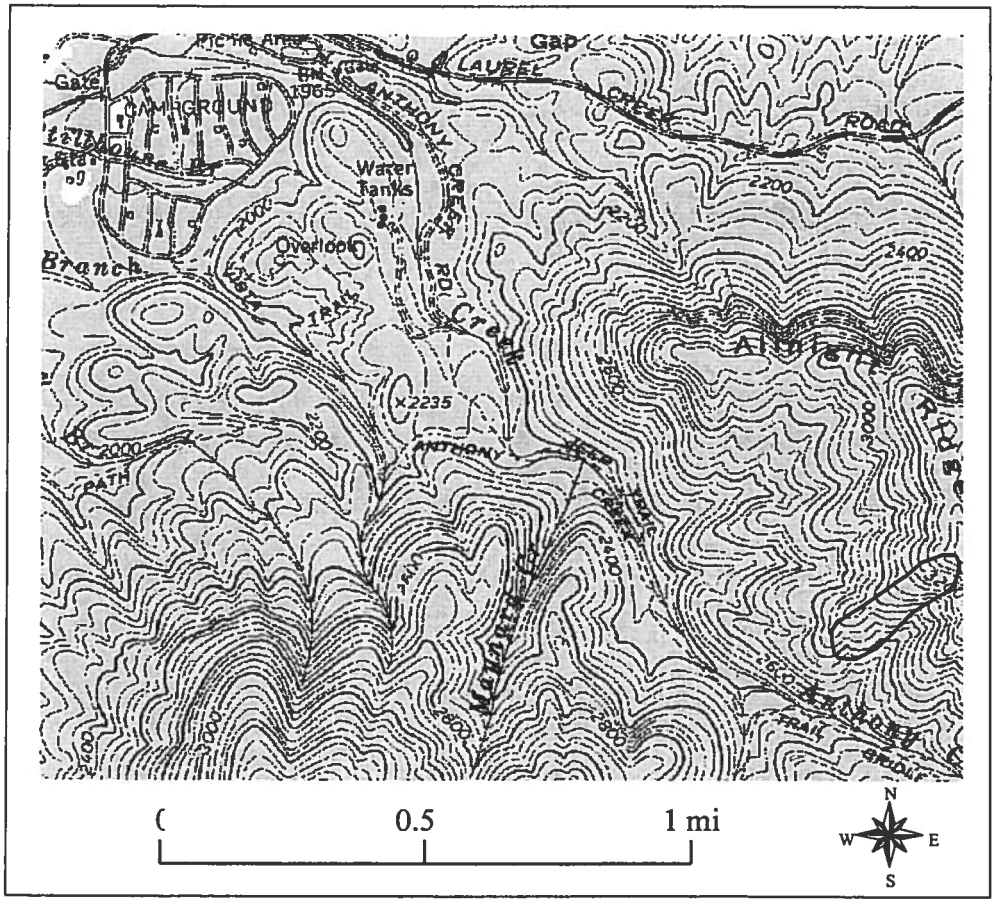


Figure 4-8. Map of the Cades Cove study site. The site boundary is designated by a thick black line in the southeast corner of the map. This map was created using the Cades Cove, TN-NC USGS 7.5 minute topographic quadrangle.

5 METHODS

5.1 Field Methods

In August 2001, I began field work in GSMNP to collect core samples and fire-scarred cross-sections from my five sample sites. I also collected information on stand composition and structure.

5.1.1 Age Structure

To begin sampling Table Mountain pine for age structure, I first obtained a bearing from the bottom of each stand to use as my transect bearing. The bearing changed from site to site due to differing slope aspects; however, transects generally ran from the bottom of a stand to the top of the ridge with an average bearing of N30°E. The width of each belt transect also changed at each stand. I determined the width of each belt transect based on the frequency of Table Mountain pine and the shape of the stand. Belt transects varied from 5 to 10 meters (16 to 32 ft) wide. Samples were collected from a minimum of two transects at each site.

To ensure adequate sample depth, I collected at least two radii from a minimum of 75 trees at each site. Table Mountain pine seedlings and saplings too small to core were documented and their terminal bud scars and branch nodes were counted to determine their age, a technique used by Williams and Johnson (1990). I collected cores from the base of each stem and parallel to the slope contour using 40 cm and 50 cm (16 in and 20 in) Haglof increment borers. After extraction, each core was placed into a properly labeled paper straw for safe transportation and drying. I recorded relevant data

(diameter at breast height (dbh), tree height, slope angle, crown density, and lean direction) for each sampled Table Mountain pine on standard specimen cards.

5.1.2 Fire History

I extensively scouted for fire-scarred Table Mountain pine snags, stumps and downed logs at each of my study sites. When a sample was located, I recorded all pertinent information (slope, aspect, microsite conditions, diameter, height, lean degree, type of sample, and location) on a standard specimen card and photographed the scarred surface. I sketched each sample before and after cutting for easier assembly in the laboratory. Cross-sections were collected using a K-24 53 cm (21 in) rip saw (Figure 5-1), labeled with a permanent marker, photographed, and wrapped tightly in plastic wrap to preserve sample integrity for transport back to the laboratory. My original goal was to collect eight to ten fire-scarred samples from each stand; however, I was only able to find and collect a total of 17 sound fire-scarred sections from all study sites, many with multiple scars.

Because of the low sample size of suitable fire-scarred samples at many of my sites, I decided to collect additional data and samples that would provide further fire history information. Two sites in particular (Cades Cove and Cherokee Orchard) had very little visible evidence of past fires; however, both were being invaded by fire-intolerant tree species. From the Cades Cove site, I collected age structure information from 36 eastern hemlock along a transect, 11 of which were large enough for me to collect core samples. Similarly, I collected age structure information from 41 red maples

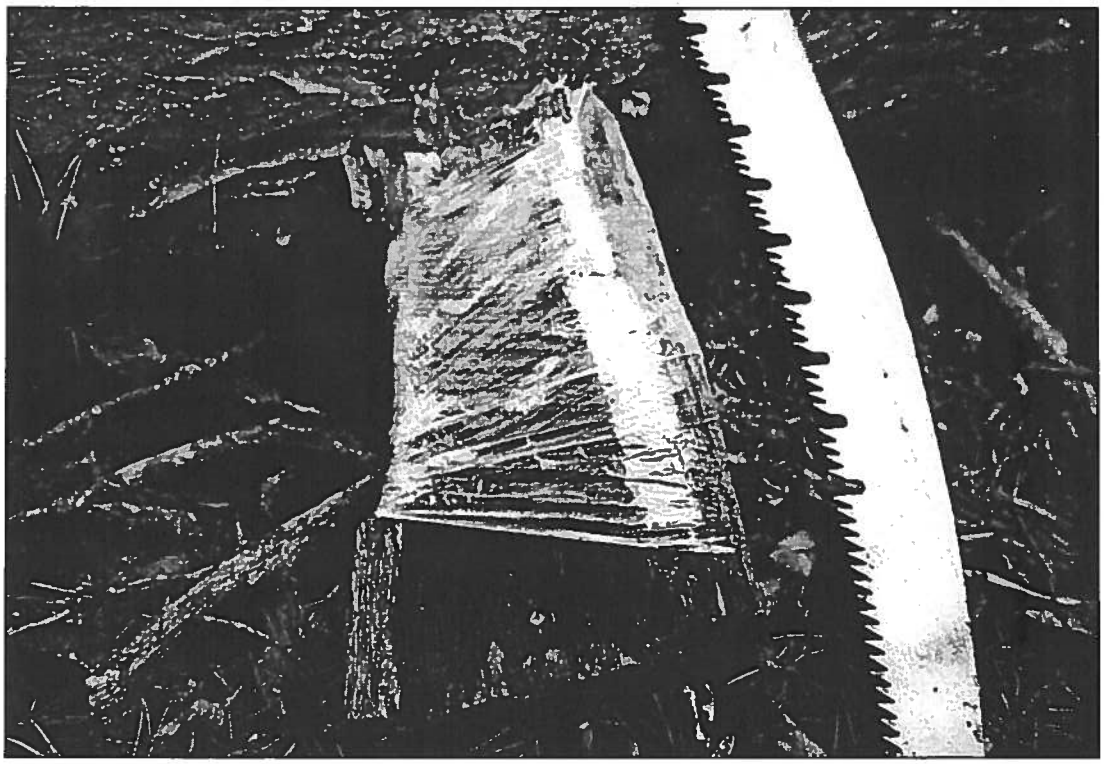


Figure 5-1. Fire-scarred stump collected from the Sugarland Mountain study site. The K-24 rip saw used to cut this sample can be seen in the photograph. This sample was wrapped with plastic wrap before sampling to preserve the fragile scars.

along a transect at the Cherokee Orchard site. I was able to take core samples from two individuals.

5.1.3 Stand Structure and Composition

I conducted an inventory of canopy and midstory tree species for all five study sites. Additionally, I noted occurrences of hardwood invasion and the forest conditions surrounding the area of invasion. These conditions included gap-dynamics, presence and extent of SPB infestation, and indications of past fire. For further information pertaining to the conditions in each stand, I measured the depth of the duff at approximately 10 to 20m (33 to 66 ft) intervals along the transect from the bottom of each stand to the ridge-top.

5.2 Laboratory Methods

All core samples were air dried for a minimum of 24 hours. Sections were removed from the protective plastic wrap and also allowed to air dry. Cores were glued to wooden core mounts and secured with masking tape. Each core mount was labeled on all three sides with the sample identification number. To achieve the optimum surface for viewing tree-ring boundaries, I sanded each sample using a 4x24 inch belt sander starting with a coarse grit sanding belt (80 grit (192-197 microns)). Each core was sanded with progressively finer sanding belts, with a 320 grit (36-46.2 microns) belt providing the final polished surface. This technique provided a smooth, flat surface on each core and ensured that the intra-annual ring detail was easily discernable under standard magnification.

Fire-scarred cross-sections were cut into manageable pieces using a 24-inch industrial band saw. When necessary, sections were reassembled and glued onto plyboard. I then sanded all sections using progressively finer sanding belts with a 4x24 inch belt sander. I started with a 40 grit (412-428 microns) sanding belt, to plane the surface, and finished with a 400 grit (23.6-35 microns) belt to polish the surface (Figure 5-2).

5.2.1 Age Structure

To assign an age for each sampled tree, I used the List Method described by Yamaguchi (1991) that allows cores from living trees to be crossdated based on the identification of reoccurring ring patterns and marker rings. I recorded the pith/inner-ring dates into a spreadsheet, along with the age of each tree (Table A-1). For cores that did not intersect the pith, I used standard pith estimators (Applequist 1958) to estimate the pith date based on the curvature of the inner-rings. This method may introduce a small amount of error for tree age, but the number of cores that did not intersect the pith was minimal. I did not have to correct for error due to sampling height, because I collected cores as close to ground level as possible. Finally, I plotted the age distributions in 10-year age-classes for each stand and for all stands combined.

5.2.2 Master Chronology

The keystone technique of dendrochronology is crossdating, which can be accomplished with both graphical and statistical methods to assign an exact year of formation to each tree ring (Fritts 1976; Swetnam *et al.* 1985). Using the core samples

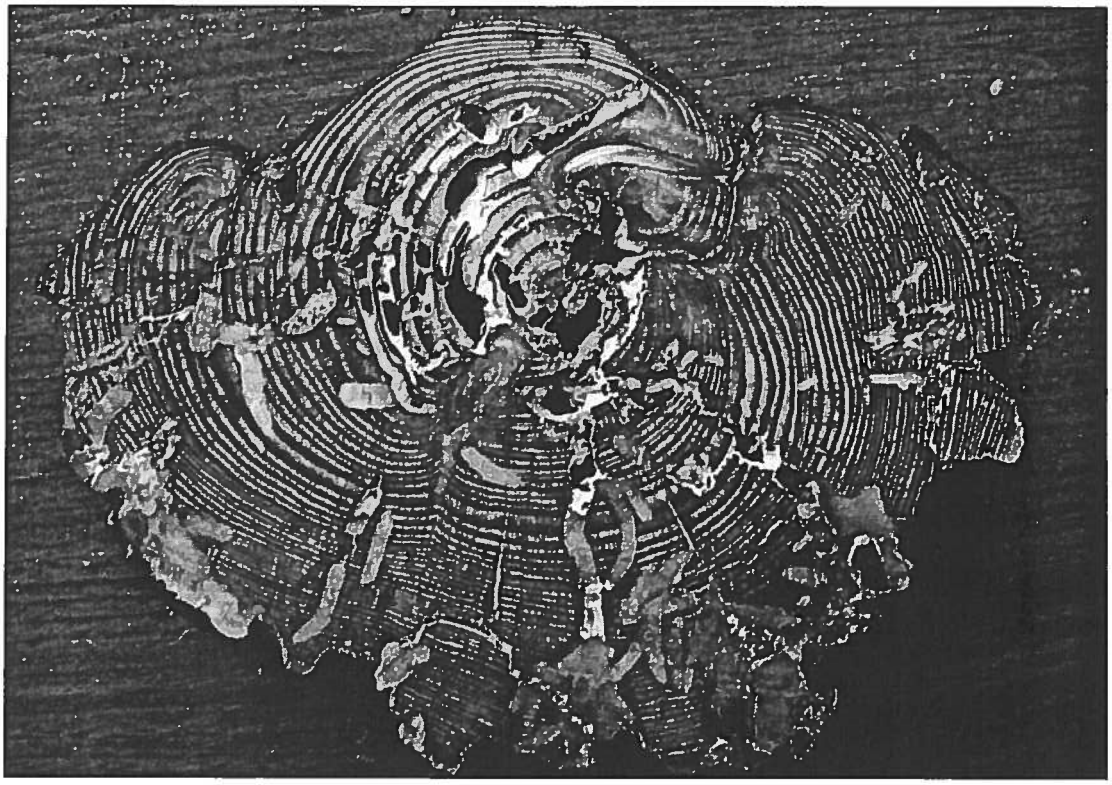


Figure 5-2. Fire-scarred sample collected at the Thunderhead study site. This section is 19 cm (7.5 in) in diameter.

dated for age structure analysis, I developed a master chronology for Table Mountain pine in GSMNP. This served two purposes: 1) to ensure the quality of my original crossdating using the List Method, and 2) to provide a master chronology for dating my fire-scarred cross-sections and wedges. I began by measuring the ring widths of each core from the Cades Cove site. This site had the oldest trees of all five sites, which allowed me to extend the chronology further back in time. I obtained ring width measurements using the software MEDIR and a 61-cm (24-inch) Velmex measuring station. I input ring-width measurements for each core into the program COFECHA, which assesses the accuracy and quality of crossdating (Holmes 1983; Grissino-Mayer 2001a). The program also allowed me to select the trees with the strongest statistical relationships for chronology development (Grissino-Mayer 1995).

After every core from the Cades Cove site was measured and checked with COFECHA, I selected the 15 oldest cores from each of the four remaining study sites to measure and include in the master chronology. When I had determined which cores were statistically significant for chronology development, I ran the program CRONOL to create a master chronology from the raw ring-width measurements (CRONOL is a scaled-down version containing the routines found in the program ARSTAN) (Cook 1985).

5.2.3 Fire History

I was unable to crossdate the fire-scarred cross-sections with confidence using the List Method or graphical techniques, largely because ring sequences were mostly complacent. Therefore, to assign dates to the fire-scarred rings, I used the program

COFECHA. First, I measured the tree-ring widths from each section, then input the undated ring-width measurements into the program COFECHA. When COFECHA located a dating placement that was statistically valid, I visually verified that dating placement based on the master chronology and input the inner and outer dates, along with the dates of fire-scarred rings, into the spreadsheet. The season of each fire event was determined by locating the exact position of the fire scar within the annual tree ring in which it occurred (Baisan and Swetnam 1990; Grissino-Mayer 1995). Eight fire-scarred sections could not be assigned a dating placement by COFECHA, nor could I date those samples using either visual or statistical methods; however, I did obtain other valuable data from those eight sections – fire seasonality, fire intervals, and statistical descriptors based on the Weibull distribution (Grissino-Mayer 1995, 1999, 2001).

I input the fire history information into a database using the program FHX2, software designed for graphing and statistically analyzing fire interval data collected from tree rings (Grissino-Mayer 1995, 1999). I used two separate databases for my analysis. One contained undated, pre-park (prior to 1934) fire history data and the other contained dated, post-park (after 1934) fire history data. One dated pre-park sample was included in both databases. The post-park fire history database included only crossdated fire-scarred samples. From this database, I created a composite fire interval graph (Dieterich 1980) showing the spatial and temporal characteristics of the fire history at two sites, Bull Head and Thunderhead (Grissino-Mayer 2001b). Because only 40% of the post-park fire-scarred sections contained multiple fire scars, I was unable to run meaningful statistical analysis to obtain fire interval information.

The pre-park fire history database I created using FHX2 contained data from all undated fire-scarred sections. To increase the sample depth for statistical analysis, I combined the information from all sites into this one database, including the one dated pre-park sample. Using the Statistics Module of FHX2, I was able to derive statistical descriptors of the fire interval data based on the Weibull distribution across all five study sites (Grissino-Mayer 2001b). These descriptors, however, were based on point fire return intervals (each tree representing one point), rather than composite fire intervals. Although this technique has been proven effective for developing information on fire regimes (Tayler 2000), this is the first study to use undated samples for point fire return interval analysis.

The Weibull distribution is desirable because it is able to model an assortment of positively skewed distributions, and has been found to provide a superior fit to fire history data than most other distributions (Grissino-Mayer 1999, 2001b). It has been effectively applied to data collected from North American boreal forests and the American Southwest, areas with different historical fire regimes (Grissino-Mayer 1999). Using the FHX2 software, I fit a Weibull distribution to my fire interval data and derived the Weibull Median Interval (MEI), Weibull Modal Interval (MOI), Lower Exceedance Interval (LEI), Upper Exceedance Interval (UEI), and Maximum Hazard Interval (MHI), as well as the mean and median fire intervals (Grissino-Mayer 1995, 1999, 2001b).

After fitting the Weibull distribution to the pre-park fire interval data, the FHX2 software creates a Weibull Distribution Exceedance Probability Table. The MEI, UEI, and LEI are all derived from this table. The UEI and LEI are based on a 12.5% exceedance probability, thus representing the extremes (very short and very long) of all

intervals. Lower percentiles (97.5 and 2.5) are perhaps too stringent for ecological and managerial purposes (Grissino-Mayer 1999). The LEI delimits the interval in the shorter range of the distribution exceeded by 87.5% of all intervals, while the UEI delimits the interval in the longer range of the distribution exceeded by only 12.5% of all intervals (Grissino-Mayer 1999). The MEI is associated with the interval of the 50th percentile. Because the MEI corresponds to the quantile midpoint of the theoretical distribution fit to the actual data, it represents a measure of central tendency that is resistant to large values in the actual fire interval data (Grissino-Mayer 1999). The MOI was found by Grissino-Mayer (1999) to be a superior overall measure of central tendency that identified a common underlying structure in Southwestern fire regimes independent of habitat and environmental gradients (Grissino-Mayer 2001b). Finally, the MHI represents the fire interval associated with the theoretical maximum fire-free period that can be sustained before burning is highly probable (Grissino-Mayer 1999). This statistic provides information concerning fire hazard that is particularly useful for management purposes.

The Cades Cove and Cherokee Orchard sites had very little visual evidence of past fires. I collected only one fire-scarred sample from the Cades Cove site, and no fire-scarred samples from the Cherokee Orchard site. Therefore, I collected age structure information from fire-intolerant tree species that were invading each site (red maple at Cherokee Orchard and eastern hemlock at Cades Cove). The majority of these trees were not old enough to core to obtain age information. Instead, I estimated the ages of individual trees based on dbh and height, and categorized each tree as either seedling (1-9

years) (<1 cm (0.4 in) dbh and <1 m (3.28 ft) in height) or sapling (10-19 years) (>1 cm (0.4 in) and <10 cm (4 in) dbh). To assess the current population structure of those tree species, I input age information into a spreadsheet and created age structure histograms.

6. RESULTS

6.1 Forest Structure and Composition

I documented a similar forest composition at all five study sites (Table 6-1). Table Mountain pine was the most common canopy species at all stands, while mountain laurel was the most common midstory species in four of the five stands. The Bull Head, Sugarland Mountain, and Thunderhead sites were all similar in species composition and forest structure. All three sites had similar canopy composition, with black gum occurring only at Bull Head and Fraser magnolia (*Magnolia fraseri* Walt.) occurring only at Sugarland Mountain. The Cades Cove site canopy included many white pine and eastern hemlock individuals. Similarly, the Cherokee Orchard site included many red maples.

The midstory composition and structure was similar in all sites, excluding the Cades Cove site. At that site, eastern hemlock was the most common midstory species from the bottom of the stand to the middle of the stand. At that point, mountain laurel and white pine began taking over as the most common midstory species. The midstory in the remaining four stands was comprised of mountain laurel (the most common species), *Vaccinium*, and greenbrier, along with various hardwood tree species.

Bull Head had the lowest average duff depth of all four sites, 10.1 cm (4 in), while Cherokee Orchard had an average duff depth of 14.2 cm (5.6 in) (Table 6-2). At the Sugarland Mountain and Thunderhead sites, I found average duff depths of 18.7 cm (7.35 in) and 18.8 cm (7.4 in) respectively. The Cades Cove site had the highest average duff depth at 23.4 cm (9.2 in).

Table 6-1. Results of species inventories at each study site. Species are grouped into midstory and canopy species, and listed in order by percent of stems.

Site	Midstory		Canopy	
Cherokee Orchard	Mountain Laurel	70%	Table Mountain Pine	75%
	Red Maple	15%	Scarlet Oak	11%
	Scarlet Oak	5%	Chestnut Oak	6%
	Greenbrier	4%	Red Maple	5%
	Chestnut Oak	4%	Pitch Pine	2%
	Vaccinium	1%	Fraser Magnolia	1%
	Rhododendron	1%		
Bull Head	Mountain Laurel	80%	Table Mountain Pine	70%
	Greenbrier	10%	Pitch Pine	20%
	Vaccinium	5%	Chestnut Oak	5%
	Red Maple	2%	Scarlet Oak	3%
	Chestnut Oak	2%	Black Gum	2%
	White Pine	1%		
Sugarland Mountain	Mountain Laurel	60%	Table Mountain Pine	80%
	Greenbrier	12%	Pitch Pine	10%
	Chestnut Oak	8%	Scarlet Oak	5%
	Scarlet Oak	9%	Chestnut Oak	4%
	Red Maple	6%	Fraser Magnolia	1%
	Vaccinium	2%		
	Rhododendron	2%		
	White Pine	1%		
Thunderhead	Mountain Laurel	60%	Table Mountain Pine	85%
	Scarlet Oak	15%	Pitch Pine	9%
	Chestnut Oak	12%	Chestnut Oak	3%
	Red Maple	6%	Scarlet Oak	3%
	Vaccinium	5%		
	White Pine	1%		
	Rhododendron	1%		
Cades Cove	Eastern Hemlock	35%	Table Mountain Pine	70%
	Mountain Laurel	30%	Pitch Pine	15%
	White Pine	20%	Chestnut Oak	5%
	Greenbrier	10%	Scarlet Oak	4%
	Vaccinium	3%	White Pine	3%
	Fraser Magnolia	2%	Eastern Hemlock	2%
			Fraser Magnolia	1%

Table 6-2. Results of duff-depth measurements at each study site. Five measurements were taken from the bottom of the slope at each site (Sample 1) to the top the ridge (Sample 5). I used these measurements to determine the average duff depth at each study site.

	Cherokee Orchard	Bull Head	Sugarland Mountain	Thunderhead	Cades Cove
Measurement 1 in (cm)	7 (17.8)	3 (7.6)	10 (25.4)	7 (17.8)	7 (17.8)
Measurement 2 in (cm)	8 (20.3)	4 (10.1)	3.5 (8.9)	8 (20.3)	11 (27.9)
Measurement 3 in (cm)	6 (15.2)	6 (15.2)	13 (33.0)	8 (20.3)	12 (30.5)
Measurement 4 in (cm)	3 (7.6)	5 (12.7)	3 (7.6)	9 (22.9)	10 (25.4)
Measurement 5 in (cm)	4 (10.1)	2 (5.1)	7.25 (18.4)	5 (12.7)	6 (15.2)
AVERAGE	5.6 (14.2)	4 (10.1)	7.35 (18.7)	7.4 (18.8)	9.2 (23.4)

6.2 Age Structure

Age structure analyses resulted in a generally J-shaped age distribution at the Sugarland Mountain, Cherokee Orchard, and Bull Head study sites, while all five study sites had a majority of trees in the 60-69 and 70-79 age-classes (Figures 6-1, 6-2, and 6-3). Seventy-eight percent of pines at the Sugarland Mountain site fell within these two age-classes, by far the highest percentage of any stand sampled. A total of 43 out of 77 trees samples at Sugarland Mountain were between 60 and 69 years old (Figure 6-1). The Cherokee Orchard stand also had a peak in age structure corresponding to those age-classes (Figure 6-2). Ninety-two percent of the trees sampled at Cherokee Orchard fell within the 60 to 89 year age-classes.

