Fire History of the Avon Park Air Force Range: Evidence from Tree-rings

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December 19, 2014

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Table of Contents

Introduction and Organization of Report

An understanding of past fire regimes is important to best manage the natural communities at Avon Park Air Force Range. The present biotic communities of the Range are the result of a long history of fires on the landscape. Changes in the fire regimes that shape these ecological communities may result in major changes in dominance of plants and animals, as well as species extirpation or extinction. Yet, characteristics of past fire regimes and how they may have changed over time in response to human populations and land uses has not been documented. This report presents the first direct evidence of past fire regimes for this region.

We reconstructed the history of past fires regimes from scars recorded in the cambium of trees. Fire history reconstructions from tree ring analysis have been completed for many regions in the world, but are very scarce in the Southeastern North American Coastal Plain and non-existent for peninsular Florida. Fire history reconstruction requires cross-sections of old trees. Hurricanes Jeanne and Charley which crossed the Avon Park Air Force Range in 2004 and felled many older trees on the Range, provided a rare opportunity to use these trees for fire history reconstruction.

This report is presented in two parts. The primary goal of this work was to determine the frequency and time of year of past fires at the Avon Park Air Force Range. Knowledge of the seasonality of cambial growth of the tree species being examined is necessary, however, to determine the time-of-year that fire scars formed within the tree ring and hence the intra-annual timing of the fire. Because there were no pre-existing data on the seasonality of growth of longleaf and slash pines of the Central Florida region, we needed to first conduct a study of seasonal cambial growth. This study is presented in Part 1. After we determined the seasonality of wood growth we then able to reconstruct fire history using cross-sections of trees that we collected from Avon Park Air Force Range. The fire history study is presented in Part 2. Summaries of Part 1 and Part 2 follow.

Summary

Part 1. Cambial growth phenology and intra-annual dating of fire scars in savanna pines at the Avon Park Air Force Range

Knowledge of the seasonality of cambial growth is necessary to characterize intra-annual timing of fire scars accurately. Because there were no prior studies, we conducted a field study of seasonal cambial growth of longleaf and south Florida slash pines in central Florida. Dendrometer bands are metal bands placed around the circumference of a tree that expand as the tree grows and are used to measure the cambial growth of trees. We installed dendrometer bands on 216 longleaf and slash pines, including a range of tree sizes and edaphic conditions, at the Avon Park Air Force Range (APAFR) in south-central Florida. We collected data on monthly growth from these trees for 27 months. We also took small wood core samples to determine the timing of the abrupt transition from light-colored, larger-celled earlywood growth to darker colored, small-celled latewood growth. We used these growth data to determine patterns of seasonal cambial growth, potential variation in cambial growth between different species, sizes and habitats of trees, and to develop a fire scar designation system appropriate for use in our study of fire history at APAFR.

Patterns of seasonal cambial growth. We determined when trees were growing or dormant, and when the transition from earlywood to latewood occurred during the growing season. We used monthly growth data to describe how patterns changed during the year, as well as relative to dry (October-May) and wet (June-September) seasons. Cambial growth almost completely ceased in January and February in the late dry season. In March there was an initiation of rapid earlywood growth. Earlywood growth continued in April during the late dry season, but this growth slowed somewhat in May, at the peak of the dry season. In June with the onset of the summer wet season most trees initiated latewood growth. Latewood growth peaked in July and continued strong through the summer but declined greatly in November and December as the fall/winter dry season progressed. We found that for most trees earlywood growth occurred for 3.5 months from March to June, during the late dry season to the start of the wet season, latewood growth occurred for 6.5 months from June through December, during the summer wet season and the early dry season, and dormancy occurred during 2 months of the dry season. These analyses allowed us to assign different positions within the growth ring to specific times of the year.

Variation in seasonal timing of cambial growth. We explored differences in the seasonal timing of cambial growth between longleaf pine and slash pine, between trees growing in different habitats, and between different sizes of trees. We further examined differences in the timing of cambial growth between years. We found that the initiation of earlywood growth, initiation of latewood growth and cessation of latewood growth were similar for longleaf and slash pines, trees in different habitats, and different size classes (with less precision for small trees). For the majority of trees, they were also nearly the same between years. The generally synchronous timing of cambial growth indicates that assignment of months to ring positions using all trees is applicable to longleaf and south Florida slash pines of different sizes growing in different habitats and is applicable across

years of varying rainfall and fire. These analyses strengthened the assignment of within year fire scars to specific times of the year.

Development of a fire scar position designation system for the APAFR tree sections. In fire history reconstructions, fire scars are placed into ring-position categories. A default standard system for describing the positions of fire scars in tree rings exists based on western pines, but this system is not very applicable to southeastern pines. To produce a relevant fire scar position designation system for APAFR, we first established the months that correspond to the basic different ring positions (i.e., earlywood, latewood and dormant) using the cambial growth data we collected. We then described the climatic variables most relevant to fire initiation and spread (e.g., rainfall and lightning) for the period of