Bull Head and Thunderhead both had 63% of trees within the 60-69 and 70-79 age-classes. At the Bull Head site, 83% of all trees sampled fell within the 60-89 year age-classes, while the remaining 17% of all trees sampled fell within the 20-29 year age-class (Figure 6-3). While the Thunderhead site had the same percentage of trees within the 60-79 year age-classes, a much higher percentage of trees fell within the 1-19 year age- classes (Figure 6-4). Though it does not necessarily have a bimodal age structure, this site has the most similar age structure to those found in the Sutherland *et al.* (1995) study at their Brush Mountain, Virginia site.

The Cades Cove site had the oldest age-classes of all five sites (Figure 6-5), which resulted in a skewed age distribution. While 54% of all trees sampled fell between the 60-79 year age-classes, 32% of trees at this site were between 80 and 190 years old. The oldest tree (190 years) was found at this site.

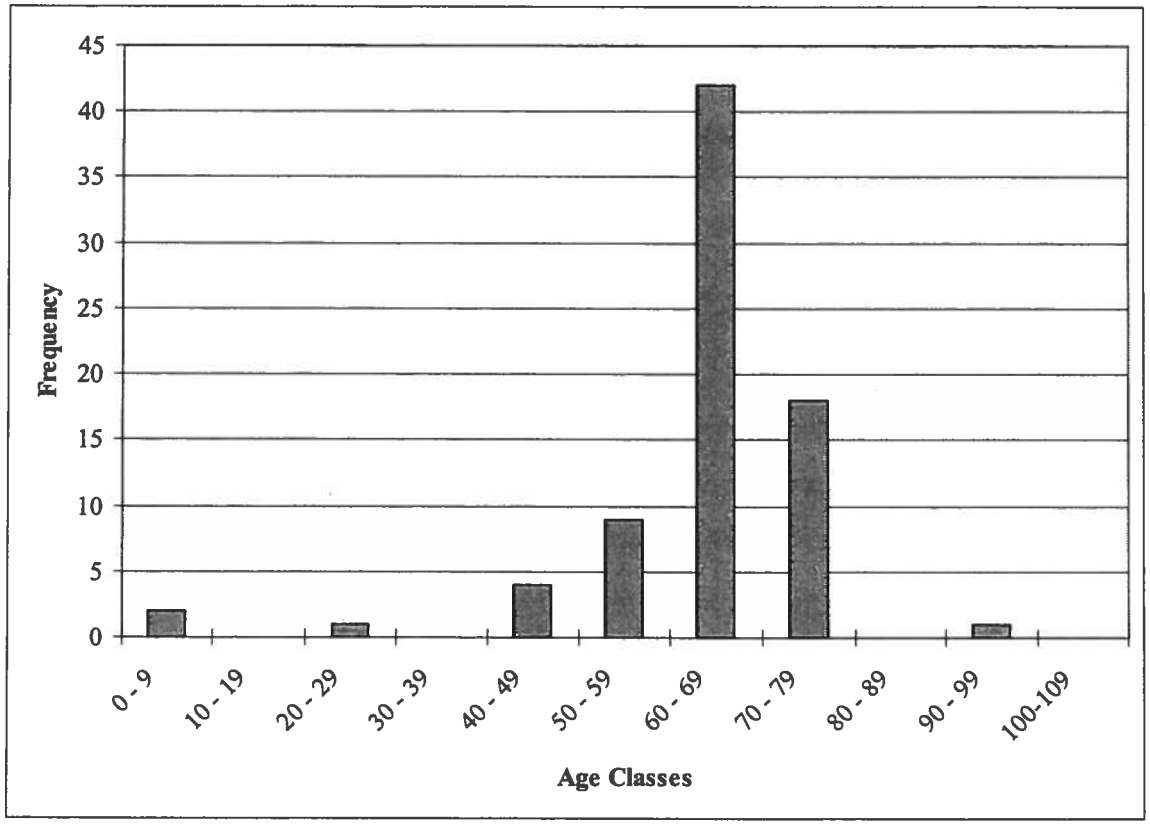


Figure 6-1. Age structure histogram for the Sugarland Mountain (SM) site.

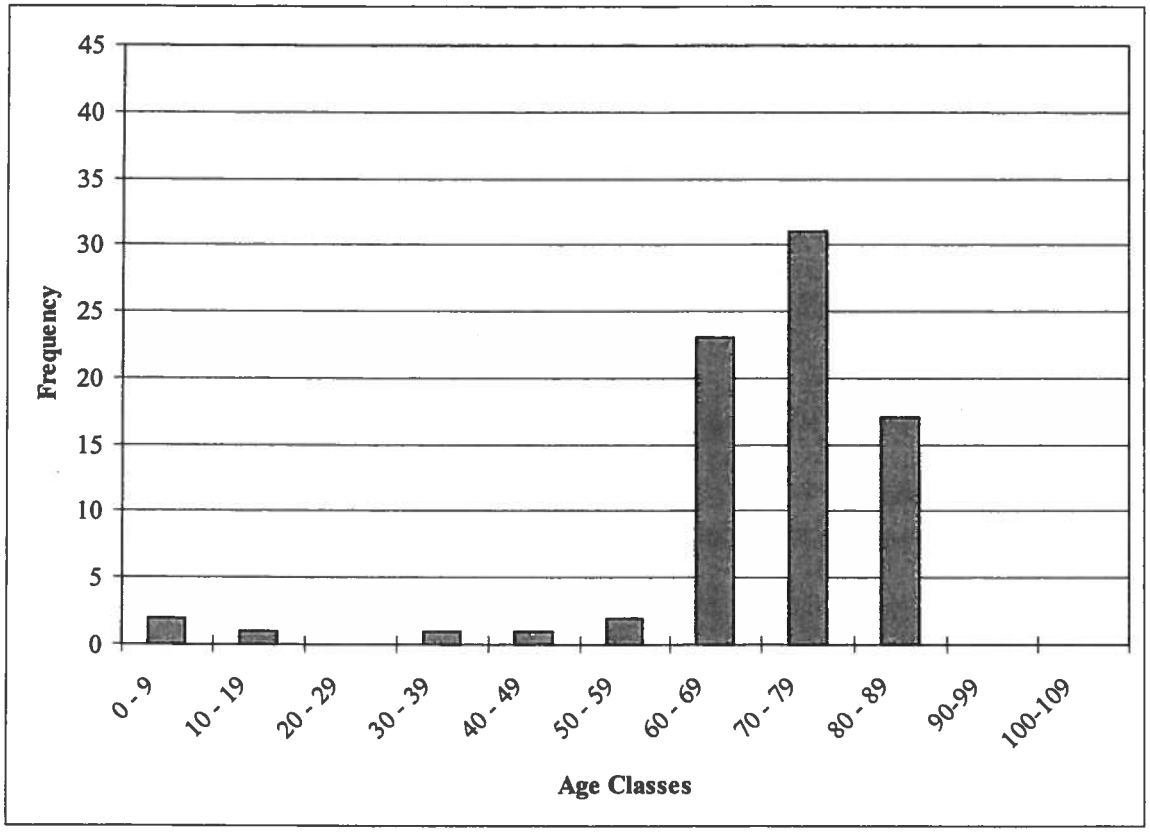


Figure 6-2. Age structure histogram for the Cherokee Orchard (CO) site.

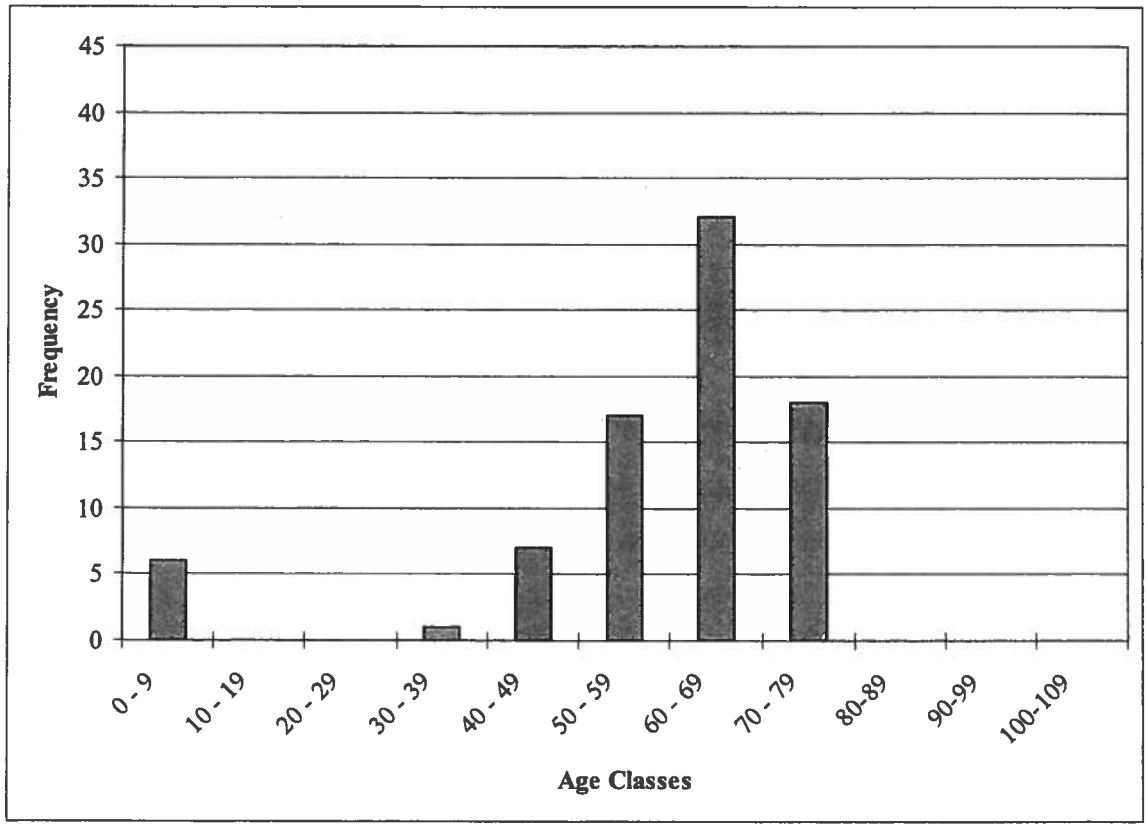


Figure 6-3. Age structure histogram for the Bull Head (BH) site.

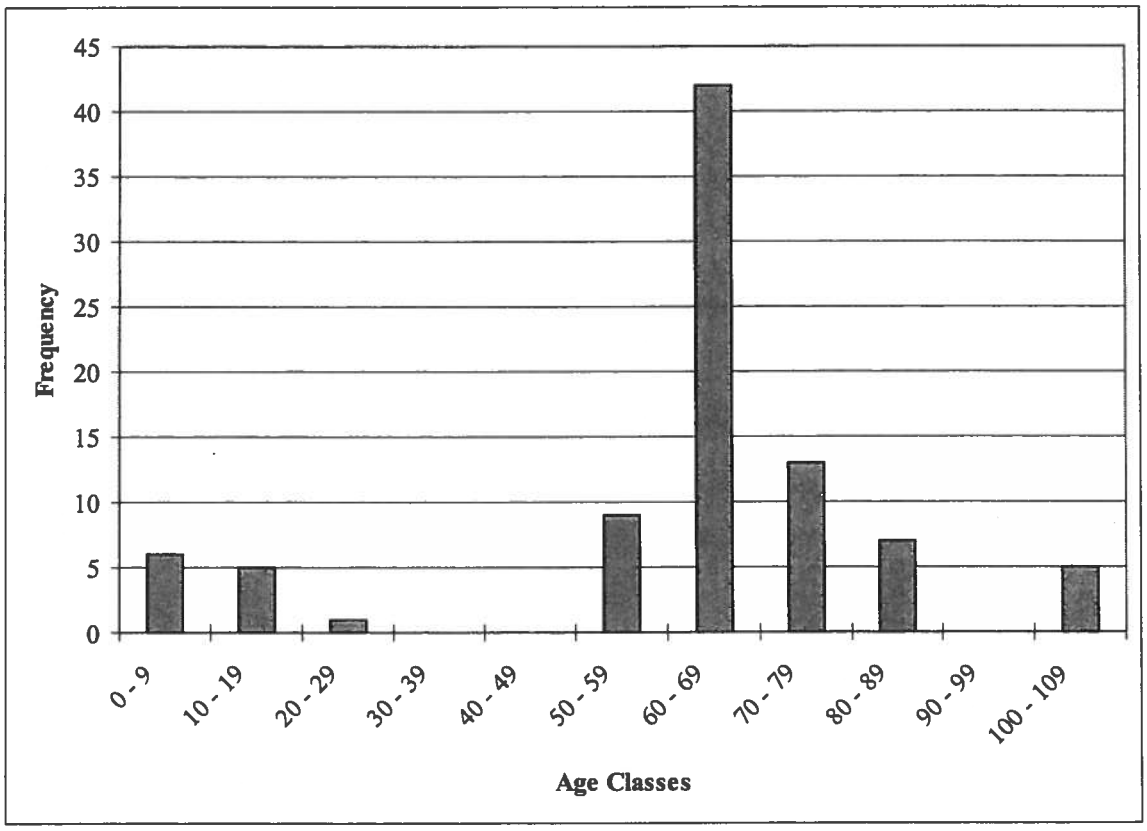


Figure 6-4. Age structure histogram for the Thunderhead (TH) site.

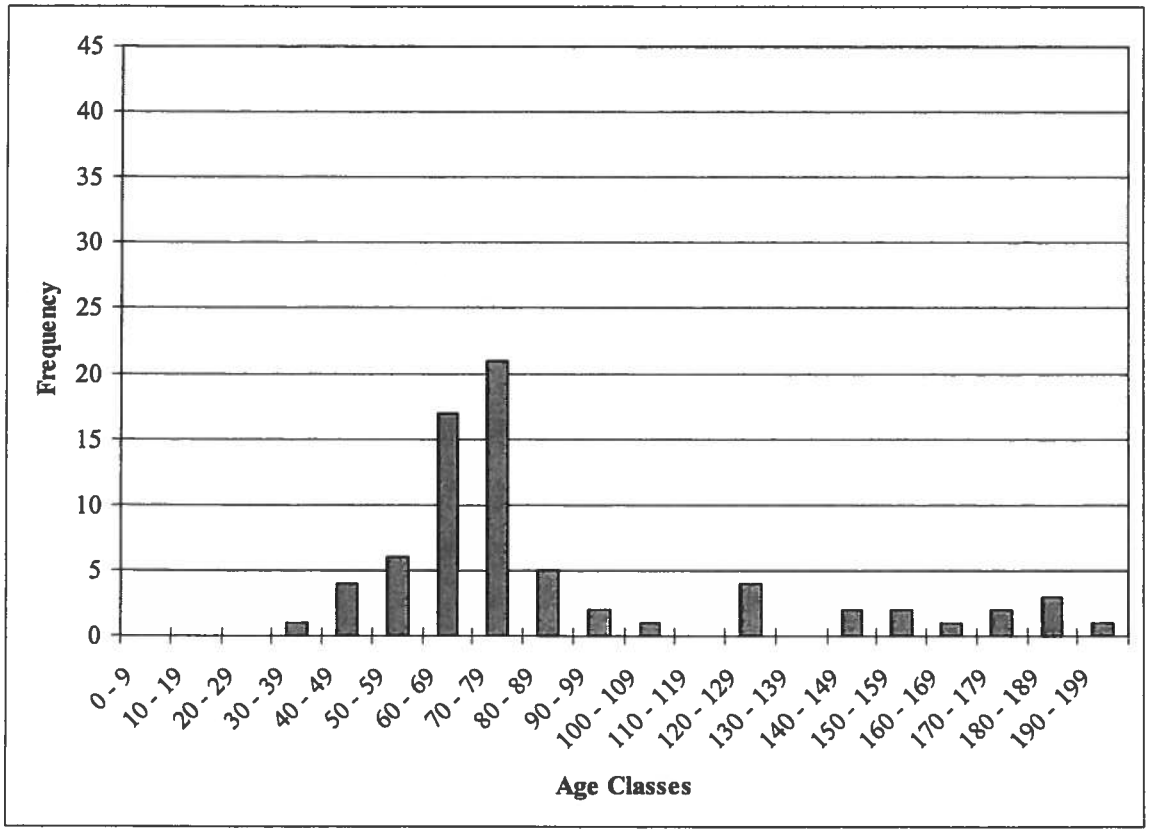


Figure 6-5. Age structure histogram for the Cades Cove (CC) site.

The combined composite age structure histogram for all five study sites showed that 39.5% of all trees fell into the 60-69 year age-class and 25.3% fell into the 70-79 year age-class (Figure 6-6). While 10.9% of samples were between 50 and 59 years old, only 11% fell into age-classes younger than 50 years old. Seven percent of samples fell into the 80 to 89 year age-class, while 6% of all samples fell into age-classes beyond that 80 to 89 year category.

6.3 Master Chronology

I constructed a master chronology for Table Mountain pine in GSMNP that extended back to 1837 based largely on the statistical information provided by the program COFECHA (Tables A-2 and A-3). However, the sample depth prior to 1887 was limited to one sample between 1837 and 1887. Some of the cores that I measured and input into COFECHA were not statistically significant enough, based on interseries correlations, to include in the final master chronology. Eventually, 61 cores were used, representing 45 trees, with a final interseries correlation coefficient of 0.538. While some cores had ring series that were not statistically similar, there were enough cores with common ring patterns to suggest a common pattern between trees from all five sample sites.

6.4 Fire History

I was able to establish dates for nine of the 17 fire-scarred samples (Table A-4). While COFECHA should not be used as the sole means of crossdating samples in most cases, I was able to determine statistically significant dating placements for two

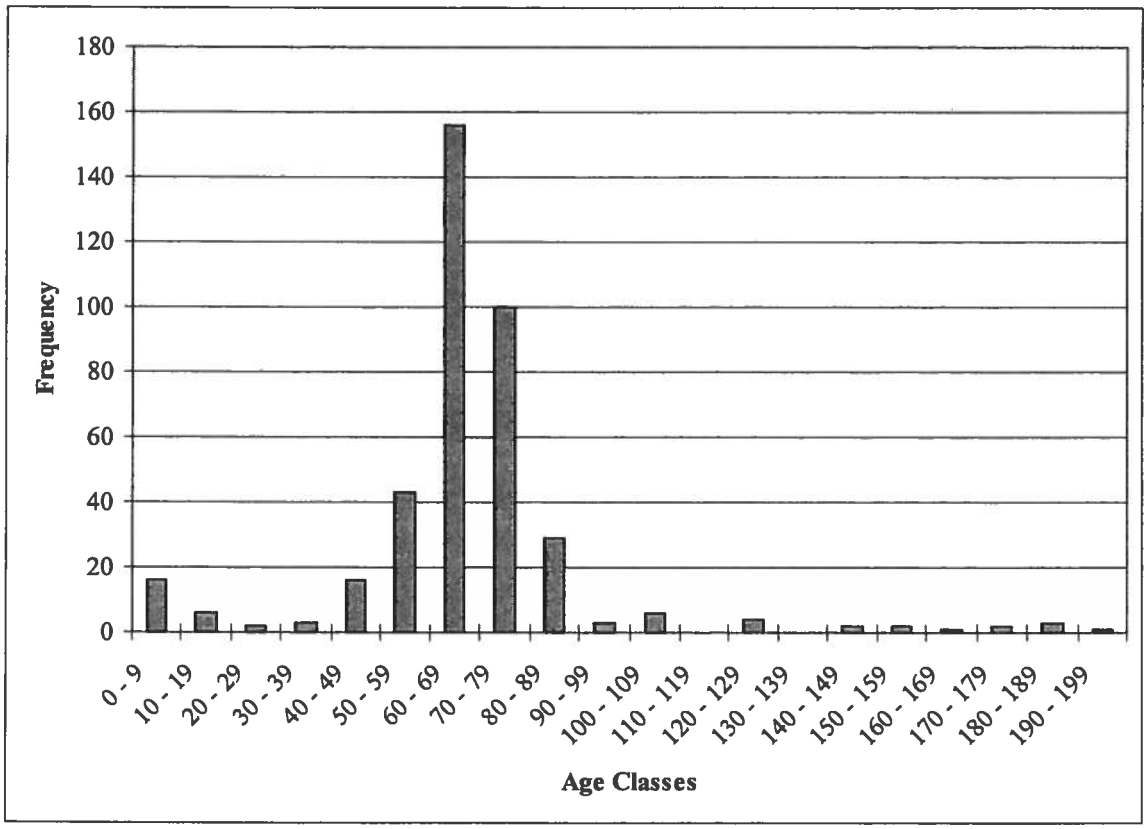


Figure 6-6. Composite age structure histogram for all five study sites.

samples from Bull Head and three samples from Thunderhead. Additionally, I was able to establish dates for four other Thunderhead samples using the known outer ring date. The composite fire chart located at the bottom of the master fire history graph (Figure 6-7) indicates a large gap from 1917 to 1962 caused largely by the implementation of fire suppression management practices. While the one pre-park sample shows a more frequent fire regime in the mid-1800s, the presence of fires during the mid- to late-1900s is possibly a result of the relationship between SPB and fire in the southeastern United States (Schowalter *et al.* 1981). The majority of all fires that occurred during both the pre-park and post-park periods were dormant season (September to February) fires.

The master fire history graph for the pre-park samples could not be used for temporal analysis, because all but one of the fire-scarred samples are undated. However, it is valuable to visually plot and statistically analyze the data (Figure 6-8). The frequency distribution graph of the actual fire interval data indicated a classic Weibull distribution (Figure 6-9), and the FHX2 output for this database contained a number of important statistics (Table 6-3). The MEI for the pre-park fire history database was 6.75, which falls between the mean fire interval (7.48) and the median fire interval (6.00). The MOI, another important measure of central tendency, was 4.83. The LEI was 2.50 and the UEI was 13.09 (Table 6-4), while the MHI was 80.57 years.

Results of the age structure analysis of fire-intolerant tree species that were invading the Cades Cove and Cherokee Orchard sites indicated a concave age distribution curve for both species. Of the 41 red maple individuals sampled at the Cherokee Orchard site, 26 were categorized as seedlings (1-9 years) and 13 were categorized as saplings (10-19 years) (Figure 6-10). Only two individuals were large enough to collect core

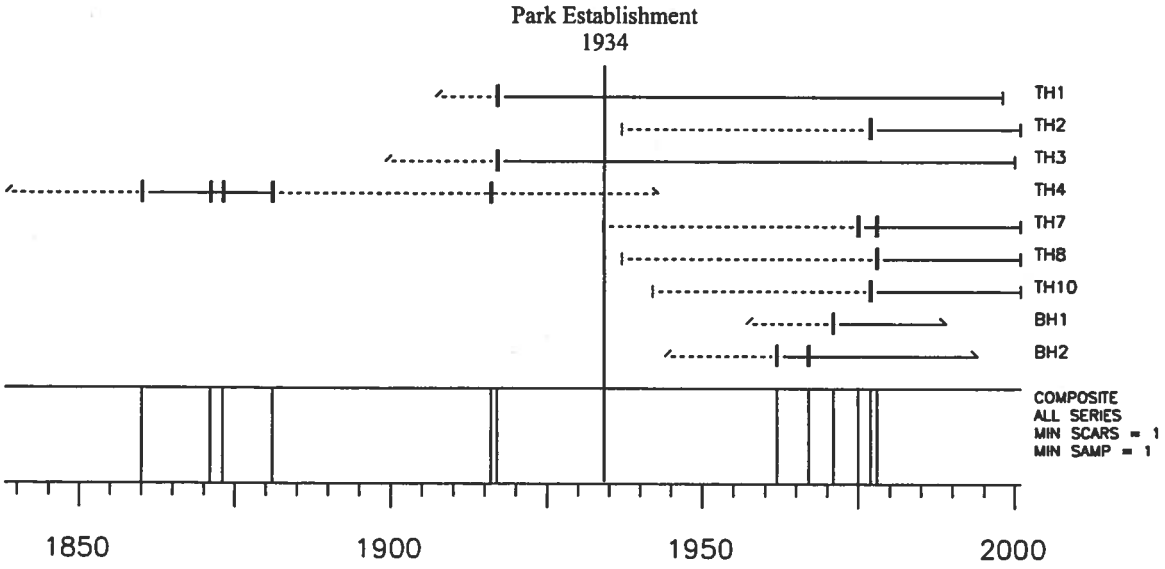


Figure 6-7. Master fire history graph showing crossdated, post-park fire-scarred samples and one pre-park sample. Horizontal lines represent individual fire-scarred trees with sample identification numbers located to the right. Dotted lines indicate null years, or years where a tree was not considered a recorder of fire history. Pith and bark years are represented by short vertical bars, while inner and outer years (where pith and bark respectively were not present) are represented by arrows. Small vertical bars indicate dated fire scars. The composite fire chart is located at the bottom of the graph.

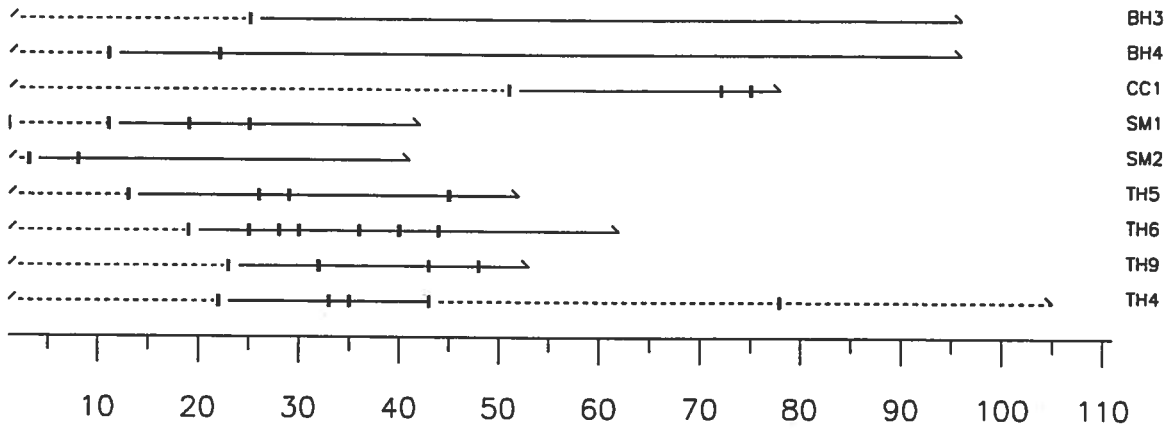


Figure 6-8. Master fire history graph showing undated, pre-park samples. Values on the x-axis represent the number of rings. Horizontal lines represent individual fire-scarred trees with sample identification numbers located to the right. Dotted lines indicate null years, or years where a tree was not considered a recorder of fire history. Pith and bark years are represented by short vertical bars, while inner and outer years (where pith and bark respectively were not present) are represented by arrows. Small vertical bars indicate undated fire scars.

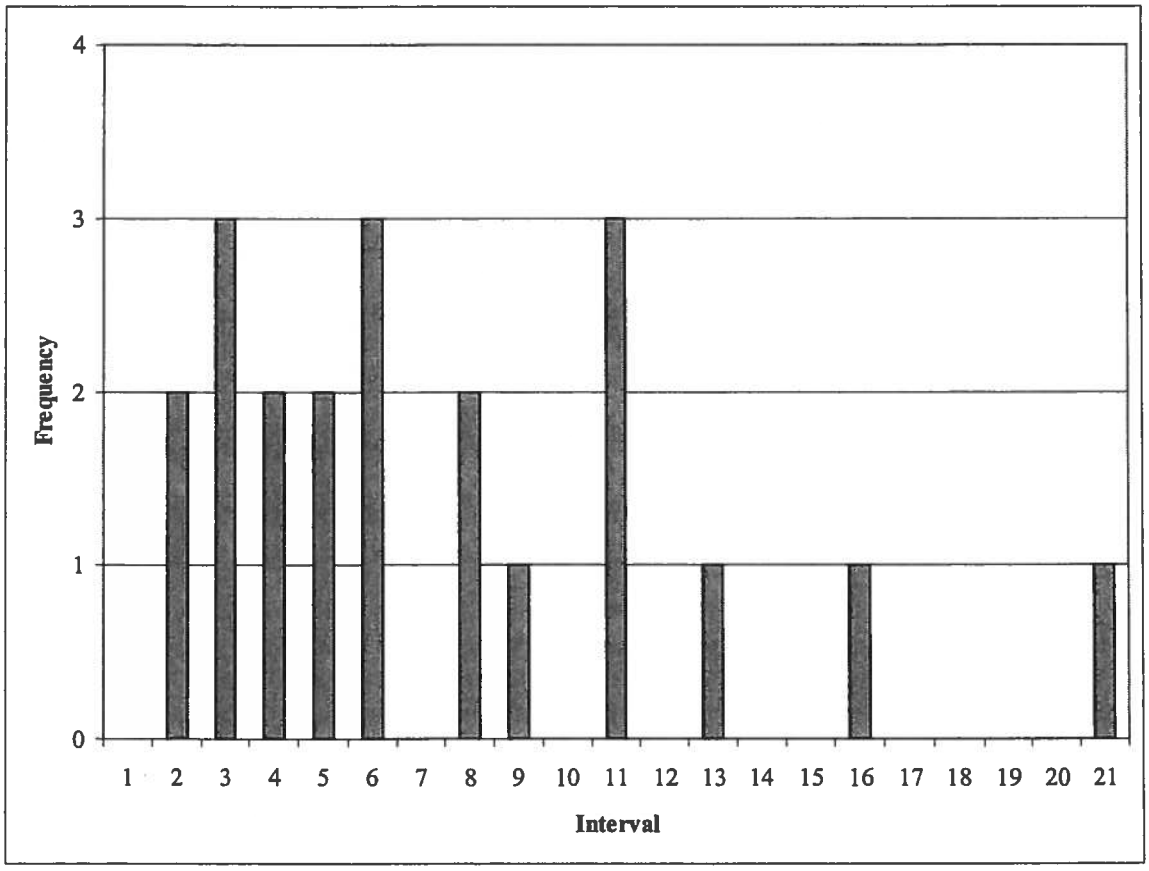


Figure 6-9. The frequency distribution of fire intervals for the undated, pre-park database.

Table 6-3. Statistical descriptors from the final FHX2 output for fire interval analysis of undated, pre-park fire-scarred samples. This output was created using the Statistics Module of FHX2 (Grissino-Mayer 1995).

Mean Fire Interval	7.48
Median Fire Interval	6.00
Weibull Modal Interval (MOI)	4.83
Weibull Median Interval (MEI)	6.75
Lower Exceedance Interval (LEI)	2.50
Upper Exceedance Interval (UEI)	13.09
Maximum Hazard Interval (MHI)	80.57

Table 6-4. Weibull distribution exceedance probability table from the final FHX2 output for fire interval analysis of undated, pre-park fire-scarred samples. This output was created using the Statistics Module of FHX2 (Grissino-Mayer 1995).

<< = significantly short interval, >> = significantly long interval

Exceedance Probability	Associated Fire Interval
0.999	0.13 <<
0.990	0.53 <<
0.975	0.92 <<
0.950	1.41 <<
0.900	2.17 <<
0.875	2.50 << - LEI
0.800	3.41
0.750	3.98
0.700	4.53
0.667	4.89
0.500	6.75 < - MEI
0.333	8.91
0.300	9.42
0.250	10.25
0.200	11.22
0.125	13.09 >> - UEI
0.100	13.92 >>
0.050	16.31 >>
0.025	18.49 >>
0.010	21.13 >>
0.001	26.98 >>

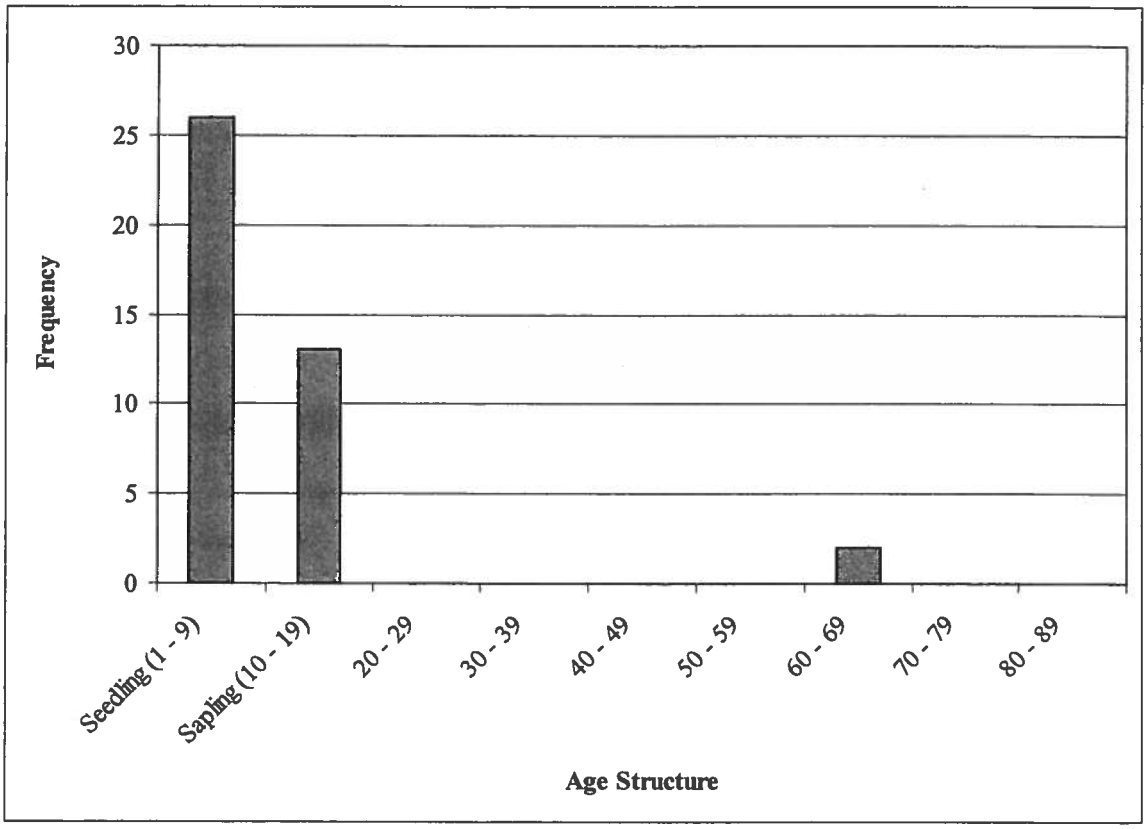


Figure 6-10. Age structure histogram for red maple at the Cherokee Orchard (CO) site.

samples; those two trees were 63 and 65 years old. Of the 36 eastern hemlocks sampled at the Cades Cove site, four were categorized as seedlings (1-9 years) and 21 were categorized as saplings (10-19 years) (Figure 6-11). The remaining individuals, however, were much older, with at least two individuals falling into the 70-79 and 80-89 year age-classes.

Figure 6-11. Age structure histogram for eastern hemlock at the Cades Cove (CC) site.

7. DISCUSSION

Much of the current research concerning Table Mountain pine is focused on the impacts of prescribed burning (Turrill 1998; Waldrop *et al.* 1999; Waldrop and Brose 1999; Welch *et al.* 2000; Brose and Waldrop 2000; Ellis *et al.* 2002; Randles *et al.* 2002). This research plays an important role in the development of fire management plans. Forest managers in both GSMNP and surround national forests rely upon the information gained from such studies to safely and efficiently reintroduce fire to Table Mountain pine forests. However, it is critical to understand the current successional status and historical fire regime in those pine forests for fire management plans to be complete. That knowledge can be obtained by using dendroecological analyses of the age structures of Table Mountain pine stands and the fire history within those stands.

7.1 Age Structure

Typically, the age structure of tree species that are dependent upon fire disturbances are polymodal or bimodal as a result of increased recruitment after a fire in the stand (Williams and Johnson 1990; Barden 1977). Both Sutherland *et al.* (1995) and Williams and Johnson (1990) found bimodal age structures in Table Mountain pine stands at Brush Mountain, Virginia. Sutherland *et al.* (1995) indicated that two major fire occurrences led to the two major recruitment events at their study sites.

I found a generally J-shaped age distribution at all of the Table Mountain pine stands in this study and in the composite age structure for those stands. The resulting peak in age structure indicates a major recruitment event occurred in Table Mountain pine stands in GSMNP in the 60-69 and 70-79 year age-classes, or from 1922 to 1941.

This peak in age structure corresponds to the period before and during the creation of the park, when frequent fires and heavy logging drastically altered forest composition. After the official creation of the park in 1934, fire suppression was implemented as a primary forest management technique. The resulting fire-free period explains the dramatic decline in Table Mountain pine recruitment around the early 1940s.

Another hypothesis, proposed by Barden (2000), suggests that climate may be playing a large role in Table Mountain pine recruitment. Barden (2000) found that the delayed effects of an extreme drought during the 1980s were preventing the recruitment of the pine. He also hypothesized that other climactic factors, such as an increase in temperature, may be responsible for poor Table Mountain pine recruitment. While higher temperatures may increase the rate of opening of serotinous cones (Williams and Johnson 1992; Barden 2000), a lack of viable seed production and inhibited germination may also result (Zobel 1969; Barden 2000).

7.1.1 Why are the oldest age-classes not well represented?

Age structure analyses of stands in GSMNP did not indicate a high number of Table Mountain pine individuals older than 90 years. There are three possible explanations for this phenomenon. First, the majority of the current Table Mountain pine population in GSMNP is likely second growth following major disturbances that occurred in the early 1900s. Logging played an important role in shaping the current GSMNP landscape (Turrill 1998; Davis 2000; Pierce 2000). Logging companies commonly practiced techniques that removed the most lumber in the shortest amount of time (Pierce 2000). These techniques also resulted in devastating erosion that produced a

harsh habitat for colonizing tree species. However, on logged sites, Table Mountain pine can constitute as much as 80% of the regrowth (Della-Bianca 1990). Therefore, the current Table Mountain pine population in GSMNP is likely the cohort that established after heavy logging from 1880 to the 1930s. Another possible explanation is also related to a major disturbance during the early 1900s. Fires that resulted from early logging practices in GSMNP were widespread, stand-initiating fires (Turrill 1998; Pierce 2000). These fires were often ignited in the slash left behind by loggers. Table Mountain pine was typically not harvested by logging companies due to the pine's poor growth form and low value; therefore, the tree was able to establish quickly after logging fires, even if the original "seed trees" were killed (Williams and Johnson 1990).

Second, the repeated SPB infestations within Table Mountain pine stands throughout the park may have killed older trees that are often weakened and easier for the beetle to infect. Detailed records concerning SPB infestations in Tennessee are available dating back to the early 1950s (Kuykendall 1978). Those records indicate that there have been 5 to 8 years in the Great Smoky Mountains in which SPB infestation has reached outbreak status between 1960 and 1995 (Hoffard *et al.* 2001). Southern pine beetles typically establish in trees that have been weakened by disease, lightning strikes, or excessive age, and can then infect vigorous, healthy pine hosts (Hoffard *et al.* 2001). I noted SPB activity at all five sites that had occurred between 1992 (when the original NPS Table Mountain pine reports were compiled) and 2001; therefore, the SPB has been an important influence in the shaping of the current Table Mountain pine population in GSMNP.

A third hypothesis might exist. Present-day Table Mountain pine stands in GSMNP have historically been mixed pine-hardwood stands. With the removal of the forest by logging and widespread fires at the beginning of the 20th century, Table Mountain pine was able to migrate down slope from the extremely xeric, rocky ridge tops it had historically inhabited. As fire frequency declined in those stands, however, hardwoods, such as red maple, chestnut oak, and scarlet oak, began encroaching back upslope. In this scenario, the oldest pines would be limited to the top of the stand, where the frequency of old trees would have been originally reduced by logging, fire, and SPB infestation. The current stand composition and structure in Table Mountain pine stands in GSMNP is consistent with the forest predicted by this hypothesis.

7.2 Fire History

I obtained valuable information concerning the fire history in Table Mountain pine stands in GSMNP from the 17 sound fire-scarred sections, despite ten of those samples coming from the same site, Thunderhead. The lack of fire scars in Table Mountain pine stands in GSMNP is evidence enough to indicate the long absence of fire. The climate of the southern Appalachians is primarily responsible for the lack of fire scars. The humid climate of the region increases the rate of decomposition, thus expediting the decomposition of the fire-scarred snags and stumps. Four of the five stands contained fire-scarred stumps and snags that were too decomposed to collect.

I was able to use the master chronology I developed from Table Mountain pine cores to date nine of the 17 fire-scarred samples. The composite fire chart for those post-park samples revealed a major gap in fire events during the period between the creation

of GSMNP and the 1960s, especially at the Thunderhead site. This gap is the result of the implementation of fire suppression within the park.

Various histories written about the park describe the pre-park fire regime, which was largely influenced by human activities. Around the late 19th century, major fires were ignited in the slash left behind by the logging industry and by arsonists. Compounded by the fact that there were some years of major drought in the early 20th century, those fires were easily ignited and often severe (Pierce 2000; Davis 2000). Devastating fires occurred in different areas of the park in both 1922 and 1925 (Pierce 2000; Jenkins 2000). The single pre-park sample that I was able to date contained five individual fire scars. All but one of the remaining undated, pre-park samples contained multiple fire scars, evidence that the pre-park fire regime was characterized by frequent fires.

The MEI indicated that the pre-park fire interval was approximately seven years, an interval perhaps more representative for the park than the 12.7 year fire interval found by Harmon (1982). As indicated by the post-park composite fire chart, no recorded fires occurred in the five study sites between 1917 and 1962, a period of 45 years. According to the MEI derived from the pre-park samples, six fire events should have occurred during that period. The MOI, a statistical descriptor found by Grissino-Mayer (1999) to be a superior overall indicator of fire frequency in the American Southwest, was only 4.8 years, meaning there should have been approximately nine fire events during the same 45-year period. The LEI value for the pre-park fire regime indicates that adequate fuel build-up can occur in only 2.5 years, with the length of the fire-free period becoming critical after only 13.1 years according to the UEI. Because the post-park fire interval has

greatly exceeded the UEI value, litter has accumulated on the forest floor and the understory has become almost impenetrable in Table Mountain pine stands throughout the park.

7.2.1 Post-Park Fire Events and the Southern Pine Beetle

The fires that occurred after the establishment of the park tended to coincide with major SPB outbreaks. An historical relationship likely exists between SPB outbreaks and fire events in the conifer forests of the southeastern United States (Schowalter *et al.* 1981). While this relationship has been altered by fire suppression, fires that occurred after park establishment were likely a result of major SPB outbreaks. In this study, post-park fires were documented in 1962, 1967, 1975, 1977, and 1978. Periods of elevated SPB activity in GSMNP occurred from 1954 to 1958 and 1967 to 1977. According to the Tennessee Division of Forestry, a major SPB outbreak occurred in 1975, when approximately 1,800,000 tons of pines were killed throughout Tennessee (Tennessee Department of Forestry 2001). An outbreak of that size would result in a large amount of highly flammable litter and debris on the floor of pine forests.

A similar relationship between pine beetles and fire was noted by Amman (1990) around Yellowstone National Park. Mountain pine beetle was found to play a significant role in the conversion of live fuels to dead fuels over a short period. Amman (1990) theorized that this behavior probably promotes hot stand-replacement fires that assure the persistence of lodgepole pine *(Pinus contorta* Dougl. ex Loud.), the beetle's host. Amman (1990) also noted a definite increase in mountain pine beetle infestations in fire-injured pines. If this type of natural relationship exists between SPB and Table Mountain

pine, then it would provide further evidence to support the reintroduction of fire to pine forests in GSMNP.

7.2.2 Maximum Hazard Interval

In this study, average duff depths vary from stand to stand, but are overall very thick. The increase in flammable litter and duff on the floors of Table Mountain pine stands increases the likelihood of high-severity fires. Southern pine beetle activity further increases the likelihood of severe fires, by adding heavy vertical and horizontal fuels in the form of downed logs and snags (Figure 7-1). Additionally, the presence of a thick midstory comprised largely of tall mountain laurel acts as a fire ladder that can carry fire from the forest floor into the canopy (Turrell *et al.* 1997). At all fire study sites, the midstory was dense with mountain laurel. Overall, the current conditions in Table Mountain pine stands in GSMNP are very conducive to widespread, stand-eliminating fires. The MHI represents the maximum fire interval that an ecosystem can sustain before burning becomes highly probable (Grissino-Mayer 1999). The resulting MHI from the analysis of pre-park fire-scarred samples was 80.6 years. Because fires have been suppressed in GSMNP since the early 1930s, the probability that the fire interval within Table Mountain pine stands throughout the park will reach the Maximum Hazard Interval within the near future is extremely high. The MHI of approximately 80 years appears to be supported by the current Table Mountain pine stand composition and structure in GSMNP.

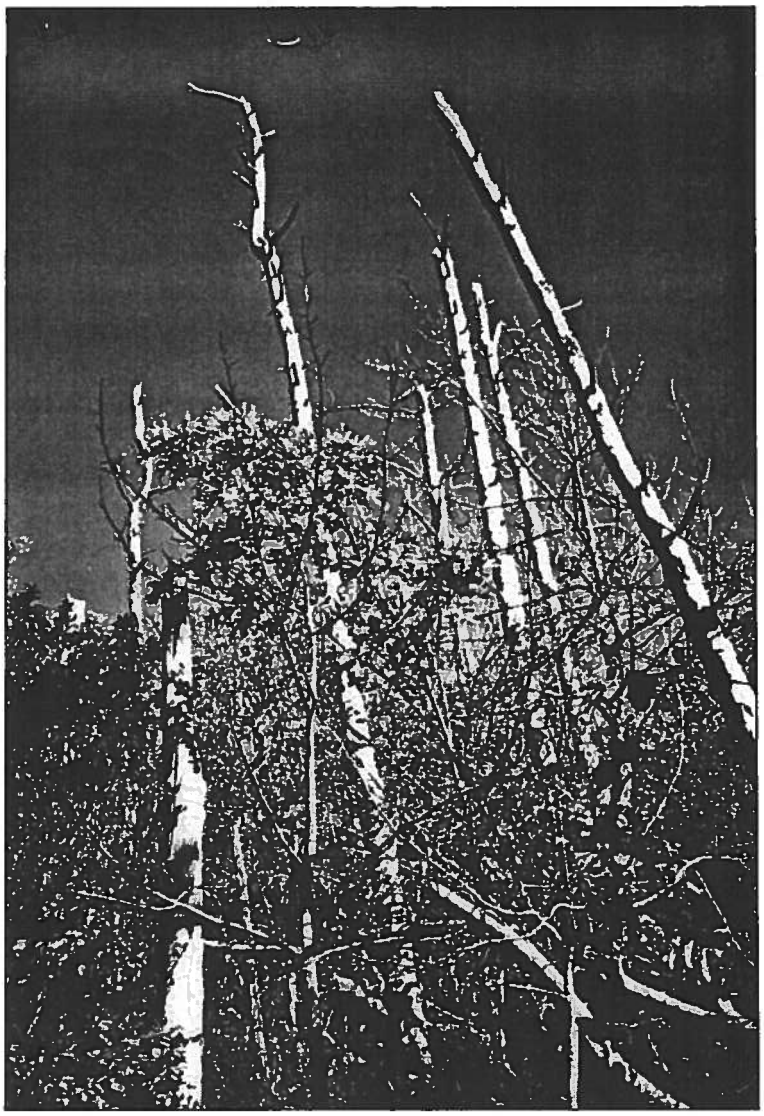


Figure 7-1. Table Mountain pine snags at the Cherokee Orchard study site. These snags are an example of the dramatic fuel load that has accumulated as a result of southern pine beetle infestation.

7.2.3 What is the "natural" fire regime?

The 12.7 year fire interval for the westernmost portion of GSMNP found by Harmon (1982) and the 6.8 year fire interval found in this study were both established using fire history information obtained from fire scars that formed during the mid-1800s to the mid-1900s. Those fire intervals are based on a human-altered fire regime for a time in which fire was used for land clearing (for settlement and livestock grazing), agriculture, and hunting. The fire regime of the 19th and early 20th centuries was also influenced by invasive logging practices and rampant arson (Davis 2000; Pierce 2000). Even before European settlement, Native Americans used fire to shape the landscape (Delcourt and Delcourt 1987, 1997, 1998). They relied upon fire much the same way European settlers did, for agriculture, land clearing, and hunting (Delcourt and Delcourt 1987, 1997, 1998; Davis 2000; Pierce 2000). Nevertheless, should this fire regime be considered the "natural" fire regime of Table Mountain pine stands in GSMNP? Because humans have altered the fire regime of the southern Appalachians for thousands of years, the anthropogenic role should not be ignored. The question of how much influence the human-altered fire regime should have in the development of fire management plans needs to be addressed.

Lightning as an ignition source accounts for only 10% of all fires in GSMNP (NPS 1997), therefore, a lightning-only fire management plan might not be enough to promote the persistence of the Table Mountain pine stands seen today. Nevertheless, lightning must have played an important role in the adaptation of Table Mountain pine, and other Appalachian species, to fire. Even before the presence of humans in the region,

Table Mountain pine was adapting to fire. Could it be that historically, lightning was a more important ignition source than it is today?

7.3 Current Successional Status of Table Mountain Pine

By combining the information obtained from age structure analysis and fire history analysis, along with species inventories, I assessed the current successional status of Table Mountain pine stands in GSMNP. The original goal of this research was to associate past fire events with peaks in age structure. Due to the influence of fire suppression and a high rate of decomposition, I was unable to collect fire-scarred samples that corresponded to the last major Table Mountain pine recruitment event. Nevertheless, the samples that I collected provided other useful information concerning fire history in the park.

The age structure analysis resulted in a generally J-shaped population trend at each study site, with the major peak occurring in the 60-69 and 70-79 year age-classes. Those trees recruited during the time that the park was being established, a time when fires were still occurring on the landscape. There was no evidence of significant Table Mountain pine regeneration at any of the five study sites. The post-park fires that did occur in the late 1970s were spatially limited. While I was not able to determine the severity of those fires, they did not result in a significant recruitment of Table Mountain pine. Areas where I found charred snags and lightning-scarred trees had no evidence of increased pine recruitment. Furthermore, fire-intolerant tree species (such as red maple and eastern hemlock) are encroaching into those pine stands. Typically, the fire-intolerant tree species were invading upslope from the bottom of Table Mountain pine

stands; however, gaps caused by SPB infestation have provided opportunities for red maples and oaks to establish throughout the stand. It seems that once those tree species establish, Table Mountain pine seedlings, if they can establish at all, are not able to compete.

7.3.1 Will prescribed fire promote Table Mountain pine persistence?

Pine-hardwood forest conditions tend toward a characteristically hardwood forest when fire is removed from the landscape for a long period, making it difficult to use fire to restore a pine-dominated forest. As plant succession occurs, a "site-building" process also occurs, in which the soil depth and nutrient levels in the forest floor increase (Switzer *et al.* 1979; Groeschl *et al.* 1993). Eventually, the site becomes more mesic and fertile enough for invasion by deciduous species like oaks and red maple (Groeschl *et al.* 1993). Once a pine forest reaches this state of succession, it becomes more difficult to use prescribed fire to manage for xeric, shade-intolerant pine species, like Table Mountain pine.

Harmon (1984) found that after long periods of fire suppression, mid-elevation pine forests become "safe" for thin-barked, slow growing tree species. Bark thickness and diameter together determine fire susceptibility; therefore, a thin-barked tree with a high dbh will be less susceptible to fire than the same species with a smaller dbh (Harmon 1984). Management plans will have to call for higher intensity fires to remove the establishing hardwood component from the canopy of Table Mountain pine stands. Related findings by Turrill (1998) and Waldrop and Brose (1999), however, indicate that even high-intensity fires fail to control the regeneration of hardwoods and shrubs from

sprouts after fires. Frequent low- to medium-intensity burns would be necessary after the original burn to keep hardwood regeneration in check. In combination with manual thinning of fuels and the midstory and understory, prescribed burning would be an effective tool for promoting the survivability of Table Mountain pine in the southern Appalachians.

7.3.2 Management Implications

The current GSMNP fire management plan allows lightning-caused fires to burn providing they do not threaten property or human life. Under this plan, the park is divided into three zones. Zone 1 "includes most of the park boundary and all historic and developed areas in the park" (NPS 1997). To prevent damage to valuable property and to ensure human safety, all fires in this zone are immediately suppressed. Zone 2 acts as a buffer area between Zone 1 and Zone 3. Lightning-caused fires are allowed to burn in this zone "if they are not predicted to threaten Zone 1 areas within 48 hours" (NPS 1997). Finally, Zone 3 contains the undeveloped interior of the park. Fires in this zone are "allowed to burn if they stay within predetermined parameters and are not predicted to leave the zone within 48 hours" (NPS 1997). While this fire management policy has allowed the NPS to reintroduce fire to the park, it has not effectively promoted the regeneration of Table Mountain pine.

Based on this and other studies concerning Table Mountain pine in the southern Appalachians, forest managers should be able to better construct fire management plans that will ensure the persistence of the pine. Harmon (1982, 1984) outlined three possible management policies that could prove effective in maintaining fire-dependent forest

communities. By incorporating current research into those policies, I present three updated fire management strategies for Table Mountain pine stands in GSMNP and the surrounding southern Appalachians.

7.3.2.1 The "Natural" Strategy

This strategy is similar to the current fire management plan practiced in GSMNP, based on the assumption that the "natural" fire regime in mid-elevation pine stands is dominated by lightning-caused fires. The human influence on fire frequency has been removed from the strategy. As stated earlier, the NPS (1997) claims that only 10% of all fires in the park are lightning-caused fires. Under this plan, Table Mountain pine stands would continue on the current successional pathway toward a pine-hardwood forest. Eventually, the community structure in those forests would become hardwood-dominated with Table Mountain pine existing only on extremely xeric, rocky sites, unless the frequency and size of lightning-caused fires increases over the present level (Harmon 1982). Barden (1977) found a population of Table Mountain pine that had continuously recruited survivors since 1889 without fire on an extremely xeric site. However, in 1996, Barden (2000) found that the same population was experiencing a loss in regeneration due to climatic factors. If ignition sources in Table Mountain pine stands were limited to lightning, and factors such as climate change are found to limit regeneration, then current mid-elevation pine stands might be slowly extirpated from the landscape.

7.3.2.2 The 19th Century Strategy

This fire management option is based on the fire intervals described in this study, and would promote the survivability of Table Mountain pine stands that resulted from the human-altered fire regime of the late 1800s. The 6.8 year fire interval would be the key to prescribing frequent fires that would maintain Table Mountain pine dominance. Studies by Turrill (1998) and Waldrop and Brose (1999) have indicated how difficult it is to apply fire to forests in the southern Appalachians, both physically and ecologically. High-intensity fires are necessary to remove hardwood species from the understory and midstory, and to obtain the desired outcomes of pine regeneration and persistence. Additional burns every seven years at varying intensities would be necessary to prevent hardwood and shrub regeneration. However, this scenario is not reasonable due to the extreme cost, in both money and labor, of park-wide prescribed burning. Furthermore, the seven year fire interval is probably too ambitious considering it was obtained using information from the widespread fires caused by logging and arson.

7.3.2.3 The Compromise Strategy

This fire management strategy is based on the possible fire regime that existed before the introduction of railroads and logging into the southern Appalachian region, when Native Americans and early European settlers used fire for agriculture and hunting. There is currently a gap in the knowledge concerning the fire regime of this period. Studies like those of Delcourt and Delcourt (1997, 1998), however, are beginning to uncover clues to the burning practices of early Native Americans. Under this strategy, representative stands throughout the region would be selected based on site

characteristics and the current successional stage. After manual thinning of living and dead fuels, prescribed fire would be applied to the site. The intensity of the burn would be based on soil characteristics and the level of hardwood invasion. After the initial burn, low-intensity maintenance burns would be used to maintain the dominance of Table Mountain pine. While this scenario would be more economically efficient and would allow managers to retain the policy that provides for the safety of humans and valuable property, it would also present an important ethical question: why should one stand be maintained and not another?

8. CONCLUSIONS

Table Mountain pine is an ecologically valuable species endemic to the Appalachian Mountains. Historically, it has been found throughout the southern Appalachians, especially within GSMNP, on dry south-facing slopes and ridge tops. This species is highly dependent on fire for reproduction. Fire releases seeds by opening serotinous cones and creates the stand characteristics necessary for Table Mountain pine to establish. With the establishment of GSMNP in 1934, fire suppression became a primary forest management technique. With fire removed from the southern Appalachian landscape, this pine has been unable to regenerate. Table Mountain pine populations within the park are in decline, and stands are being invaded by fire-intolerant hardwood species. Long-term studies of prescribed burning and regional-scale studies using tree rings to analyze age structure and fire history will be valuable in the ongoing development of fire management plans that promote the survival of Table Mountain pine in the southern Appalachians.

Currently, researchers are developing a region-wide dendroecological study of Table Mountain pine to collect samples for age structure and fire history analysis throughout the southern Appalachians. The results of their future research might indicate an even more frequent fire regime in Table Mountain pine stands, and will help to answer questions concerning the use of fire in the management of southern Appalachian pine forests.

8.1 Primary Conclusions

While previous research has focused on the successful reintroduction of fire to these habitats, this project focused on the current state of Table Mountain pine stands and the fire history within those stands. Current knowledge of Table Mountain pine indicates that fire must be applied to these ecosystems to ensure that the tree will persist within GSMNP and the southern Appalachian region. Furthermore, the conclusions of this study will strengthen the foundation for future research into the population dynamics of Table Mountain pine.

1. Table Mountain pine from sites across GSMNP crossdate very well.

I was able to develop a chronology that extends back to 1837 using 61 cores collected from Table Mountain pine stands across GSMNP. The final interseries correlation coefficient for this chronology was 0.538. The establishment of a chronology for this pine species was important, because the tree-ring chronology can be used to interpret environmental processes such as climate change and insect infestation, as well as fire. Future Table Mountain pine studies can build on the chronology I developed by increasing the sample depth and extending the chronology further back in time.

2. The age structure of Table Mountain pine stands in GSMNP contains a peak in the 60-69 and 70-79 year age-classes.

This peak in age structure correlates to the period before and just after the official creation of the park in 1934. Widespread, high-severity fires are known to have been rampant during that period. Therefore, this peak indicates that the last major recruitment

event that occurred in Table Mountain pine stands was largely a result of the end-phase of the pre-park fire regime.

3. Little to no significant Table Mountain pine regeneration is currently occurring in representative stands in GSMNP.

I found little to no evidence of Table Mountain pine regeneration at my five study sites. Seedlings were found mostly along trails where mineral soil was exposed and sunlight was readily available. Bull Head and Thunderhead, sites with the most recent fire events, had the most regeneration, but seedlings and saplings were still rare and were scattered throughout both stands. At the Thunderhead site, the majority of all regeneration was documented along the ridge top where the canopy was open. The lack of significant regeneration is most likely due to fire suppression that began in the late 1930s, although Barden (2000) theorized that climate changes are also playing a role in Table Mountain pine population dynamics.

4. Fire history information can be obtained from Table Mountain pines in GSMNP using fire scars.

Valuable baseline information concerning the fire regime in Table Mountain pine stands in GSMNP was obtained from 17 fire-scarred samples. Nine samples provided specific dates for fires that occurred primarily after the 1930s. Analysis of those post-park samples revealed a decline in fire frequency due to the implementation of fire suppression, and provided evidence of the relationship between southern pine beetle and fire. Important statistical information was obtained from the remaining eight undated and

one dated pre-park fire-scarred samples. Although the majority of those samples could not be dated with accuracy, I was able to use point fire return intervals to gain information vital for the establishment of effective fire management policies.

5. The Weibull Median Fire Interval (MEI) and the Weibull Modal Fire Interval (MOI) for Table Mountain pine stands within GSMNP are 6.8 and 4.8 years respectively.

Using pre-park fire scars, I was able to calculate the MEI and MOI for Table Mountain pine stands in GSMNP using the FHX2 fire history program (Grissino-Mayer 1995). These statistical descriptors indicate a pre-park fire regime that was characterized by frequent fires. While Grissino-Mayer (1999) found the MOI to be a superior overall measure of fire frequency in the American Southwest, more research is needed to determine which descriptor best describes the historical fire regime in GSMNP. This research also should focus on collecting fire-scarred samples from numerous sites within GSMNP.

6. The Maximum Hazard Interval (MHI) for Table Mountain pine stands within GSMNP is 80.6 years.

The MHI is a statistical descriptor that represents the longest fire-free period an ecosystem can sustain before burning becomes highly probable (Grissino-Mayer 1995, 1999). The MHI for Table Mountain pine stands in GSMNP indicates that, within the next 10 years, the probability that burning will occur is extremely high. The heavy fuel load, deep duff layer, and thick midstory of the stands in this study seem to support the

high probability that high-severity fires will occur in the next 10 years. As additional fire-scarred samples are collected and analyzed, the MHI for Table Mountain pine stands in the southern Appalachians could decrease.

7. Evidence from post-park fire history analysis in Table Mountain pine stands indicates a relationship between southern pine beetle (SPB) and fire.

Post-park fire history analysis indicates that SPB infestations naturally perpetuate the fire regime of mid-elevation pine stands in the southern Appalachians. SPB infestation begins with individuals weakened by age, injury or disease, and quickly spreads throughout a pine stand. Post-park fires in the 1960s and late 1970s correspond to elevated levels of SPB infestations. The largest SPB outbreak ever recorded in Tennessee began in 1999 and is expected to continue into 2002. In 2000, pine mortality resulting from SPB infestation was seven times greater than that caused by the 1975 outbreak associated with the fires in this study (Tennessee Department of Forestry 2002). As SPB infestation continues, heavy fuels will accumulate in Table Mountain pine stands, adding to the probability that high-severity, stand-eliminating fire will occur.

REFERENCES

Abrams, M.D. 1992. Fire and the development of oak forests. *Bioscience* **42**: 346-358.

Abrams, M.D., D.A. Orwig, and T.E. Demeo. 1995. Dendroecological analysis of successional dynamics for a presettlement-origin white-pine-mixed-oak forest in the southern Appalachians, USA. *Journal of Ecology* **83**: 123-133.

Amman, G.D. 1991. Bark beetle-fire associations in the greater Yellowstone area. pp. 313-320. In: S.C. Nodvin and T.A. Waldrop [Eds.], *Fire and the environment: ecological and cultural perspectives*. USDA Forest Service Southeastern Forest Experiment Station *General Technical Report* SE-69.

Applequist, M.B. 1958. A simple pith locator for use with off-center increment cores. *Journal of Forestry* **56**: 141.

Baisan, C.H. and T.W. Swetnam. 1990. Fire history on a desert mountain range: Rincon Mountain Wilderness, Arizona, U.S.A. *Canadian Journal of Forest Research* **20**: 1559-1569.

Barden, L.S. 1974. Lightning fires in southern Appalachian forests. Doctoral Dissertation. University of Tennessee, Knoxville.

Barden, L.S. 1977. Self-maintaining populations of *Pinus pungens* Lam. in the southern Appalachians. *Castanea* **42**: 316-323.

Barden, L.S. 1978. Serotiny and seed variability of *Pinus pungens* Lam. in the southern Appalachians. *Castanea* **44**: 44-47.

Barden, L.S. 2000. Population maintenance of *Pinus pungens* Lam. after a century without fire. *Natural Areas Journal* **20**: 227–233.

Brose, P.H. and T.A. Waldrop. 2000. Using prescribed fire to regenerate Table Mountain pine in the southern Appalachian Mountains. pp. 191-196. In: W.K. Moser and C.F. Moser [Eds.], *Fire and forest ecology: innovative silviculture and vegetation management.* Tall Timbers Fire Ecology Conference Proceedings, No. 21. Tall Timbers Research Station, Tallahassee, FL.

Brouillet, L. and Whetstone, R. 1993. Climate and physiography. pp. 15-46. In: Flora of North America Editorial Committee. *Flora of North America: Introduction*. Oxford University Press, New York.

Campbell, C.C. 1960. *Birth of a national park in the Great Smoky Mountains.* The University of Tennessee Press, Knoxville.

Christensen, N.L. 1993. Fire regimes and ecosystem dynamics. pp. 233-244. In: Crutzen, P.J. and J.G. Goldhammer [Eds.], *Fire in the Environment: The Ecological, Atmospheric, and Climatic Importance of Vegetation Fires.* John Wiley and Sons, New York.

Clebsch, E and D. DeFoe [Eds.]. 1993. *Trees of the Smokies.* Great Smoky Mountains Natural History Association, Gatlinburg.

Cook, E.R. 1985. A time series analysis approach to tree ring standardization. Doctoral dissertation. The University of Arizona, Tucson.

Davis, D.E. 2000. Where there are mountains: an environmental history of the southern Appalachians. The University of Georgia Press, Athens.

Delcourt, P.A. and H.R. Delcourt. 1987. *Long-term forest dynamics of the temperate zone.* Springer Verlag, New York.

Delcourt, P.A. and H.R. Delcourt. 1997. Pre-Columbian Native American use of fire on southern Appalachian landscapes. *Conservation Biology* **11**: 1010-1014.

Delcourt, P.A. and H.R. Delcourt. 1998. The influence of pre-historic human set fires on oak-chestnut forests in the southern Appalachians. *Castanea* **63**: 337-345.

Della-Bianca L. 1990. *Pinus pungens* Lamb. pp. 425-432. In: R.M. Burns & B.H. Honkala [Eds.] *Silvics of North America. Vol. 1 Conifers.* USDA Handbook 654.

DeVivo, M.S. 1991. Indian use of fire and land clearance in the southern Appalachians. pp. 306-312. In: S.C. Nodvin and T.A. Waldrop [Eds.], *Fire and the environment: ecological and cultural perspectives.* USDA Forest Service Southeastern Forest Experiment Station *General Technical Report* SE-69.

Dieterich, J.H. 1980. The composite fire interval – a tool for more accurate interpretation of fire history. In: M.A. Stokes and J.H. Dieterich [Eds.], *Proceedings of the fire history workshop.* USDA Forest Service *General Technical Report* RM-81: 8-14.

Elliot, K., R. Hendrick, A. Major, J. Vose, and W. Swank. 1999. Vegetation dynamics after a prescribed fire in the southern Appalachians. *Forest Ecology and Management* **114**: 199-213.

Ellis, L.E., T.A. Waldrop, and F.H. Tainter. 2002. Ectomycorrhizae of Table Mountain pine and the influence of prescribed burning on their survival. pp. 128-131. In: Outcalt, K.W. [Ed.]. *Proceedings of the eleventh biennial southern silvicultural research conference. General Technical Report* SRS-48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station.

Fritts, H.C. 1976. *Tree rings and climate.* Academic Press, New York.

Gibson, J.P. and J.L. Hamrick. 1991a. Heterogeneity in pollen allele frequencies among cones, whorls, and trees of Table Mountain pine. *American Journal of Botany* **78**: 1244-1251.

Gibson, J.P. and J.L. Hamrick. 1991b. Genetic diversity and structure in *Pinus pungens* populations. *Canadian Journal of Forest Research* **21**: 635-642.

Gray, E.A.J. 2001 Patterns of seed production in Table Mountain pine (*Pinus pungens* Lamb.). Masters Thesis. University of Tennessee, Knoxville.

Greller, A. 1988. Deciduous forest. pp. 287-316. In: Barbour, M. and W. Billings [Eds.]. 1988. *North American Terrestrial Vegetation.* Cambridge University Press, New York.

Grissino-Mayer, H.D. 1995. Tree-ring reconstructions of climate and fire history at El Malpais National Monument, New Mexico. Doctoral Dissertation. University of Arizona, Tucson.

Grissino-Mayer, H.D. 1999. Modeling fire interval data from the American Southwest with the Weibull distribution. *International Journal of Wildland Fire* **9**: 37-50.

Grissino-Mayer, H.D. 2001a. Assessing crossdating accuracy: A manual and tutorial for the computer program COFECHA. *Tree-Ring Research* **57**(2): 67-83.

Grissino-Mayer, H.D. 2001b. FHX2 – software for analyzing temporal and spatial patterns in fire regimes from tree rings. *Tree-Ring Research* **57**(1): 115-124.

Groeschl, D.A., J.E. Johnson, and D.W. Smith. 1993. Wildfire effects on forest floor and surface soil in a Table Mountain pine-pitch pine forest. *International Journal of Wildland Fire* **3**: 149-154.

Harmon, M. 1982. Fire history of the westernmost portion of Great Smoky Mountains National Park. *Bulletin of the Torrey Botanical Society* **109**: 74-79.

Harmon, M. 1984. Survival of trees after low-intensity surface fires in Great Smoky Mountains National Park. *Ecology* **65**: 796-802.

Harrod, J., P. White, and M. Harmon. 1998. Changes in xeric forests in western Great Smoky Mountains National Park, 1936-1995. *Castanea* **63**: 346-360.

Henry, J.D. and J.M. Swan. 1974. Reconstructing forest history from live and dead plant material – an approach to the study of forest succession in Southwest New Hampshire. *Ecology* **55**: 772 - 783.

Hoffard, W.H., D.H. Marx, and H.D. Brown. 2002. Stressors of pine forests: southern pine beetles. The health of southern forests. USDA Forest Service Online Publications. http://fhpr8.srs.fs.fed.us/pubs.html

Holmes, R.L. 1983. Computer-assisted quality control in tree-ring dating and measurement. *Tree-Ring Bulletin* **43**: 69-78.

Jenkins, M. 2000. Great Smoky Mountains National Park, *personal communication.*

Keeley, J.E. and P.H. Zedler. 1998. Evolution in life histories in *Pinus*. pp. 219-250. In: Richardson, D.M. [Ed.]. *Ecology and Biogeography of Pinus*. Cambridge University Press, Cambridge.

King, P.B., R.B. Neuman, and J.B. Hadley. 1968. *Geology of the Great Smoky Mountains National Park, Tennessee and North Carolina.* Geological Survey Professional Paper 587. U.S. Government Printing Office, Washington.

Kuykendall, N.W. III. 1978. Composition and structure of replacement forest stands following southern pine beetle infestations as related to selected site variables in the Great Smoky Mountains. Masters Thesis. University of Tennessee, Knoxville.

Moore, H.L. 1988. *A roadside guide to the geology of the Great Smoky Mountains National Park.* The University of Tennessee Press, Knoxville.

Morino, K.A. 1996. Reconstruction and interpretation of historical patterns of fire occurrence in the Organ Mountains, New Mexico. Masters Thesis. University of Arizona, Tucson.

Mutch, R.W. 1970. Wildland fires and ecosystems – a hypothesis. *Ecology* **51**: 1046-1051.

National Park Service. 1997. Great Smoky Mountains National Park Management Folio #3: Fire Management. Great Smoky Mountains Natural History Association, Gatlinburg.

National Park Service. 2002. Great Smoky Mountains National Park. http://www.nps.gov/grsm.

Pederson, N.A., R.H. Jones, and R.R. Sharitz. 1997. Age structure and possible origins of old *Pinus taeda* stands in a floodplain forest. *Journal of the Torrey Botanical Society* **124**: 111-123.

Pierce, D.S. 2000. The Great Smoky Mountains: from natural habitat to national park. The University of Tennessee Press, Knoxville.

Platt, W.J., G.W. Evans, and S.L. Rathbun. 1988. The population dynamics of a long-lived conifer (*Pinus palustris*). *The American Naturalist* **131**: 491-525.

Randles, R.B., D.H. Van Lear, T.A. Waldrop, and D.M. Simon. 2002 Periodic burning in Table Mountain-pitch pine stands. pp. 114-118. In: Outcalt, K.W. [Ed.]. *Proceedings of the eleventh biennial southern silvicultural research conference. General Technical Report* SRS-48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station.

Schowalter, T.D., R.N. Coulson, and D.A. Crossley Jr. 1981. Role of southern pine beetle (Dendroctonus frontalis) and fire in maintenance of structure and function of the southern (USA) coniferous forest. *Environmental Entomology* **10**: 821-825.

Sanders, G.L. 1992. The role of fire in the regeneration of Table Mountain pine in the southern Appalachian Mountains. Masters Thesis. University of Tennessee, Knoxville.

Southern Appalachian Man and the Biosphere (SAMAB). 1996. The southern Appalachian assessment terrestrial technical report. Report 5 of 5. USDA Forest Service, Southern Region.

Southern Appalachian Man and the Biosphere (SAMAB). 2002. Southern Appalachian assessment GIS online database. Southern Appalachian Man and the Biosphere Program. http://www.samab.org/data/SAA_data.html

Stephenson, S.L. and H.S. Adams. 1989. The high-elevation red oak (*Quercus rubra*) community type in western Virginia. *Castanea* **54**: 217-229.

Sutherland, E.K., H.D. Grissino-Mayer, C.A. Woodhouse, W.W. Covington, S. Horn, L. Huckaby, R. Kerr, J. Kush, M. Moore, and T. Plumb. 1995. Two centuries of fire in a southwestern Virginia *Pinus pungens* community. In: Inventory and management techniques in the context of catastrophic events: altered states of the forest. Hypertext Proceedings, University Park, Pennsylvania State University, Center for Statistical Ecology and Environmental Statistics.

Swetnam, T.W., M.A. Thompson, and E.K. Sutherland. 1985. Using dendrochronology to measure radial growth of defoliated trees. USDA Forest Service *Agricultural Handbook* 639. U.S. Government Printing Office, Washington.

Switzer, G.L., M.G. Shelton, and L.E. Nelson. 1979. Successional development of the forest floor and soil surface on upland sites of the east Gulf Coastal Plain. *Ecology* **60**: 1162-1171.

Taylor, A.H. 2000. Fire regimes and forest changes in mid and upper montane forests of the southern Cascades, Lassen Volcanic National Park, California, USA. *Journal of Biogeography* **27**: 87-104.

Tennessee Department of Forestry. 2002. Southern pine beetle (*Dendroctonus frontalis*). TennesseeAnytime. http://www.state.tn.us/agriculture/forestry/health/spb.html

Turrill, N. 1998. Using prescribed fire to regenerate *Pinus echinata*, *P. pungens*, and *P. rigida* communities in the southern Appalachian Mountains. Doctoral Dissertation. University of Tennessee, Knoxville.

Turrill, N., E. Buckner, and T. Waldrop. 1997. *Pinus pungens* Lamb. (Table Mountain pine): a threatened species without fire? pp. 301-306. In: Greenlee, J. [Ed.], *Proceedings, effect of fire on threatened and endangered species and habitats*. International Association of Wildland Fire. Coeur d'Alene, ID.

USDA Forest Service. 1989. A guide for prescribed fire in southern forests. Southern Region *Technical Publication* R8-TP-11.

Van Lear, D.H. and T.A. Waldrop. 1989. History, uses, and effects of fire in the Appalachians. USDA Forest Service Southeastern Forest Experimental Station *General Technical Report* SE-54.

Waldrop, T.A. and P.H. Brose. 1999. A comparison of fire intensity levels for stand replacement of Table Mountain pine. *Forest Ecology and Management* **113**: 155-166.

Waldrop, T.A., H.H. Mohr, P.H. Brose, and R.B. Baker. 1999. Seedbed requirements for regenerating Table Mountain pine with prescribed fire. In: J.D. Haywood [Ed.]. *Proceedings of the tenth biennial southern silvicultural research conference*, February 16-18, Shreveport, LA. USDA Forest Service Southern Research Station *General Technical Report* SRS-30.

Welch, N., T. Waldrop, and E. Buckner. 2000. Response of southern Appalachian table mountain pine (*Pinus pungens*) and pitch pine (*P. rigida*) stands to prescribed burning. *Forest Ecology and Management* **136**: 185-197.

Whittaker, R. H. 1956. Vegetation of the Great Smoky Mountains. *Ecological Monographs* **26**: 1-80.

Williams, C.E. and W.C. Johnson. 1990. Age structure and the maintenance of *Pinus pungens* in pine-oak forests of southwestern Virginia. *American Midland Naturalist* **124**: 130-141.

Williams, C.E. and W.C. Johnson. 1992. Factors affecting recruitment of *Pinus pungens* in the southern Appalachian Mountains. *Canadian Journal of Forest Research* **22**: 878-887.

Williams, C.E., M.V. Lipscomb, and W.C. Johnson. 1990. Influence of leaf litter and soil moisture regime on early establishment of *Pinus pungens*. *American Midland Naturalist* **124**: 142-151.

Williams, C.E. 1992. An Appalachian original. *American Forests* **98**: 24-26.

Wright, H.A. and A.W. Bailey. 1982. *Fire ecology: United States and Southern Canada*. John Wiley & Sons, New York.

Yamaguchi, D.K. 1991. A simple method for crossdating increment cores from living trees. *Canadian Journal of Forest Research* **21**: 414-416.

Zobel, D.B. 1969. Factors affecting the distribution of *Pinus pungens*, an Appalachian endemic. *Ecological Monographs* **39**: 303-333.

APPENDIX

Table A-1. Core sample data for dendrochronological analyses of the age structure of Table Mountain pine stands in GSMNP.

Sample	Core Type	Height (m)	Height (ft)	DBH (cm)	DBH (in)	Inner Date	Age
BH001	AB	6.5	21.3	19.3	7.6	1930	71
BH002	AB	6.5	21.3	13.0	5.1	1963	38
BH003	AB	7.0	23.0	12.0	4.7	1932	69
BH004	AB	6.0	19.7	13.4	5.3	1931	70
BH005	AB	8.0	26.2	13.8	5.4	1942	59
BH006	AB	4.0	13.1	8.0	3.1	1958	43
BH007	AB	4.5	14.8	9.3	3.7	1942	59
BH008	AB	10.0	32.8	16.5	6.5	1934	67
BH009	AB	20.0	65.6	17.5	6.9	1928	73
BH010	AB	10.0	32.8	16.9	6.7	1926	75
BH011	AB	8.0	26.2	11.1	4.4	1934	67
BH012	AB	6.5	21.3	11.1	4.4	1943	58
BH013	AB	6.5	21.3	16.2	6.4	1928	73
BH014	AB	15.0	49.2	20.0	7.9	1929	72
BH015	AB	8.0	26.2	15.4	6.1	1940	61
BH016	AB	7.0	23.0	11.2	4.4	1926	75
BH017	AB	8.0	26.2	11.5	4.5	1939	62
BH018	AB	6.5	21.3	11.5	4.5	1942	59
BH019	AB	7.0	23.0	9.0	3.5	1953	48
BH020	AB	10.0	32.8	24.3	9.6	1939	62
BH021	AB	9.0	29.5	16.7	6.6	1942	59
BH022	AB	6.0	19.7	11.7	4.6	1939	62
BH023	AB	4.0	13.1	6.8	2.7	1938	63
BH024	AB	7.0	23.0	10.0	3.9	1938	63
BH025	AB	8.0	26.2	13.1	5.2	1937	64
BH026	AB	20.0	65.6	24.5	9.6	1934	67
BH027	AB	5.5	18.0	13.4	5.3	1942	59
BH028	AB	10.0	32.8	13.7	5.4	1931	70
BH029	AB	9.0	29.5	12.2	4.8	1931	70
BH030	AB	10.0	32.8	12.7	5.0	1936	65
BH031	AB	10.5	34.5	15.4	6.1	1942	59
BH032	AB	9.5	31.2	17.4	6.9	1929	72
BH033	AB	10.0	32.8	17.2	6.8	1932	69
BH034	AB	6.0	19.7	4.5	1.8	1942	59

Table A-1. Core sample data for dendrochronological analyses of the age structure of Table Mountain pine stands in GSMNP. (Continued)

Sample	Core Type	Height (m)	Height (ft)	DBH (cm)	DBH (in)	Inner Date	Age
BH035	AB	11.0	36.1	13.9	5.5	1941	60
BH036	AB	9.0	29.5	11.9	4.7	1933	68
BH037	AB	10.0	32.8	13.4	5.3	1933	68
BH038	AB	10.0	32.8	11.8	4.6	1940	61
BH039	AB	8.0	26.2	10.0	3.9	1941	60
BH040	AB	8.0	26.2	16.4	6.5	1945	56
BH041	AB	5.0	16.4	7.2	2.8	1944	57
BH042	AB	8.0	26.2	16.4	6.5	1936	65
BH043	AB	6.5	21.3	10.9	4.3	1945	56
BH044	AB	3.0	9.8	6.5	2.6	1951	50
BH045	AB	6.0	19.7	11.1	4.4	1937	64
BH046	AB	1.5	4.9	5.0	2.0	1952	49
BH047	Node	0.1	0.3	1.0	0.4	1996	5
BH048	Node	0.1	0.3	1.0	0.4	1996	5
BH049	Node	0.1	0.3	1.0	0.4	1996	5
BH050	Node	0.1	0.3	1.0	0.4	1997	4
BH051	AB	7.0	23.0	13.5	5.3	1931	70
BH052	AB	3.0	9.8	5.3	2.1	1952	49
BH053	AB	4.0	13.1	10.0	3.9	1933	68
BH054	AB	10.0	32.8	19.5	7.7	1929	72
BH055	AB	12.0	39.4	30.6	12.0	1927	74
BH056	AB	10.0	32.8	11.1	4.4	1942	59
BH057	AB	11.0	36.1	15.6	6.1	1929	72
BH058	AB	3.0	9.8	6.5	2.6	1948	53
BH059	AB	4.0	13.1	11.0	4.3	1937	64
BH060	AB	7.0	23.0	13.0	5.1	1952	49
BH061	AB	3.0	9.8	6.3	2.5	1955	46
BH062	AB	12.0	39.4	22.6	8.9	1929	72
BH063	AB	11.0	36.1	19.8	7.8	1934	67
BH064	AB	8.0	26.2	11.5	4.5	1937	64
BH065	AB	7.0	23.0	9.2	3.6	1949	52
BH066	AB	12.0	39.4	21.4	8.4	1939	62
BH067	AB	9.0	29.5	12.9	5.1	1930	71
BH068	AB	11.0	36.1	17.0	6.7	1931	70

Table A-1. Core sample data for dendrochronological analyses of the age structure of Table Mountain pine stands in GSMNP. (Continued)

Sample	Core Type	Height (m)	Height (ft)	DBH (cm)	DBH (in)	Inner Date	Age
BH069	AB	7.0	23.0	10.8	4.3	1932	69
BH070	AB	12.0	39.4	15.9	6.3	1928	73
BH071	AB	14.0	45.9	20.5	8.1	1932	69
BH072	AB	2.0	6.6	7.5	3.0	1949	52
BH073	AB	4.0	13.1	13.6	5.4	1942	59
BH074	AB	15.0	49.2	30.6	12.0	1932	69
BH075	AB	3.0	9.8	6.8	2.7	1954	47
BH076	AB	12.0	39.4	14.0	5.5	1935	66
BH077	AB	12.0	39.4	13.8	5.4	1934	67
BH078	AB	5.0	16.4	6.5	2.6	1937	64
BH079	AB	8.0	26.2	15.4	6.1	1936	65
BH080	Node	15.0	49.2	1.0	0.4	1996	5
BH081	Node	13.0	42.7	1.0	0.4	1996	5
CC001	A / B / C	23.0	75.5	59.2	23.3	1858	143
CC002	A / B	20.0	65.6	45.4	17.9	1845	156
CC003	A / B	22.0	72.2	40.9	16.1	1915	86
CC004	AB	15.0	49.2	21.5	8.5	1929	72
CC005	AB	17.0	55.8	33.3	13.1	1932	69
CC006	AB	12.0	39.4	12.0	4.7	1940	61
CC007	AB	15.0	49.2	17.2	6.8	1939	62
CC008	A / B	20.0	65.6	40.0	15.7	1814	187
CC009	AB	13.0	42.7	13.1	5.2	1940	61
CC010	A / B	15.0	49.2	26.6	10.5	1855	146
CC011	AB	12.0	39.4	18.5	7.3	1921	80
CC012	AB	6.0	19.7	14.0	5.5	1933	68
CC013	AB	6.0	19.7	10.3	4.1	1948	53
CC014	AB	8.0	26.2	14.0	5.5	1935	66
CC015	AB	15.0	49.2	22.3	8.8	1917	84
CC016	AB	6.0	19.7	13.5	5.3	NO DATE	X
CC017	A / B	23.0	75.5	34.4	13.5	1924	77
CC018	AB	15.0	49.2	18.0	7.1	NO DATE	X
CC019	AB	4.0	13.1	6.9	2.7	1953	48
CC020	A / B	18.0	59.1	36.4	14.3	1872	129
CC021	AB	15.0	49.2	11.2	4.4	1937	64

Table A-1. Core sample data for dendrochronological analyses of the age structure of Table Mountain pine stands in GSMNP. (Continued)

Sample	Core Type	Height (m)	Height (ft)	DBH (cm)	DBH (in)	Inner Date	Age
CC022	AB	10.0	32.8	20.7	8.1	1929	72
CC023	AB	10.0	32.8	8.9	3.5	1944	57
CC024	AB	20.0	65.6	18.3	7.2	1931	70
CC025	AB	12.0	39.4	9.7	3.8	1938	63
CC026	AB / C	14.0	45.9	17.3	6.8	1931	70
CC027	AB	19.0	62.3	35.5	14.0	1874	127
CC028	AB	15.0	49.2	13.7	5.4	1966	35
CC029	AB	20.0	65.6	22.2	8.7	1931	70
CC030	AB	22.0	72.2	21.3	8.4	1928	73
CC031	AB	16.0	52.5	26.0	10.2	1928	73
CC032	AB	17.0	55.8	22.8	9.0	1922	79
CC033	AB	17.0	55.8	22.9	9.0	1945	56
CC034	AB	8.0	26.2	15.0	5.9	1930	71
CC035	AB	10.0	32.8	21.8	8.6	1933	68
CC036	A / B	17.0	55.8	40.2	15.8	1897	104
CC037	AB	10.0	32.8	29.2	11.5	1929	72
CC038	AB	12.0	39.4	29.1	11.5	1942	59
CC039	AB	18.0	59.1	31.8	12.5	1929	72
CC040	AB	12.0	39.4	28.7	11.3	1927	74
CC041	AB	16.0	52.5	30.0	11.8	1917	84
CC042	AB	17.0	55.8	32.5	12.8	1911	90
CC043	AB	16.0	52.5	33.9	13.3	1935	66
CC044	A / B	20.0	65.6	33.1	13.0	1930	71
CC045	AB	8.0	26.2	15.9	6.3	NO DATE	X
CC046	AB	17.0	55.8	25.5	10.0	1933	68
CC047	AB	20.0	65.6	41.0	16.1	1825	176
CC048	AB	9.0	29.5	24.0	9.4	1943	58
CC049	AB	9.0	29.5	30.4	12.0	1926	75
CC050	AB	9.0	29.5	17.8	7.0	1936	65
CC051	AB	10.0	32.8	26.3	10.4	1940	61
CC052	AB	7.5	24.6	23.2	9.1	1932	69
CC053	AB	10.0	32.8	34.0	13.4	1940	61
CC054	AB	8.5	27.9	22.3	8.8	1922	79
CC055	AB	10.5	34.5	38.5	15.2	1875	126

Table A-1. Core sample data for dendrochronological analyses of the age structure of Table Mountain pine stands in GSMNP. (Continued)

Sample	Core Type	Height (m)	Height (ft)	DBH (cm)	DBH (in)	Inner Date	Age
CC056	AB	6.5	21.3	13.7	5.4	1954	47
CC057	A / B	10.5	34.5	47.3	18.6	1811	190
CC058	AB	8.0	26.2	33.8	13.3	1850	151
CC059	AB	8.0	26.2	15.5	6.1	1931	70
CC060	AB	5.0	16.4	10.0	3.9	1927	74
CC061	AB	7.0	23.0	13.0	5.1	1903	98
CC062	AB	9.0	29.5	35.5	14.0	1880	121
CC063	AB	6.0	19.7	11.8	4.6	1936	65
CC064	AB	11.0	36.1	36.5	14.4	1921	80
CC065	AB	12.0	39.4	19.2	7.6	1927	74
CC066	AB	9.0	29.5	12.7	5.0	1954	47
CC067	AB	7.0	23.0	11.7	4.6	1955	46
CC068	AB	10.0	32.8	17.0	6.7	1930	71
CC069	AB	17.0	55.8	37.5	14.8	1840	161
CC070	AB	7.0	23.0	14.2	5.6	1931	70
CC071	AB	14.0	45.9	24.8	9.8	1822	179
CC072	A / B	18.0	59.1	43.5	17.1	1816	185
CC073	AB	10.0	32.8	38.4	15.1	1813	188
CC074	AB	5.0	16.4	12.8	5.0	1950	51
CC075	A / B	21.0	68.9	42.9	16.9	1934	67
CO001	AB	13.5	44.3	30.9	12.2	1921	80
CO002	Node	0.5	1.6	1.0	0.4	1997	4
CO003	AB	17.0	55.8	39.0	15.4	1919	82
CO004	Node	0.8	2.5	1.0	0.4	1995	6
CO005	AB	4.0	13.1	8.2	3.2	1934	67
CO006	AB	16.0	52.5	27.2	10.7	1923	78
CO007	AB	16.5	54.1	25.1	9.9	1918	83
CO008	AB	15.0	49.2	29.8	11.7	1918	83
CO009	AB	22.0	72.2	36.1	14.2	1925	76
CO010	AB	8.5	27.9	14.9	5.9	1937	64
CO011	AB	4.0	13.1	7.5	3.0	1963	38
CO012	AB	15.0	49.2	12.4	4.9	1953	48
CO013	AB	16.0	52.5	23.2	9.1	1919	82
CO014	AB	15.0	49.2	16.9	6.7	1923	78

Table A-1. Core sample data for dendrochronological analyses of the age structure of Table Mountain pine stands in GSMNP. (Continued)

Sample	Core Type	Height (m)	Height (ft)	DBH (cm)	DBH (in)	Inner Date	Age
CO015	AB	10.0	32.8	19.2	7.6	1921	80
CO016	AB	8.0	26.2	16.0	6.3	1935	66
CO017	AB	10.0	32.8	17.7	7.0	1920	81
CO018	AB	8.0	26.2	15.3	6.0	1924	77
CO019	AB	7.0	23.0	12.9	5.1	1931	70
CO020	AB	8.0	26.2	15.0	5.9	1932	69
CO021	AB	10.0	32.8	14.2	5.6	1933	68
CO022	AB	17.0	55.8	21.0	8.3	1918	83
CO023	AB	15.0	49.2	14.5	5.7	1921	80
CO024	A / B	14.0	45.9	24.7	9.7	1925	76
CO025	AB	7.0	23.0	15.2	6.0	1922	79
CO026	AB	6.0	19.7	14.6	5.7	1922	79
CO027	AB	5.0	16.4	11.5	4.5	1928	73
CO028	AB	15.0	49.2	24.9	9.8	1923	78
CO029	AB	6.0	19.7	14.0	5.5	1929	72
CO030	AB	11.0	36.1	25.7	10.1	1919	82
CO031	AB	8.0	26.2	17.8	7.0	1929	72
CO032	AB	12.0	39.4	20.2	8.0	1924	77
CO033	AB	8.0	26.2	15.5	6.1	1934	67
CO034	AB	12.0	39.4	25.5	10.0	1923	78
CO035	AB	9.0	29.5	10.0	3.9	1943	58
CO036	AB	12.0	39.4	11.9	4.7	1939	62
CO037	AB	6.0	19.7	15.7	6.2	1929	72
CO038	AB	12.0	39.4	15.9	6.3	1933	68
CO039	AB	8.0	26.2	17.7	7.0	1930	71
CO040	AB	9.0	29.5	12.4	4.9	1938	63
CO041	AB	9.0	29.5	12.8	5.0	1926	75
CO042	AB	10.0	32.8	15.3	6.0	1934	67
CO043	AB	11.0	36.1	17.6	6.9	1933	68
CO044	Node	0.8	2.6	1.0	0.4	1990	11
CO045	AB	10.0	32.8	14.4	5.7	1936	65
CO046	AB	9.0	29.5	17.6	6.9	1938	63
CO047	AB	6.0	19.7	11.6	4.6	1942	59
CO048	AB	13.0	42.7	21.8	8.6	1924	77

Table A-1. Core sample data for dendrochronological analyses of the age structure of Table Mountain pine stands in GSMNP. (Continued)

Sample	Core Type	Height (m)	Height (ft)	DBH (cm)	DBH (in)	Inner Date	Age
CO049	AB	17.0	55.8	32.8	12.9	1914	87
CO050	AB	10.0	32.8	14.8	5.8	1934	67
CO051	AB	8.0	26.2	15.3	6.0	1934	67
CO052	AB	11.0	36.1	15.5	6.1	1936	65
CO053	AB	7.0	23.0	13.6	5.4	1929	72
CO054	AB	11.0	36.1	19.7	7.8	1924	77
CO055	AB	10.0	32.8	23.6	9.3	1925	76
CO056	AB	11.0	36.1	20.5	8.1	1936	65
CO057	AB	13.5	44.3	25.8	10.2	1923	78
CO058	AB	8.0	26.2	22.3	8.8	1923	78
CO059	AB	8.0	26.2	14.1	5.6	1926	75
CO060	AB	9.0	29.5	16.5	6.5	1921	80
CO061	AB	10.0	32.8	17.1	6.7	1935	66
CO062	AB	8.0	26.2	14.3	5.6	1927	74
CO063	AB	10.0	32.8	15.9	6.3	1939	62
CO064	AB	17.0	55.8	20.7	8.1	1923	78
CO065	AB	16.0	52.5	21.8	8.6	1922	79
CO066	AB	16.0	52.5	19.8	7.8	1921	80
CO067	AB	15.0	49.2	24.5	9.6	1916	85
CO068	AB	8.0	26.2	13.0	5.1	1938	63
CO069	AB	10.0	32.8	16.1	6.3	1921	80
CO070	AB	8.0	26.2	11.6	4.6	1931	70
CO071	AB	10.0	32.8	14.2	5.6	1936	65
CO072	AB	10.0	32.8	12.8	5.0	1935	66
CO073	AB	8.0	26.2	12.4	4.9	1932	69
CO074	AB	12.0	39.4	18.0	7.1	1922	79
CO075	AB	11.0	36.1	19.8	7.8	1919	82
CO076	AB	16.0	52.5	25.9	10.2	1924	77
CO077	AB	17.0	55.8	27.4	10.8	1920	81
CO078	AB	14.0	45.9	21.9	8.6	1926	75
SM001	AB	9.0	29.5	12.9	5.1	1935	66
SM002	AB	6.5	21.3	18.1	7.1	1932	69
SM003	AB	10.0	32.8	21.3	8.4	1928	73
SM004	AB	10.5	34.5	22.6	8.9	1932	69

Table A-1. Core sample data for dendrochronological analyses of the age structure of Table Mountain pine stands in GSMNP. (Continued)

Sample	Core Type	Height (m)	Height (ft)	DBH (cm)	DBH (in)	Inner Date	Age
SM005	AB	8.5	27.9	15.5	6.1	1934	67
SM006	AB	10.0	32.8	21.6	8.5	1937	64
SM007	AB	9.0	29.5	12.5	4.9	1940	61
SM008	AB	10.0	32.8	19.1	7.5	1925	76
SM009	AB	5.0	16.4	9.5	3.7	1934	67
SM010	AB	11.0	36.1	18.3	7.2	1933	68
SM011	AB	10.5	34.5	18.3	7.2	1932	69
SM012	AB	15.0	49.2	19.5	7.7	1931	70
SM013	AB	15.0	49.2	19.5	7.7	1931	70
SM014	AB	16.0	52.5	20.9	8.2	1934	67
SM015	AB	14.0	45.9	18.1	7.1	1928	73
SM016	AB	15.0	49.2	16.5	6.5	1936	65
SM017	AB	16.0	52.5	20.3	8.0	1930	71
SM018	AB	10.0	32.8	9.7	3.8	1946	55
SM019	AB	6.0	19.7	8.8	3.5	1955	46
SM020	AB	3.0	9.8	4.5	1.8	1953	48
SM021	AB	17.0	55.8	20.5	8.1	1933	68
SM022	AB	20.0	65.6	24.7	9.7	1931	70
SM023	AB	17.0	55.8	19.9	7.8	1934	67
SM024	AB	10.0	32.8	11.5	4.5	1947	54
SM025	AB	20.0	65.6	22.4	8.8	1933	68
SM026	AB	10.0	32.8	16.8	6.6	1936	65
SM027	AB	10.0	32.8	14.3	5.6	1934	67
SM028	AB	9.0	29.5	12.5	4.9	1938	63
SM029	AB	11.0	36.1	20.3	8.0	1926	75
SM030	AB	9.0	29.5	17.6	6.9	1940	61
SM031	AB	5.0	16.4	16.1	6.3	1935	66
SM032	AB	5.0	16.4	13.0	5.1	1932	69
SM033	AB	9.0	29.5	14.0	5.5	1929	72
SM034	AB	8.5	27.9	15.7	6.2	1924	77
SM035	AB	8.0	26.2	15.3	6.0	1931	70
SM036	AB	7.5	24.6	19.7	7.8	1930	71
SM037	AB	12.0	39.4	34.9	13.7	1929	72
SM038	AB	10.0	32.8	23.3	9.2	1924	77

Table A-1. Core sample data for dendrochronological analyses of the age structure of Table Mountain pine stands in GSMNP. (Continued)

Sample	Core Type	Height (m)	Height (ft)	DBH (cm)	DBH (in)	Inner Date	Age
SM039	AB	8.0	26.2	16.7	6.6	1933	68
SM040	Node	1.5	4.9	2.7	1.1	1981	20
SM041	AB	10.0	32.8	20.6	8.1	1928	73
SM042	AB	7.5	24.6	13.5	5.3	1944	57
SM043	AB	8.5	27.9	16.1	6.3	1937	64
SM044	AB	8.5	27.9	17.0	6.7	1936	65
SM045	AB	10.4	34.1	14.5	5.7	1932	69
SM046	AB	10.0	32.8	18.1	7.1	1935	66
SM047	AB	8.0	26.2	13.2	5.2	1937	64
SM048	AB	7.3	24.0	12.2	4.8	1960	41
SM049	AB	7.0	23.0	10.6	4.2	NO DATE	X
SM050	AB	13.0	42.7	20.5	8.1	1934	67
SM051	AB	6.0	19.7	8.7	3.4	1944	57
SM052	AB	4.2	13.8	7.0	2.8	1935	66
SM053	AB	13.5	44.3	36.3	14.3	1931	70
SM054	AB	3.0	9.8	6.7	2.6	1937	64
SM055	AB	4.0	13.1	8.8	3.5	1938	63
SM056	AB	2.0	6.6	5.4	2.1	1943	58
SM057	Node	10.0	32.8	1.0	0.4	1997	4
SM058	Node	10.0	32.8	1.0	0.4	1997	4
SM059	AB	6.5	21.3	9.7	3.8	1938	63
SM060	AB	7.5	24.6	10.5	4.1	1937	64
SM061	AB	8.5	27.9	22.6	8.9	1933	68
SM062	A / B	20.0	65.6	39.2	15.4	1904	97
SM063	AB	7.0	23.0	11.9	4.7	1947	54
SM064	AB	10.0	32.8	12.5	4.9	1944	57
SM065	AB	11.0	36.1	18.7	7.4	1938	63
SM066	AB	9.0	29.5	13.6	5.4	1936	65
SM067	AB	8.0	26.2	10.7	4.2	1928	73
SM068	AB	11.0	36.1	14.9	5.9	1939	62
SM069	AB	9.0	29.5	14.5	5.7	1947	54
SM070	AB	9.0	29.5	14.2	5.6	1942	59
SM071	AB	8.0	26.2	12.9	5.1	1936	65
SM072	AB	11.0	36.1	16.2	6.4	1938	63

Table A-1. Core sample data for dendrochronological analyses of the age structure of Table Mountain pine stands in GSMNP. (Continued)

Sample	Core Type	Height (m)	Height (ft)	DBH (cm)	DBH (in)	Inner Date	Age
SM073	AB	3.5	11.5	6.2	2.4	1952	49
SM074	AB	12.0	39.4	23.7	9.3	1934	67
SM075	AB	9.0	29.5	10.5	4.1	1938	63
SM076	AB	13.0	42.7	19.5	7.7	1936	65
SM077	AB	10.0	32.8	15.8	6.2	1931	70
SM078	AB	8.0	26.2	11.5	4.5	1939	62
TH001	A / B	22.0	72.2	52.8	20.8	1897	104
TH002	AB	10.0	32.8	15.6	6.1	1934	67
TH003	AB	7.0	23.0	11.8	4.6	1929	72
TH004	AB	21.0	68.9	32.1	12.6	1921	80
TH005	AB	20.0	65.6	24.6	9.7	1915	86
TH006	AB	9.5	31.2	12.9	5.1	1938	63
TH007	AB	15.0	49.2	21.3	8.4	1921	80
TH008	AB	21.0	68.9	27.3	10.7	1919	82
TH009	AB	8.0	26.2	22.3	8.8	1912	89
TH010	AB	22.0	72.2	31.5	12.4	1920	81
TH011	AB	23.0	75.5	36.1	14.2	1912	89
TH012	AB	8.5	27.9	12.5	4.9	1933	68
TH013	AB	14.0	45.9	25.0	9.8	1931	70
TH014	AB	14.0	45.9	17.3	6.8	1931	70
TH015	AB	9.0	29.5	18.2	7.2	1932	69
TH016	AB	11.0	36.1	16.5	6.5	1933	68
TH017	AB	7.0	23.0	9.0	3.5	1946	55
TH018	AB	11.0	36.1	20.6	8.1	1930	71
TH019	AB	8.0	26.2	16.4	6.5	1932	69
TH020	AB	11.0	36.1	21.3	8.4	1933	68
TH021	AB	6.0	19.7	11.8	4.6	1938	63
TH022	AB	11.0	36.1	16.8	6.6	1933	68
TH023	AB	12.0	39.4	26.0	10.2	1932	69
TH024	AB	10.0	32.8	15.5	6.1	1938	63
TH025	AB	7.0	23.0	14.4	5.7	1944	57
TH026	AB	9.0	29.5	15.7	6.2	1936	65
TH027	AB	21.0	68.9	31.3	12.3	1929	72
TH028	AB	4.5	14.8	12.5	4.9	1929	72

Table A-1. Core sample data for dendrochronological analyses of the age structure of Table Mountain pine stands in GSMNP. (Continued)

Sample	Core Type	Height (m)	Height (ft)	DBH (cm)	DBH (in)	Inner Date	Age
TH029	AB	2.0	6.6	5.5	2.2	1947	54
TH030	AB	7.0	23.0	13.5	5.3	1934	67
TH031	AB	12.0	39.4	18.0	7.1	1898	103
TH032	A / B	20.0	65.6	32.2	12.7	1894	107
TH033	AB	2.5	8.2	8.2	3.2	1939	62
TH034	AB	3.5	11.5	6.9	2.7	1937	64
TH035	AB	7.0	23.0	12.5	4.9	1931	70
TH036	AB	6.5	21.3	10.0	3.9	1937	64
TH037	AB	7.5	24.6	10.3	4.1	1935	66
TH038	AB	15.0	49.2	26.5	10.4	1896	105
TH039	AB	10.0	32.8	11.1	4.4	1932	69
TH040	AB	8.0	26.2	17.9	7.0	1932	69
TH041	AB	7.0	23.0	12.0	4.7	1931	70
TH042	AB	8.0	26.2	12.6	5.0	1940	61
TH043	AB	9.0	29.5	13.6	5.4	1933	68
TH044	AB	8.0	26.2	7.0	2.8	1931	70
TH045	AB	12.0	39.4	18.0	7.1	1932	69
TH046	AB	10.0	32.8	18.1	7.1	1929	72
TH047	AB	8.0	26.2	14.2	5.6	1935	66
TH048	AB	8.0	26.2	9.9	3.9	1936	65
TH049	AB	10.0	32.8	22.0	8.7	1942	59
TH050	AB	7.0	23.0	12.9	5.1	1930	71
TH051	AB	7.0	23.0	8.7	3.4	1939	62
TH052	AB	16.0	52.5	19.2	7.6	1932	69
TH053	AB	10.0	32.8	21.0	8.3	1929	72
TH054	AB	11.0	36.1	20.5	8.1	1932	69
TH055	AB	19.0	62.3	22.3	8.8	1931	70
TH056	AB	7.0	23.0	9.1	3.6	1936	65
TH057	AB	11.0	36.1	19.3	7.6	1932	69
TH058	AB	10.0	32.8	16.0	6.3	1933	68
TH059	AB	14.0	45.9	18.5	7.3	1934	67
TH060	AB	17.0	55.8	19.4	7.6	1940	61
TH061	AB	7.0	23.0	15.2	6.0	1937	64
TH062	AB	9.0	29.5	12.6	5.0	1937	64

Table A-1. Core sample data for dendrochronological analyses of the age structure of Table Mountain pine stands in GSMNP. (Continued)

Sample	Core Type	Height (m)	Height (ft)	DBH (cm)	DBH (in)	Inner Date	Age
TH063	AB	8.5	27.9	13.9	5.5	1939	62
TH064	AB	7.0	23.0	10.0	3.9	1949	52
TH065	AB	6.5	21.3	11.5	4.5	1945	56
TH066	AB	6.5	21.3	8.7	3.4	1947	54
TH067	AB	21.0	68.9	24.8	9.8	1948	53
TH068	AB	14.0	45.9	17.0	6.7	1933	68
TH069	AB	12.5	41.0	17.2	6.8	1937	64
TH070	AB	15.0	49.2	22.2	8.7	1936	65
TH071	AB	20.0	65.6	30.0	11.8	1934	67
TH072	AB	11.0	36.1	15.8	6.2	1934	67
TH073	AB	8.0	26.2	9.0	3.5	1944	57
TH074	AB	9.0	29.5	12.8	5.0	1940	61
TH075	AB	15.0	49.2	15.9	6.3	1940	61
TH076	AB	12.0	39.4	27.4	10.8	1897	104
TH077	Node	1.0	3.3	1.5	0.6	1981	20
TH078	Node	0.8	2.5	1.0	0.4	1986	15
TH079	Node	0.3	1.0	1.0	0.4	1987	14
TH080	Node	0.5	1.6	1.0	0.4	1987	14
TH081	Node	1.8	5.7	1.3	0.5	1988	13
TH082	Node	0.7	2.1	1.0	0.4	1990	11
TH083	Node	0.5	1.5	1.0	0.4	1995	6
TH084	Node	0.4	1.2	1.0	0.4	1995	6
TH085	Node	0.1	0.3	1.0	0.4	1995	6
TH086	Node	0.2	0.8	1.0	0.4	1996	5
TH087	Node	0.2	0.7	1.0	0.4	1997	4
TH088	Node	0.2	0.5	1.0	0.4	1999	2

Table A-2. Final COFECHA output showing the correlation among core samples used to develop a master chronology for this study.

QUALITY CONTROL AND DATING CHECK OF TREE-RING MEASUREMENTS

File of DATED series: aa.rwl

CONTENTS:

Part 1: Title page, options selected, summary, absent rings by series
Part 2: Histogram of time spans
Part 3: Master series with sample depth and absent rings by year
Part 4: Bar plot of Master Dating Series
Part 5: Correlation by segment of each series with Master
Part 6: Potential problems: low correlation, divergent year-to-year changes, absent rings, outliers
Part 7: Descriptive statistics

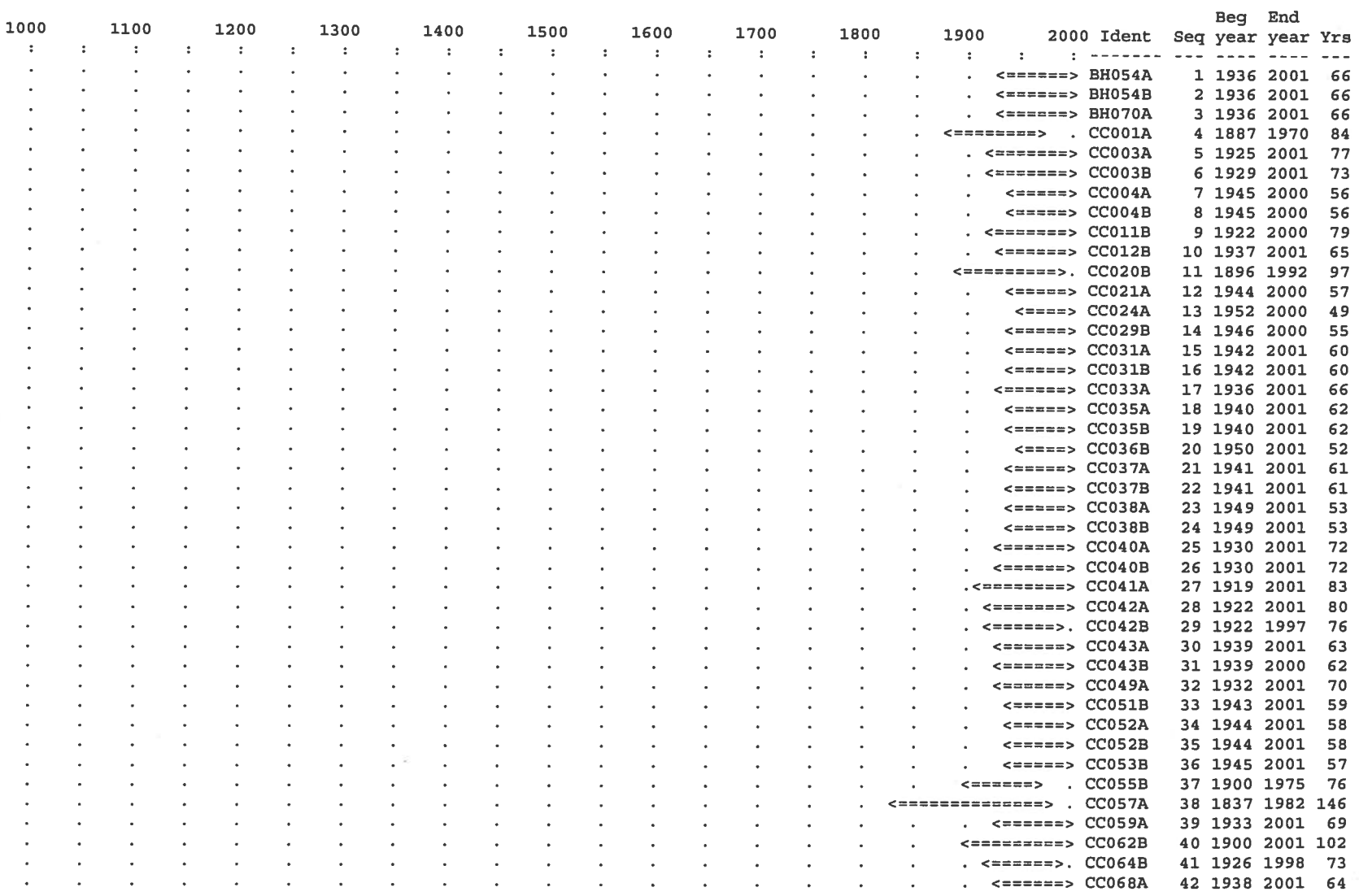
RUN CONTROL OPTIONS SELECTED		VALUE
1	Cubic smoothing spline 50% wavelength cutoff for filtering	32 years
2	Segments examined are	50 years lagged successively by 25 years
3	Autoregressive model applied	A Residuals are used in master dating series and testing
4	Series transformed to logarithms	Y Each series log-transformed for master dating series and testing
5	CORRELATION is Pearson (parametric, quantitative) Critical correlation, 99% confidence level	.3281
6	Master dating series saved	N
7	Ring measurements listed	N
8	Parts printed	1234567
9	Absent rings are omitted from master series and segment correlations	(Y)

Time span of Master dating series is	1837 to 2001		165 years
Continuous time span is	1837 to 2001		165 years
Portion with two or more series is	1887 to 2001		115 years

```
****************************************
*C* Number of dated series         61 *C*
*O* Master series 1837 2001  165 yrs *O*
*F* Total rings in all series    4321 *F*
*E* Total dated rings checked    4271 *E*
*C* Series intercorrelation       .538 *C*
*H* Average mean sensitivity      .258 *H*
*A* Segments, possible problems     0 *A*
*** Mean length of series        70.8 ***
****************************************
```

ABSENT RINGS listed by SERIES: (See Master Dating Series for absent rings listed by year)

No ring measurements of zero value



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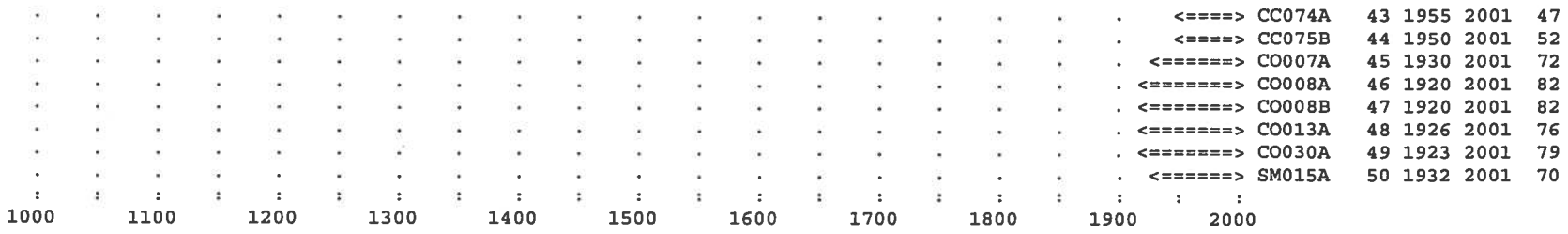
BH054B	2	1936	2001	66
BH070A	3	1936	2001	66
CC001A	4	1887	1970	84
CC003A	5	1925	2001	77
CC003B	6	1929	2001	73
CC004A	7	1945	2000	56
CC004B	8	1945	2000	56
CC011B	9	1922	2000	79
CC012B	10	1937	2001	65
CC020B	11	1896	1992	97
CC021A	12	1944	2000	57
CC024A	13	1952	2000	49
CC029B	14	1946	2000	55
CC031A	15	1942	2001	60
CC031B	16	1942	2001	60
CC033A	17	1936	2001	66
CC035A	18	1940	2001	62
CC035B	19	1940	2001	62
CC036B	20	1950	2001	52
CC037A	21	1941	2001	61
CC037B	22	1941	2001	61
CC038A	23	1949	2001	53
CC038B	24	1949	2001	53
CC040A	25	1930	2001	72
CC040B	26	1930	2001	72
CC041A	27	1919	2001	83
CC042A	28	1922	2001	80
CC042B	29	1922	1997	76
CC043A	30	1939	2001	63
CC043B	31	1939	2000	62
CC049A	32	1932	2001	70
CC051B	33	1943	2001	59
CC052A	34	1944	2001	58
CC052B	35	1944	2001	58
CC053B	36	1945	2001	57
CC055B	37	1900	1975	76
CC057A	38	1837	1982	146
CC059A	39	1933	2001	69
CC062B	40	1900	2001	102
CC064B	41	1926	1998	73
CC068A	42	1938	2001	64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<========> CO030A 49 1923 2001 79
<=======> SM015A 50 1932 2001 70
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000

PART 2: TIME PLOT OF TREE-RING SERIES: 16:02 Wed 16 Jan 2002 Page 3

```
1000      1100      1200      1300      1400      1500      1600      1700      1800      1900      2000 Ident    Seq  Beg year  End year  Yrs
  :    :    :    :    :    :    :    :    :    :    :    :    :    :    :    :    :    :    :    :    :  -------  ---  --------  --------  ---
  .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .  <=======> SM015B   51      1932      2001   70
  .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .  <=======> SM053A   52      1933      2001   69
  .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .  <=======> SM053B   53      1933      2001   69
  .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .  <==========> TH001A   54      1898      2001  104
  .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    . <========> TH004A   55      1923      2000   78
  .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .   .<=========> TH005A   56      1916      2001   86
  .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .   .<========>. TH005B   57      1916      1999   84
  .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    . <========> TH008A   58      1921      2001   81
  .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    . <========> TH008B   59      1921      2000   80
  .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .   .<=========> TH010A   60      1919      2000   82
  .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    . <========> TH038B   61      1920      2001   82
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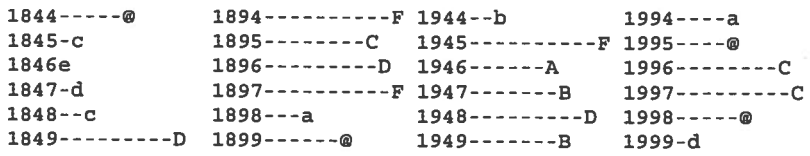
Year	Value	No Ab	Year	Value	No Ab	Year	Value	No Ab	Year	Value	No Ab	Year	Value	No Ab	Year	Value	No Ab
									1850	.792	1	1900	-1.276	6	1950	-.572	59
									1851	-.240	1	1901	.540	6	1951	-.525	59
									1852	1.480	1	1902	.036	6	1952	-.927	60
									1853	.611	1	1903	.919	6	1953	.194	60
									1854	1.482	1	1904	-.135	6	1954	-.494	60
									1855	1.274	1	1905	.162	6	1955	.220	61
									1856	.317	1	1906	1.023	6	1956	.470	61
									1857	.437	1	1907	.238	6	1957	1.295	61
									1858	-.008	1	1908	.510	6	1958	1.176	61
									1859	-.605	1	1909	-.129	6	1959	-.318	61
									1860	-.680	1	1910	-1.779	6	1960	-.427	61
									1861	-.053	1	1911	-1.243	6	1961	.335	61
									1862	-.667	1	1912	-.417	6	1962	-.700	61
									1863	-7.829	1	1913	-.875	6	1963	-1.076	61
									1864	-.286	1	1914	-1.353	6	1964	-.768	61
									1865	.154	1	1915	-.452	6	1965	-.559	61
									1866	.496	1	1916	.860	8	1966	.043	61
									1867	1.930	1	1917	.150	8	1967	.322	61
									1868	1.293	1	1918	.580	8	1968	-.495	61
									1869	.317	1	1919	.560	10	1969	-.503	61
									1870	.158	1	1920	.559	13	1970	-.186	61
									1871	.225	1	1921	-.232	15	1971	-.004	60
									1872	-.230	1	1922	-.193	18	1972	.503	60
									1873	-.474	1	1923	.241	20	1973	.826	60
									1874	.966	1	1924	.124	20	1974	1.232	60
									1875	.117	1	1925	-.703	21	1975	1.020	60
									1876	-.933	1	1926	.278	23	1976	-.052	59
									1877	.603	1	1927	.168	23	1977	-.027	59
									1878	1.569	1	1928	.289	23	1978	-1.009	59
									1879	-2.709	1	1929	.346	24	1979	-1.129	59
									1880	-.842	1	1930	-1.737	27	1980	-.062	59
									1881	-.941	1	1931	-.163	27	1981	.058	59
									1882	.847	1	1932	-.371	30	1982	-.084	59
									1883	-.683	1	1933	.738	33	1983	.857	58
									1884	-.340	1	1934	-.336	33	1984	.630	58
									1885	.894	1	1935	.954	33	1985	-.513	58
									1886	1.159	1	1936	-.216	37	1986	-1.154	58
						1837	-.246	1	1887	-.012	2	1937	.709	38	1987	-.943	58
						1838	-1.433	1	1888	.003	2	1938	.888	39	1988	-.441	58
						1839	-.306	1	1889	.526	2	1939	-.031	41	1989	.563	58

1840	.212	1	1890	-.902	2	1940	-.395	43	1990	1.210	58
1841	1.577	1	1891	-1.479	2	1941	-1.428	45	1991	1.119	58
1842	1.447	1	1892	-.327	2	1942	-.206	47	1992	-.475	58
1843	-.366	1	1893	.663	2	1943	.158	48	1993	.554	57
1844	-.030	1	1894	1.414	2	1944	-.582	51	1994	-.174	57
1845	-.762	1	1895	.643	2	1945	1.378	54	1995	-.086	57
1846	-1.221	1	1896	1.010	3	1946	.296	55	1996	.693	57
1847	-1.039	1	1897	1.477	3	1947	.534	55	1997	.840	57
1848	-.686	1	1898	-.335	4	1948	.911	55	1998	.016	56
1849	.986	1	1899	.113	4	1949	.477	57	1999	-.997	55

PART 3: Master Dating Series: 16:02 Wed 16 Jan 2002 Page 5

Year	Value	No Ab	Year	Value	No Ab	Year	Value	No Ab	Year	Value	No Ab	Year	Value	No Ab	Year	Value	No Ab
2000	-.272	54															
2001	-.111	44															

Year	Rel value	Year	Rel value	Year	Rel value	Year	Rel value	Year	Rel value	Year	Rel value	Year	Rel value	Year	Rel value
										1850	--------C	1900	e	1950	--b
										1851	----a	1901	-------B	1951	--b
										1852	----------F	1902	-----@	1952	-d
										1853	--------B	1903	---------D	1953	------A
										1854	----------F	1904	----a	1954	--b
										1855	----------E	1905	------A	1955	------A
										1856	------A	1906	---------D	1956	-------B
										1857	-------B	1907	------A	1957	----------E
										1858	-----@	1908	-------B	1958	---------E
										1859	--b	1909	----a	1959	---a
										1860	--c	1910	g	1960	--b
										1861	-----@	1911	e	1961	------A
										1862	--c	1912	---b	1962	-c
										1863	<	1913	-d	1963	-d
										1864	---a	1914	e	1964	-c
										1865	------A	1915	--b	1965	--b
										1866	-------B	1916	---------C	1966	-----@
										1867	----------H	1917	------A	1967	------A
										1868	----------E	1918	--------B	1968	--b
										1869	------A	1919	--------B	1969	--b
										1870	------A	1920	-------B	1970	----a
										1871	------A	1921	----a	1971	-----@
										1872	----a	1922	----a	1972	-------B
										1873	--b	1923	------A	1973	---------C
										1874	---------D	1924	------@	1974	----------E
										1875	------@	1925	-c	1975	---------D
										1876	-d	1926	------A	1976	-----@
										1877	--------B	1927	------A	1977	-----@
										1878	----------F	1928	------A	1978	-d
										1879	k	1929	-------A	1979	e
										1880	-c	1930	g	1980	-----@
										1881	-d	1931	----a	1981	-----@
										1882	---------C	1932	---a	1982	----@
										1883	--c	1933	--------C	1983	---------C
										1884	---a	1934	---a	1984	--------C
										1885	---------D	1935	---------D	1985	--b
										1886	---------E	1936	----a	1986	e
						1837	----a	1887	-----@	1937	--------C	1987	-d
						1838	f	1888	-----@	1938	---------D	1988	--b
						1839	---a	1889	-------B	1939	-----@	1989	--------B
						1840	------A	1890	-d	1940	---b	1990	----------E
						1841	----------F	1891	f	1941	f	1991	---------D
						1842	----------F	1892	---a	1942	----a	1992	--b
						1843	---a	1893	--------C	1943	------A	1993	-------B


1844-----@
1845-c
1846e
1847-d
1848--c
1849---------D
1894----------F
1895--------C
1896---------D
1897----------F
1898---a
1899------@
1944--b
1945----------F
1946------A
1947-------B
1948---------D
1949-------B
1994----a
1995----@
1996--------C
1997---------C
1998-----@
1999-d

Year Rel value Year Rel value Year Rel value Year Rel value Year Rel value Year Rel value Year Rel value Year Rel value
2000---a
2001----@

PART 5: CORRELATION OF SERIES BY SEGMENTS: 16:02 Wed 16 Jan 2002 Page 5

Correlations of 50-year dated segments, lagged 25 years
Flags: A = correlation under .3281 but highest as dated; B = correlation higher at other than dated position

Seq	Series	Time_span	1875 1924	1900 1949	1925 1974	1950 1999	1975 2024
1	BH054A	1936 2001			.53	.54	.54
2	BH054B	1936 2001			.51	.42	.41
3	BH070A	1936 2001			.54	.58	.60
4	CC001A	1887 1970	.42	.36	.43		
5	CC003A	1925 2001			.69	.64	.63
6	CC003B	1929 2001			.71	.62	.61
7	CC004A	1945 2000			.49	.44	.41
8	CC004B	1945 2000			.47	.46	.44
9	CC011B	1922 2000		.62	.65	.51	.50
10	CC012B	1937 2001			.53	.58	.57
11	CC020B	1896 1992	.71	.72	.58	.45	
12	CC021A	1944 2000			.68	.67	.67
13	CC024A	1952 2000				.44	
14	CC029B	1946 2000			.40	.46	.46
15	CC031A	1942 2001			.64	.61	.60
16	CC031B	1942 2001			.59	.60	.59
17	CC033A	1936 2001			.51	.60	.58
18	CC035A	1940 2001			.57	.52	.51
19	CC035B	1940 2001			.64	.65	.65
20	CC036B	1950 2001				.48	.51
21	CC037A	1941 2001			.71	.67	.67
22	CC037B	1941 2001			.70	.73	.72
23	CC038A	1949 2001			.48	.52	.52
24	CC038B	1949 2001			.51	.55	.54
25	CC040A	1930 2001			.52	.55	.53
26	CC040B	1930 2001			.50	.57	.56
27	CC041A	1919 2001		.49	.56	.51	.51
28	CC042A	1922 2001		.55	.54	.53	.51
29	CC042B	1922 1997		.48	.48	.46	
30	CC043A	1939 2001			.49	.52	.51
31	CC043B	1939 2000			.54	.51	.54
32	CC049A	1932 2001			.60	.67	.67
33	CC051B	1943 2001			.57	.58	.57
34	CC052A	1944 2001			.55	.70	.71
35	CC052B	1944 2001			.56	.55	.57
36	CC053B	1945 2001			.45	.42	.40
37	CC055B	1900 1975		.61	.46	.47	
38	CC057A	1837 1982	.52	.55	.45	.46	
39	CC059A	1933 2001			.44	.34	.35

40	CC062B	1900	2001		.69	.50	.38	.36
41	CC064B	1926	1998			.50	.63	
42	CC068A	1938	2001			.44	.60	.59
43	CC074A	1955	2001				.50	
44	CC075B	1950	2001				.44	.43
45	CO007A	1930	2001			.37	.41	.44
46	CO008A	1920	2001		.54	.65	.37	.35
47	CO008B	1920	2001		.50	.64	.61	.59
48	CO013A	1926	2001			.49	.48	.48
49	CO030A	1923	2001		.58	.61	.40	.40
50	SM015A	1932	2001			.49	.52	.51
51	SM015B	1932	2001			.62	.50	.48
52	SM053A	1933	2001			.60	.54	.53
53	SM053B	1933	2001			.52	.47	.46
54	TH001A	1898	2001	.57	.61	.51	.48	.49
55	TH004A	1923	2000		.49	.51	.62	.62
56	TH005A	1916	2001		.64	.75	.60	.59
57	TH005B	1916	1999		.57	.67	.52	
58	TH008A	1921	2001		.57	.63	.66	.68
59	TH008B	1921	2000		.53	.60	.70	.69
60	TH010A	1919	2000		.58	.66	.64	.63
61	TH038B	1920	2001		.56	.67	.66	.65
Av segment correlation				.55	.56	.56	.54	.54

For each series with potential problems the following diagnostics may appear:

[A] Correlations with master dating series of flagged 50-year segments of series filtered with 32-year spline, at every point from ten years earlier (-10) to ten years later (+10) than dated

[B] Effect of those data values which most lower or raise correlation with master series

[C] Year-to-year changes very different from the mean change in other series

[D] Absent rings (zero values)

[E] Values which are statistical outliers from mean for the year

---

BH054A 1936 to 2001 66 years Series 1

[B] Entire series, effect on correlation (.537) is:
Lower 1975 -.027 1952 -.027 1963 -.020 1951 -.017 Higher 1941 .039 1974 .014 1959 .014 1978 .013

[E] Outliers 2 3.0 SD above or -4.5 SD below mean for year
1951 +3.5 SD; 1952 +3.9 SD

BH054B 1936 to 2001 66 years Series 2

[B] Entire series, effect on correlation (.484) is:
Lower 1993 -.024 1957 -.019 1970 -.018 1986 -.018 Higher 1941 .052 1945 .021 1962 .017 1990 .015

[E] Outliers 1 3.0 SD above or -4.5 SD below mean for year
1953 +3.6 SD

BH070A 1936 to 2001 66 years Series 3

[B] Entire series, effect on correlation (.579) is:
Lower 1975 -.039 1946 -.021 1997 -.017 1950 -.013 Higher 1999 .016 1986 .013 1993 .013 1990 .013

[E] Outliers 1 3.0 SD above or -4.5 SD below mean for year
1972 +3.0 SD

CC001A 1887 to 1970 84 years Series 4

[B] Entire series, effect on correlation (.394) is:
Lower 1948 -.029 1957 -.025 1959 -.019 1916 -.014 Higher 1930 .025 1962 .022 1941 .018 1945 .016

[E] Outliers 5 3.0 SD above or -4.5 SD below mean for year
1927 +3.1 SD; 1948 -5.4 SD; 1959 +3.2 SD; 1960 +3.1 SD; 1970 +3.5 SD

==========

CC003A 1925 to 2001 77 years Series 5

[B] Entire series, effect on correlation (.678) is:
Lower 1962 -.021 1934 -.016 1965 -.011 1978 -.010 Higher 1941 .018 1930 .013 1945 .013 1992 .012

[E] Outliers 1 3.0 SD above or -4.5 SD below mean for year
1931 +3.3 SD

==========

CC003B 1929 to 2001 73 years Series 6

[B] Entire series, effect on correlation (.688) is:
Lower 1998 -.040 1968 -.024 1943 -.019 1936 -.014 Higher 1930 .046 1941 .017 1962 .009 1986 .008

[E] Outliers 1 3.0 SD above or -4.5 SD below mean for year
1973 +3.0 SD

==========

CC004A 1945 to 2000 56 years Series 7

[B] Entire series, effect on correlation (.432) is:
Lower 1997 -.047 1986 -.035 1969 -.033 1968 -.031 Higher 1978 .036 1990 .023 1957 .021 1945 .019

[E] Outliers 1 3.0 SD above or -4.5 SD below mean for year
1986 +3.5 SD

==========

CC004B 1945 to 2000 56 years Series 8

[B] Entire series, effect on correlation (.475) is:
Lower 1962 -.046 1968 -.039 1986 -.031 1964 -.021 Higher 1978 .034 1959 .028 1945 .024 1963 .017

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==========================================================================================================================

CC011B    1922 to  2000      79 years                                                                          Series 9

[B] Entire series, effect on correlation (  .523) is:
      Lower   1927  -.025   1999  -.019   1954  -.018   1977  -.017  Higher   1941   .016   1986   .013   1930   .012   1957 .011

[E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
      1999 -7.8 SD
==========================================================================================================================

CC012B    1937 to  2001      65 years                                                                          Series10

[B] Entire series, effect on correlation (  .514) is:
      Lower   1938  -.066   1941  -.032   1996  -.030   1998  -.017  Higher   1999   .030   1945   .025   1957   .021   1937 .016

[E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
      1937 +3.2 SD

==========================================================================================================================

CC020B    1896 to  1992      97 years                                                                          Series11

[B] Entire series, effect on correlation (  .562) is:
      Lower   1968  -.033   1992  -.019   1978  -.016   1985  -.015  Higher   1910   .017   1900   .017   1930   .012   1986 .009

[E] Outliers     2   3.0 SD above or -4.5 SD below mean for year
      1978 +3.2 SD;    1985 +3.3 SD

==========================================================================================================================

CC021A    1944 to  2000      57 years                                                                          Series12

[B] Entire series, effect on correlation (  .695) is:
      Lower   1992  -.043   1958  -.016   1986  -.014   1965  -.014  Higher   1999   .018   1962   .016   1957   .013   1945 .013

==========================================================================================================================

CC024A    1952 to  2000      49 years                                                                          Series13

[B] Entire series, effect on correlation (  .439) is:
      Lower   1985  -.051   1990  -.043   1994  -.033   1991  -.024  Higher   1963   .033   1974   .033   1986   .028   1952 .025

[E] Outliers     3   3.0 SD above or -4.5 SD below mean for year
      1953 +3.3 SD;    1985 +3.7 SD;    1994 +3.2 SD
```

CC029B 1946 to 2000 55 years Series14

[B] Entire series, effect on correlation (.437) is:
Lower 1978 -.036 1967 -.028 1948 -.023 1992 -.022 Higher 1999 .041 1986 .032 1979 .025 1957 .017

[E] Outliers 1 3.0 SD above or -4.5 SD below mean for year
1978 +3.9 SD

CC031A 1942 to 2001 60 years Series15

[B] Entire series, effect on correlation (.611) is:
Lower 1979 -.040 1959 -.031 1954 -.026 1947 -.022 Higher 1990 .019 1957 .015 1992 .014 1962 .014

[E] Outliers 1 3.0 SD above or -4.5 SD below mean for year
1979 +3.4 SD

CC031B 1942 to 2001 60 years Series16

[B] Entire series, effect on correlation (.595) is:
Lower 1958 -.026 1985 -.025 1993 -.023 1945 -.015 Higher 1992 .022 1957 .016 1978 .016 1986 .011

CC033A 1936 to 2001 66 years Series17

[B] Entire series, effect on correlation (.534) is:
Lower 1976 -.033 1936 -.029 1953 -.016 1999 -.016 Higher 1962 .024 1957 .018 1978 .017 1992 .012

CC035A 1940 to 2001 62 years Series18

[B] Entire series, effect on correlation (.567) is:
Lower 1981 -.072 1994 -.030 1986 -.011 1944 -.010 Higher 1941 .030 1962 .025 1992 .023 1957 .016

[E] Outliers 1 3.0 SD above or -4.5 SD below mean for year
1982 -6.5 SD

CC035B 1940 to 2001 62 years Series19

[B] Entire series, effect on correlation (.672) is:
Lower 1978 -.022 1982 -.014 1958 -.013 1954 -.012 Higher 1999 .018 1945 .012 1959 .012 1962 .011

CC036B 1950 to 2001 52 years Series20

[B] Entire series, effect on correlation (.473) is:
Lower 1995 -.047 1950 -.034 1959 -.026 1989 -.025 Higher 1999 .038 1974 .025 1983 .020 1957 .020

[E] Outliers 1 3.0 SD above or -4.5 SD below mean for year
1977 +3.1 SD

CC037A 1941 to 2001 61 years Series21

[B] Entire series, effect on correlation (.705) is:
Lower 1952 -.032 1954 -.030 1976 -.012 1999 -.012 Higher 1941 .014 1945 .014 1974 .009 1996 .007

[E] Outliers 1 3.0 SD above or -4.5 SD below mean for year
1953 +4.0 SD

CC037B 1941 to 2001 61 years Series22

[B] Entire series, effect on correlation (.707) is:
Lower 1963 -.021 1943 -.021 1944 -.017 1997 -.017 Higher 1941 .021 1957 .016 1990 .010 1962 .010

CC038A 1949 to 2001 53 years Series23

[B] Entire series, effect on correlation (.495) is:
Lower 1962 -.040 1956 -.031 1963 -.029 1953 -.018 Higher 1999 .029 1957 .025 1986 .021 1974 .020

[E] Outliers 2 3.0 SD above or -4.5 SD below mean for year
1963 +3.5 SD; 1995 +3.0 SD

CC038B 1949 to 2001 53 years Series24

[B] Entire series, effect on correlation (.541) is:
Lower 1956 -.042 1962 -.041 1965 -.040 1968 -.018 Higher 1999 .032 1963 .023 1974 .018 1990 .017

[E] Outliers 1 3.0 SD above or -4.5 SD below mean for year
1962 +3.2 SD

CC040A 1930 to 2001 72 years Series25

[B] Entire series, effect on correlation (.532) is:
Lower 2001 -.031 1962 -.021 1934 -.019 1964 -.019 Higher 1930 .015 1978 .015 1999 .014 1990 .012

CC040B 1930 to 2001 72 years Series26

[B] Entire series, effect on correlation (.507) is:
Lower 1946 -.048 1937 -.024 1989 -.022 1955 -.021 Higher 1945 .025 1941 .024 1930 .018 1957 .017

[E] Outliers 1 3.0 SD above or -4.5 SD below mean for year
1940 +3.1 SD

CC041A 1919 to 2001 83 years Series27

[B] Entire series, effect on correlation (.527) is:
Lower 1921 -.050 1962 -.033 1953 -.014 1973 -.013 Higher 1930 .039 1935 .017 1945 .015 1959 .014

[E] Outliers 3 3.0 SD above or -4.5 SD below mean for year
1921 +4.6 SD; 1935 +3.0 SD; 1962 +3.2 SD

CC042A 1922 to 2001 80 years Series28

[B] Entire series, effect on correlation (.521) is:
Lower 1968 -.023 1973 -.021 1996 -.019 1929 -.015 Higher 1945 .024 1963 .014 1990 .012 1983 .012

[E] Outliers 2 3.0 SD above or -4.5 SD below mean for year

1924 +3.1 SD; 1931 +3.9 SD

==========

CC042B 1922 to 1997 76 years Series29

[B] Entire series, effect on correlation (.520) is:

Lower	1959	-.050	1941	-.030	1925	-.015	1995	-.015	Higher	1930	.080	1945	.027	1935	.013	1963	.013

[E] Outliers 1 3.0 SD above or -4.5 SD below mean for year

1959 +4.4 SD

==========

CC043A 1939 to 2001 63 years Series30

[B] Entire series, effect on correlation (.539) is:

Lower	1974	-.029	1962	-.026	1959	-.021	1952	-.016	Higher	1999	.024	1945	.022	1941	.019	1990	.017

[E] Outliers 1 3.0 SD above or -4.5 SD below mean for year

1960 +3.4 SD

==========

CC043B 1939 to 2000 62 years Series31

[B] Entire series, effect on correlation (.560) is:

Lower	1965	-.047	1962	-.036	1950	-.025	1948	-.018	Higher	1941	.040	1945	.025	1999	.024	1957	.016

[E] Outliers 1 3.0 SD above or -4.5 SD below mean for year

1965 -8.3 SD

==========

CC049A 1932 to 2001 70 years Series32

[B] Entire series, effect on correlation (.600) is:

Lower	1936	-.050	1979	-.019	1934	-.016	1933	-.014	Higher	1945	.018	1957	.014	1963	.013	1992	.012

==========

CC051B 1943 to 2001 59 years Series33

[B] Entire series, effect on correlation (.559) is:

Lower	1999	-.028	1986	-.019	1990	-.018	1985	-.015	Higher	1992	.026	1957	.021	1978	.018	1983	.016

[E] Outliers 1 3.0 SD above or -4.5 SD below mean for year
2000 +3.6 SD

==========

CC052A 1944 to 2001 58 years Series34

[B] Entire series, effect on correlation (.580) is:
Lower 1949 -.107 1992 -.027 1950 -.015 1983 -.011 Higher 1978 .022 1999 .021 1957 .017 1990 .017

[E] Outliers 1 3.0 SD above or -4.5 SD below mean for year
1953 +4.1 SD

==========

CC052B 1944 to 2001 58 years Series35

[B] Entire series, effect on correlation (.496) is:
Lower 1949 -.065 1999 -.047 1970 -.034 1991 -.024 Higher 1986 .022 1962 .019 1948 .018 1957 .016

[E] Outliers 2 3.0 SD above or -4.5 SD below mean for year
1948 +3.4 SD; 1965 +3.2 SD

==========

CC053B 1945 to 2001 57 years Series36

[B] Entire series, effect on correlation (.432) is:
Lower 1972 -.070 1959 -.045 1973 -.037 1999 -.020 Higher 1992 .033 1952 .024 1983 .022 1954 .021

[E] Outliers 2 3.0 SD above or -4.5 SD below mean for year
1972 -4.7 SD; 1973 -5.1 SD

==========

CC055B 1900 to 1975 76 years Series37

[B] Entire series, effect on correlation (.525) is:
Lower 1900 -.034 1962 -.031 1974 -.020 1959 -.017 Higher 1910 .061 1930 .032 1945 .024 1935 .013

[E] Outliers 1 3.0 SD above or -4.5 SD below mean for year
1900 +3.0 SD

==========

CC057A 1837 to 1982 146 years Series38

[*] Early part of series cannot be checked from 1837 to 1886 -- not matched by another series

[B] Entire series, effect on correlation (.463) is:
Lower 1974 -.039 1973 -.029 1910 -.024 1972 -.020 Higher 1945 .021 1897 .015 1914 .013 1941 .012

[E] Outliers 5 3.0 SD above or -4.5 SD below mean for year
1910 +3.1 SD; 1911 +3.8 SD; 1961 +3.3 SD; 1973 -4.5 SD; 1974 -5.2 SD

==========

CC059A 1933 to 2001 69 years Series39

[B] Entire series, effect on correlation (.348) is:
Lower 1998 -.057 1933 -.042 1934 -.030 1986 -.022 Higher 1941 .037 1957 .030 1945 .023 1975 .014

[E] Outliers 5 3.0 SD above or -4.5 SD below mean for year
1933 -4.5 SD; 1956 +3.0 SD; 1986 +3.1 SD; 1987 +3.3 SD; 1998 -6.2 SD

==========

CC062B 1900 to 2001 102 years Series40

[B] Entire series, effect on correlation (.534) is:
Lower 1962 -.025 1979 -.013 1959 -.013 1961 -.013 Higher 1910 .043 1930 .027 1945 .020 1935 .011

[E] Outliers 1 3.0 SD above or -4.5 SD below mean for year
1979 -5.5 SD

==========

CC064B 1926 to 1998 73 years Series41

[B] Entire series, effect on correlation (.526) is:
Lower 1941 -.031 1944 -.021 1934 -.019 1931 -.018 Higher 1930 .041 1992 .015 1945 .013 1957 .011

[E] Outliers 1 3.0 SD above or -4.5 SD below mean for year
1941 +3.4 SD

==========

CC068A 1938 to 2001 64 years Series42

[B] Entire series, effect on correlation (.473) is:
Lower 1941 -.056 1939 -.026 1946 -.019 1953 -.019 Higher 1999 .023 1957 .023 1945 .021 1963 .020

[E] Outliers 3 3.0 SD above or -4.5 SD below mean for year
1941 +4.6 SD; 1966 +3.8 SD; 1970 +3.3 SD

```
================================================================================================================================

 CC074A    1955 to  2001      47 years                                                                          Series43

 [B] Entire series, effect on correlation (  .496) is:
      Lower   1992  -.049   1971  -.029   1986  -.029   1999  -.023  Higher   1962   .043   1968   .019   1983   .019   1993 .017

 [E] Outliers     2   3.0 SD above or -4.5 SD below mean for year
      1960 +3.3 SD;    1971 -4.7 SD

================================================================================================================================

 CC075B    1950 to  2001      52 years                                                                          Series44

 [B] Entire series, effect on correlation (  .439) is:
      Lower   1977  -.050   1957  -.043   1963  -.038   1952  -.025  Higher   1993   .023   1985   .018   1954   .018   1999 .015

 [E] Outliers     3   3.0 SD above or -4.5 SD below mean for year
      1961 +3.1 SD;    1963 +3.0 SD;    1977 -4.8 SD

================================================================================================================================

 CO007A    1930 to  2001      72 years                                                                          Series45

 [B] Entire series, effect on correlation (  .443) is:
      Lower   1966  -.045   1963  -.033   1994  -.023   1962  -.022  Higher   1986   .020   1999   .020   1992   .015   1990 .015

 [E] Outliers     5   3.0 SD above or -4.5 SD below mean for year
      1931 +3.3 SD;    1943 +4.7 SD;    1963 +4.7 SD;    1965 +3.1 SD;    1994 +3.7 SD

================================================================================================================================

 CO008A    1920 to  2001      82 years                                                                          Series46

 [B] Entire series, effect on correlation (  .434) is:
      Lower   1920  -.065   1980  -.037   1983  -.018   1921  -.018  Higher   1930   .090   1941   .029   1957   .019   1992 .016

 [E] Outliers     4   3.0 SD above or -4.5 SD below mean for year
      1920 -5.7 SD;    1932 +3.5 SD;    1964 +3.5 SD;    2001 +3.1 SD

================================================================================================================================

 CO008B    1920 to  2001      82 years                                                                          Series47

 [B] Entire series, effect on correlation (  .505) is:
      Lower   1920  -.067   1921  -.021   1945  -.014   1968  -.013  Higher   1930   .043   1992   .015   1959   .014   1963 .012
```

[C] Year-to-year changes diverging by over 4.0 std deviations:
1920 1921 4.2 SD

[E] Outliers 2 3.0 SD above or -4.5 SD below mean for year
1920 -5.7 SD; 2001 +3.6 SD

==========

CO013A 1926 to 2001 76 years Series48

[B] Entire series, effect on correlation (.557) is:
Lower 1974 -.090 1944 -.026 1966 -.022 1969 -.013 Higher 1930 .074 1999 .019 1957 .013 1992 .013

[E] Outliers 2 3.0 SD above or -4.5 SD below mean for year
1970 +3.2 SD; 1974 -5.8 SD

==========

CO030A 1923 to 2001 79 years Series49

[B] Entire series, effect on correlation (.464) is:
Lower 1991 -.077 1981 -.054 1929 -.025 1986 -.011 Higher 1930 .026 1999 .020 1992 .017 1957 .013

[E] Outliers 1 3.0 SD above or -4.5 SD below mean for year
1991 -5.7 SD

==========

SM015A 1932 to 2001 70 years Series50

[B] Entire series, effect on correlation (.492) is:
Lower 1944 -.027 1934 -.026 1983 -.021 1954 -.014 Higher 1941 .046 1959 .017 1990 .015 1937 .013

[E] Outliers 1 3.0 SD above or -4.5 SD below mean for year
1941 -5.7 SD

==========

SM015B 1932 to 2001 70 years Series51

[B] Entire series, effect on correlation (.580) is:
Lower 1996 -.026 1999 -.020 1968 -.018 1980 -.017 Higher 1945 .020 1959 .013 1974 .013 1986 .013

[E] Outliers 2 3.0 SD above or -4.5 SD below mean for year
1952 -5.4 SD; 2000 +3.9 SD

SM053A 1933 to 2001 69 years Series52

[B] Entire series, effect on correlation (.593) is:
Lower 1971 -.025 1994 -.022 1954 -.018 1960 -.017 Higher 1941 .025 1959 .014 1935 .013 1974 .012

SM053B 1933 to 2001 69 years Series53

[B] Entire series, effect on correlation (.509) is:
Lower 1994 -.025 1978 -.024 1959 -.023 1935 -.020 Higher 1962 .027 1945 .026 1990 .015 1986 .012

[E] Outliers 1 3.0 SD above or -4.5 SD below mean for year
1994 -4.7 SD

TH001A 1898 to 2001 104 years Series54

[B] Entire series, effect on correlation (.538) is:
Lower 1956 -.039 1962 -.022 1898 -.019 1904 -.016 Higher 1910 .030 1930 .017 1945 .013 1941 .013

[E] Outliers 4 3.0 SD above or -4.5 SD below mean for year
1940 -4.7 SD; 1956 -5.4 SD; 1962 +3.9 SD; 1964 +3.9 SD

TH004A 1923 to 2000 78 years Series55

[B] Entire series, effect on correlation (.586) is:
Lower 1927 -.083 1964 -.030 1962 -.015 1926 -.013 Higher 1930 .038 1945 .020 1957 .012 1935 .011

[E] Outliers 2 3.0 SD above or -4.5 SD below mean for year
1927 -7.0 SD; 1964 +4.9 SD

TH005A 1916 to 2001 86 years Series56

[B] Entire series, effect on correlation (.591) is:
Lower 1921 -.037 1975 -.023 1996 -.018 1994 -.017 Higher 1945 .019 1999 .013 1974 .012 1957 .011

[E] Outliers 1 3.0 SD above or -4.5 SD below mean for year

1921 -4.9 SD

==========

TH005B 1916 to 1999 84 years Series57

[B] Entire series, effect on correlation (.528) is:
Lower 1921 -.057 1996 -.020 1984 -.017 1930 -.016 Higher 1945 .025 1974 .014 1957 .014 1916 .011

[E] Outliers 2 3.0 SD above or -4.5 SD below mean for year
1921 -7.4 SD; 1930 +3.0 SD

==========

TH008A 1921 to 2001 81 years Series58

[B] Entire series, effect on correlation (.626) is:
Lower 1921 -.030 1935 -.023 1959 -.015 1941 -.015 Higher 1930 .049 1945 .015 1962 .011 1986 .010

[E] Outliers 1 3.0 SD above or -4.5 SD below mean for year
1921 +3.0 SD

==========

TH008B 1921 to 2000 80 years Series59

[B] Entire series, effect on correlation (.595) is:
Lower 1921 -.044 1935 -.020 1941 -.019 1983 -.015 Higher 1930 .040 1962 .014 1992 .013 1957 .012

[E] Outliers 4 3.0 SD above or -4.5 SD below mean for year
1921 +4.0 SD; 1935 -5.1 SD; 1940 +3.3 SD; 1941 +3.7 SD

==========

TH010A 1919 to 2000 82 years Series60

[B] Entire series, effect on correlation (.607) is:
Lower 1921 -.058 1964 -.016 1970 -.013 1932 -.010 Higher 1930 .022 1957 .016 1974 .009 1986 .009

[E] Outliers 2 3.0 SD above or -4.5 SD below mean for year
1921 -6.5 SD; 1964 +3.5 SD

==========

TH038B 1920 to 2001 82 years Series61

[B] Entire series, effect on correlation (.581) is:

```
      Lower   1923  -.055   1969  -.017   2000  -.016   1936  -.016  Higher   1941   .021   1957   .013   1992   .012   1974 .011

[E] Outliers     2   3.0 SD above or -4.5 SD below mean for year
      1965 +3.3 SD;    1969 +3.5 SD

================================================================================================================================================

[*] All segments correlate highest as dated with correlation with master series over   .3281
```

Seq	Series	Interval	No. Years	No. Segmt	No. Flags	Corr with Master	Unfiltered Mean msmt	Unfiltered Max msmt	Unfiltered Std dev	Unfiltered Auto corr	Unfiltered Mean sens	Filtered Max value	Filtered Std dev	Filtered Auto corr	AR ()
1	BH054A	1936 2001	66	3	0	.537	1.35	2.90	.421	.551	.236	2.48	.435	-.086	1
2	BH054B	1936 2001	66	3	0	.484	.96	2.28	.405	.797	.229	2.72	.507	.030	1
3	BH070A	1936 2001	66	3	0	.579	.73	1.81	.390	.879	.239	2.60	.414	-.075	1
4	CC001A	1887 1970	84	3	0	.394	.84	2.11	.395	.650	.258	2.81	.570	-.069	1
5	CC003A	1925 2001	77	3	0	.678	2.77	5.17	.840	.509	.222	2.69	.575	-.036	1
6	CC003B	1929 2001	73	3	0	.688	1.87	3.02	.575	.597	.218	2.74	.564	-.069	1
7	CC004A	1945 2000	56	3	0	.432	1.15	2.05	.411	.718	.228	2.54	.495	-.016	1
8	CC004B	1945 2000	56	3	0	.475	1.56	3.25	.537	.717	.230	2.54	.591	.015	1
9	CC011B	1922 2000	79	4	0	.523	.73	1.58	.342	.718	.315	2.40	.357	-.006	1
10	CC012B	1937 2001	65	3	0	.514	.66	1.46	.409	.789	.359	3.07	.601	-.089	1
11	CC020B	1896 1992	97	4	0	.562	1.18	2.33	.470	.702	.240	2.56	.402	.006	4
12	CC021A	1944 2000	57	3	0	.695	.98	2.30	.619	.832	.289	2.70	.673	-.108	1
13	CC024A	1952 2000	49	1	0	.439	1.32	8.94	1.533	.679	.340	2.94	.612	-.021	1
14	CC029B	1946 2000	55	3	0	.437	1.46	3.02	.653	.795	.272	2.51	.482	-.010	1
15	CC031A	1942 2001	60	3	0	.611	1.25	3.98	.638	.660	.286	2.76	.501	-.060	1
16	CC031B	1942 2001	60	3	0	.595	1.57	3.55	.772	.575	.332	2.69	.553	-.034	1
17	CC033A	1936 2001	66	3	0	.534	1.27	3.51	.894	.881	.280	2.55	.495	-.146	2
18	CC035A	1940 2001	62	3	0	.567	.96	2.34	.456	.823	.236	2.57	.532	-.017	2
19	CC035B	1940 2001	62	3	0	.672	1.13	3.32	.681	.853	.200	2.56	.554	-.006	1
20	CC036B	1950 2001	52	2	0	.473	.78	1.37	.269	.485	.252	2.88	.683	.076	1
21	CC037A	1941 2001	61	3	0	.705	2.38	5.88	1.109	.616	.259	2.76	.510	-.072	2
22	CC037B	1941 2001	61	3	0	.707	1.63	3.45	.640	.492	.269	2.78	.507	-.071	2
23	CC038A	1949 2001	53	3	0	.495	3.04	5.90	1.083	.839	.151	2.59	.486	-.081	1
24	CC038B	1949 2001	53	3	0	.541	1.26	2.72	.604	.889	.195	2.65	.558	.050	1
25	CC040A	1930 2001	72	3	0	.532	1.79	3.55	.834	.855	.231	2.55	.571	-.004	1
26	CC040B	1930 2001	72	3	0	.507	1.53	3.04	.700	.846	.214	2.64	.477	-.032	1
27	CC041A	1919 2001	83	4	0	.527	1.96	5.69	1.088	.734	.270	2.88	.494	.008	1
28	CC042A	1922 2001	80	4	0	.521	1.27	3.61	.866	.885	.229	2.92	.634	.028	1
29	CC042B	1922 1997	76	3	0	.520	2.41	6.51	1.102	.801	.212	2.86	.533	.089	1
30	CC043A	1939 2001	63	3	0	.539	1.45	3.05	.653	.811	.228	2.41	.365	.015	1
31	CC043B	1939 2000	62	3	0	.560	3.02	6.53	1.082	.565	.264	2.66	.516	-.012	3
32	CC049A	1932 2001	70	3	0	.600	2.41	6.80	1.726	.885	.301	2.56	.418	-.068	3
33	CC051B	1943 2001	59	3	0	.559	1.36	4.19	.710	.740	.227	2.69	.549	-.103	1
34	CC052A	1944 2001	58	3	0	.580	1.61	3.84	.627	.675	.210	2.87	.500	-.028	2
35	CC052B	1944 2001	58	3	0	.496	.99	2.30	.354	.437	.266	2.96	.580	-.020	2
36	CC053B	1945 2001	57	3	0	.432	2.09	4.52	.949	.823	.212	2.88	.652	.089	2
37	CC055B	1900 1975	76	3	0	.525	1.62	3.46	.597	.722	.226	2.71	.465	.022	1
38	CC057A	1837 1982	146	4	0	.463	1.54	3.45	.800	.703	.317	2.47	.284	.018	1
39	CC059A	1933 2001	69	3	0	.348	.81	3.07	.475	.779	.219	2.62	.381	-.075	1
40	CC062B	1900 2001	102	4	0	.534	1.43	3.52	.631	.773	.236	2.77	.439	-.011	2

41	CC064B	1926	1998	73	2	0	.526	1.91	3.17	.603	.626	.229	2.63	.520	-.049	1
42	CC068A	1938	2001	64	3	0	.473	1.21	3.22	.819	.882	.323	2.88	.561	.011	2
43	CC074A	1955	2001	47	1	0	.496	.80	1.59	.342	.649	.325	2.58	.476	-.002	1
44	CC075B	1950	2001	52	2	0	.439	2.38	5.66	1.258	.866	.220	2.81	.591	.046	2
45	CO007A	1930	2001	72	3	0	.443	1.63	5.02	.966	.802	.271	3.06	.643	.021	1
46	CO008A	1920	2001	82	4	0	.434	1.60	3.94	.908	.837	.226	2.64	.511	-.070	1
47	CO008B	1920	2001	82	4	0	.505	1.31	2.95	.720	.800	.260	2.57	.481	-.036	3
48	CO013A	1926	2001	76	3	0	.557	1.16	2.98	.597	.702	.299	2.58	.521	-.035	1

Seq	Series	Interval	No. Years	No. Segmt	No. Flags	Corr with Master	Unfiltered Mean msmt	Unfiltered Max msmt	Unfiltered Std dev	Unfiltered Auto corr	Unfiltered Mean sens	Filtered Max value	Filtered Std dev	Filtered Auto corr	AR ()
49	CO030A	1923 2001	79	4	0	.464	1.38	3.94	.689	.754	.238	2.60	.501	.042	1
50	SM015A	1932 2001	70	3	0	.492	.85	3.17	.742	.930	.273	2.51	.412	-.042	1
51	SM015B	1932 2001	70	3	0	.580	1.30	3.49	.789	.842	.284	2.66	.498	.037	1
52	SM053A	1933 2001	69	3	0	.593	2.50	4.93	.930	.746	.228	2.65	.556	.058	1
53	SM053B	1933 2001	69	3	0	.509	2.03	3.49	.681	.674	.240	2.67	.497	.002	1
54	TH001A	1898 2001	104	5	0	.538	1.75	5.81	1.048	.772	.269	2.75	.469	.041	1
55	TH004A	1923 2000	78	4	0	.586	1.59	3.38	.616	.535	.299	2.72	.511	.008	1
56	TH005A	1916 2001	86	4	0	.591	1.26	4.56	.924	.845	.293	2.68	.448	-.035	1
57	TH005B	1916 1999	84	3	0	.528	1.20	4.59	.845	.856	.284	2.66	.390	-.036	1
58	TH008A	1921 2001	81	4	0	.626	1.63	3.48	.602	.580	.273	2.64	.524	-.057	1
59	TH008B	1921 2000	80	4	0	.595	1.09	2.93	.486	.737	.276	2.68	.529	-.041	1
60	TH010A	1919 2000	82	4	0	.607	1.60	4.02	.838	.754	.290	2.71	.417	-.030	1
61	TH038B	1920 2001	82	4	0	.581	.97	2.05	.400	.670	.271	2.69	.574	.013	1
Total or mean:			4321	193	0	.538	1.49	8.94	.725	.738	.258	3.07	.502	-.018	

Table A-3. Standard and Residual versions of the Table Mountain pine chronology developed in this study. Final output was produced using the program CRONOL.

Standard Chronology R

	Annual values									
Date	0	1	2	3	4	5	6	7	8	9
1837								657	522	710
1840	841	1231	1242	812	914	777	706	761	858	1359
1850	1316	1023	1603	1291	1602	1509	1179	1198	1059	902
1860	870	997	844	126	907	1007	1093	1570	1333	1029
1870	980	992	861	787	1235	941	626	1121	1581	170
1880	621	594	1306	698	835	1388	1541	977	1042	1181
1890	733	602	917	1274	1637	1285	1305	1540	837	1009
1900	939	1228	1061	1239	919	977	1195	970	955	825
1910	457	464	637	564	509	700	1116	966	1005	992
1920	1036	888	803	935	920	788	1004	1032	1016	1103
1930	676	1001	954	1227	986	1336	1041	1263	1317	1104
1940	1025	834	1054	1153	1009	1544	1229	1308	1421	1263
1950	986	999	903	1108	978	1125	1173	1389	1327	928
1960	865	988	770	687	720	767	848	887	731	710
1970	770	811	919	1015	1134	1065	795	821	627	614
1980	832	882	855	1128	1059	762	645	706	837	1212
1990	1478	1464	914	1233	1049	1093	1354	1367	1143	892
2000	1035	1144								

Residual Chronology R

	Annual values									
Date	0	1	2	3	4	5	6	7	8	9
1838									583	792
1840	885	1242	1182	759	938	785	740	807	892	1366
1850	1230	950	1573	1160	1522	1374	1068	1148	1009	880
1860	878	1008	835	160	1058	1011	1077	1528	1208	954
1870	962	983	853	804	1256	886	632	1175	1534	67
1880	769	659	1362	634	882	1398	1445	1133	1342	1238
1890	749	701	1069	1335	1565	1020	1215	1524	484	950
1900	801	1227	951	1064	804	981	1204	752	968	844
1910	552	905	977	848	742	1005	1262	905	1035	1113
1920	1175	820	919	1035	962	843	1125	1050	1025	1033
1930	623	1150	994	1280	827	1290	866	1205	1187	907
1940	948	834	1119	1051	891	1516	919	1111	1199	998
1950	824	969	899	1125	885	1111	1099	1290	1076	734
1960	902	1068	776	812	891	922	985	975	802	876
1970	949	939	1037	1061	1124	1006	769	935	752	820
1980	1047	984	928	1215	997	743	772	909	999	1282
1990	1339	1166	684	1278	915	1018	1264	1148	901	805
2000	1093	1029								

Table A-4. Final COFECHA output showing the correlation values for possible dating placements of the fire-scarred cross-sections used in this study.

Time span 1837 2001 165 years, best matches for 30-year segments lagged 15 years
Listed in order from highest correlation

Series	Counted Segment	Corr Add # 1	Corr Add # 2	Corr Add # 3	Corr Add # 4	Corr Add # 5	Corr Add # 6	Corr Add # 7	Corr Add # 8	Corr Add # 9	Corr Add #10	Corr Add #11
BH01	1 30	1956 .50	1892 .45	1840 .41	1946 .37	1907 .37	1855 .34	1905 .32	1843 .29	1841 .27	1888 .27	1875 .26
BH01	4 33	Lag from prior segment 3 years - insufficient										

Series	Counted Segment	Corr Add # 1	Corr Add # 2	Corr Add # 3	Corr Add # 4	Corr Add # 5	Corr Add # 6	Corr Add # 7	Corr Add # 8	Corr Add # 9	Corr Add #10	Corr Add #11
BH02	1 30	1943 .51	1837 .42	1838 .42	1890 .40	1902 .39	1871 .36	1942 .34	1959 .30	1922 .29	1855 .28	1854 .28
BH02	16 45	1898 .53	1943 .41	1838 .38	1837 .36	1879 .35	1831 .35	1956 .34	1868 .30	1927 .29	1944 .29	1921 .28
BH02	21 50	Lag from prior segment 5 years - insufficient										

Series	Counted Segment	Corr Add # 1	Corr Add # 2	Corr Add # 3	Corr Add # 4	Corr Add # 5	Corr Add # 6	Corr Add # 7	Corr Add # 8	Corr Add # 9	Corr Add #10	Corr Add #11
BH03	1 30	1850 .54	1838 .46	1885 .45	1897 .39	1866 .36	1887 .33	1951 .32	1937 .32	1878 .27	1917 .27	1938 .25
BH03	16 45	1838 .56	1885 .54	1854 .53	1953 .42	1905 .40	1865 .40	1884 .35	1937 .33	1925 .26	1939 .26	1873 .25
BH03	31 60	1808 .53	1891 .49	1937 .46	1824 .43	1930 .40	1842 .38	1931 .33	1855 .29	1913 .29	1923 .27	1904 .27
BH03	46 75	1808 .50	1886 .36	1891 .32	1914 .32	1921 .30	1850 .29	1873 .28	1815 .27	1843 .27	1842 .27	1824 .26
BH03	61 90	1847 .42	1857 .40	1852 .36	1779 .29	1901 .27	1903 .26	1820 .26	1908 .25	1841 .24	1811 .24	1795 .24
BH03	67 96	Lag from prior segment 6 years - insufficient										

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
+1937	3	.37																		

Series	Counted Segment	Corr Add # 1	Corr Add # 2	Corr Add # 3	Corr Add # 4	Corr Add # 5	Corr Add # 6	Corr Add # 7	Corr Add # 8	Corr Add # 9	Corr Add #10	Corr Add #11
BH04	1 30	1837 .53	1952 .40	1898 .39	1884 .34	1899 .33	1904 .31	1953 .31	1851 .30	1966 .29	1852 .29	1939 .29
BH04	16 45	1853 .57	1884 .53	1837 .52	1926 .36	1952 .35	1904 .34	1864 .33	1850 .32	1896 .32	1942 .28	1914 .27
BH04	31 60	1926 .48	1918 .41	1810 .40	1916 .39	1850 .37	1934 .37	1845 .36	1864 .32	1896 .31	1813 .29	1925 .28
BH04	46 75	1798 .46	1845 .44	1871 .34	1793 .33	1860 .32	1838 .32	1899 .32	1926 .31	1826 .30	1864 .30	1889 .28
BH04	61 90	1835 .47	1889 .38	1845 .35	1860 .35	1798 .33	1864 .33	1818 .32	1783 .32	1814 .30	1906 .29	1887 .26
BH04	67 96	Lag from prior segment 6 years - insufficient										

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
+1864	4	.32	+1845	3	.38	+1926	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
+1845 3	+1864 4	+1926 3										

Series	Counted Segment	Corr Add # 1	Corr Add # 2	Corr Add # 3	Corr Add # 4	Corr Add # 5	Corr Add # 6	Corr Add # 7	Corr Add # 8	Corr Add # 9	Corr Add #10	Corr Add #11
CC01	1 30	1950 .43	1926 .43	1875 .42	1937 .41	1867 .36	1850 .33	1847 .31	1866 .31	1848 .31	1886 .30	1916 .29
CC01	16 45	1831 .67	1936 .54	1882 .51	1898 .47	1953 .42	1848 .40	1847 .39	1872 .32	1909 .30	1868 .29	1937 .29
CC01	30 59	1815 .70	1831 .67	1882 .56	1937 .42	1930 .35	1902 .33	1931 .30	1813 .28	1852 .27	1898 .27	1938 .25

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
+1937	3 .38												

Series	Counted Segment	Corr Add # 1	Corr Add # 2	Corr Add # 3	Corr Add # 4	Corr Add # 5	Corr Add # 6	Corr Add # 7	Corr Add # 8	Corr Add # 9	Corr Add #10	Corr Add #11
SM01	1 30	1952 .48	1888 .42	1853 .38	1961 .38	1838 .36	1915 .35	1866 .34	1869 .34	1944 .32	1968 .28	1839 .27
SM01	13 42	1839 .49	1838 .47	1938 .46	1886 .46	1953 .43	1954 .42	1937 .36	1855 .34	1866 .32	1885 .29	1889 .27

Series	Counted Segment	Corr Add # 1	Corr Add # 2	Corr Add # 3	Corr Add # 4	Corr Add # 5	Corr Add # 6	Corr Add # 7	Corr Add # 8	Corr Add # 9	Corr Add #10	Corr Add #11
TH01	1 30	1906 .54	1839 .41	1922 .36	1954 .35	1855 .34	1902 .33	1944 .33	1960 .32	1851 .31	1957 .27	1893 .26
TH01	16 45	1906 .67	1876 .59	1829 .52	1916 .43	1835 .40	1845 .40	1896 .39	1855 .39	1928 .38	1944 .36	1951 .32
TH01	31 60	1906 .55	1864 .53	1845 .52	1829 .52	1876 .51	1896 .50	1817 .50	1916 .36	1856 .36	1854 .33	1884 .33
TH01	46 75	1817 .59	1833 .50	1906 .46	1922 .45	1854 .43	1905 .35	1908 .34	1867 .34	1844 .33	1884 .31	1923 .27
TH01	61 90	1840 .45	1859 .42	1786 .41	1869 .38	1806 .35	1877 .31	1853 .29	1847 .29	1809 .26	1828 .26	1782 .26
TH01	62 91	Lag from prior segment 1 years - insufficient										

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
+1906	4 .56												

Series	Counted Segment	Corr Add # 1	Corr Add # 2	Corr Add # 3	Corr Add # 4	Corr Add # 5	Corr Add # 6	Corr Add # 7	Corr Add # 8	Corr Add # 9	Corr Add #10	Corr Add #11
TH03	1 30	1844 .47	1871 .43	1943 .41	1864 .40	1843 .38	1933 .37	1890 .35	1967 .33	1862 .33	1850 .32	1951 .31
TH03	16 45	1898 .58	1943 .47	1843 .39	1844 .38	1871 .35	1921 .34	1879 .33	1944 .33	1864 .32	1872 .29	1949 .29
TH03	31 60	1898 .73	1908 .49	1837 .41	1868 .40	1809 .38	1876 .36	1887 .32	1909 .30	1849 .29	1896 .29	1825 .28
TH03	46 75	1898 .54	1844 .45	1809 .42	1846 .42	1909 .34	1794 .33	1797 .32	1807 .31	1896 .31	1890 .30	1792 .28
TH03	61 90	1898 .48	1783 .44	1861 .34	1841 .33	1882 .32	1830 .32	1799 .31	1850 .28	1870 .28	1820 .28	1811 .28
TH03	72 101	1767 .63	1783 .62	1882 .51	1898 .48	1834 .43	1845 .39	1866 .39	1856 .35	1883 .35	1896 .33	1795 .26

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
+1898	5 .56	+1896	3 .31	+1844	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
+1844 3	+1896 3	+1898 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
TH04	1	30	1903	.57	1852	.46	1957	.44	1925	.40	1858	.38	1965	.38	1941	.35	1841	.32	1958	.30	1914	.28	1971	.28
TH04	16	45	1888	.54	1821	.53	1950	.42	1858	.35	1868	.35	1892	.33	1837	.28	1841	.27	1894	.25	1936	.24	1956	.24
TH04	31	60	1837	.51	1821	.48	1868	.43	1862	.41	1888	.40	1917	.36	1814	.31	1934	.29	1815	.29	1914	.27	1892	.26
TH04	46	75	1810	.44	1881	.44	1891	.39	1831	.36	1914	.36	1830	.31	1861	.28	1892	.26	1915	.26	1840	.25	1814	.24
TH04	61	90	1803	.48	1891	.44	1837	.37	1841	.37	1792	.36	1890	.34	1789	.34	1892	.30	1811	.29	1908	.29	1856	.29
TH04	76	105	1837	.65	1803	.60	1775	.42	1875	.38	1833	.34	1874	.33	1795	.33	1807	.30	1811	.28	1822	.27	1826	.26
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
+1837 4	.46	+1892 4	.29	+1841 3	.32	+1914 3	.30						

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
+1837 4	+1841 3	+1892 4	+1914 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
TH05	1	30	1843	.66	1942	.38	1890	.37	1939	.35	1910	.33	1893	.33	1919	.32	1870	.30	1921	.29	1861	.29	1905	.28
TH05	16	45	1843	.55	1859	.54	1890	.53	1910	.51	1880	.43	1921	.41	1919	.31	1931	.30	1879	.29	1899	.28	1909	.27
TH05	24	53	1947	.54	1858	.51	1899	.50	1869	.47	1879	.38	1832	.38	1828	.34	1934	.32	1846	.29	1933	.28	1818	.27
TH06	1	30	1850	.61	1928	.42	1847	.42	1897	.41	1917	.39	1863	.37	1901	.34	1968	.33	1950	.30	1866	.29	1952	.29
TH06	16	45	1832	.56	1899	.53	1848	.48	1869	.41	1928	.35	1908	.35	1867	.34	1936	.32	1847	.29	1822	.29	1935	.29
TH06	31	60	1848	.60	1869	.52	1832	.48	1899	.46	1937	.43	1867	.41	1938	.39	1921	.38	1860	.30	1856	.30	1815	.30
TH06	32	61	Lag from prior segment 1 years - insufficient																					
TH09	1	30	1868	.56	1955	.46	1887	.42	1850	.42	1866	.38	1917	.38	1849	.37	1900	.30	1899	.29	1954	.26	1971	.26
TH09	16	45	1955	.49	1822	.40	1893	.36	1826	.35	1839	.33	1867	.33	1849	.29	1884	.29	1899	.28	1939	.28	1874	.27
TH09	24	53	1945	.46	1826	.46	1899	.44	1893	.41	1842	.39	1922	.37	1822	.36	1887	.33	1870	.32	1839	.30	1939	.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
+1899 3	.34												

VITA

Michael Armbrister was born in Radford, Virginia on September 20, 1977. He attended the public school system of Wise County, Virginia, including Coeburn Elementary and Coeburn Middle School. Michael graduated from Coeburn High School in 1995. He attended Emory & Henry College in Emory, Virginia, and graduated with a Bachelor of Arts Degree in Geography and a Bachelor of Science Degree in Environmental Studies in 1999. Michael enrolled at the University of Tennessee, Knoxville in August 1999. He graduated in May 2002 with a Master of Science Degree in Geography. His Master's thesis is entitled "Changes in Fire Regimes and the Successional Status of Table Mountain Pine (*Pinus pungens* Lamb.) in the Southern Appalachians."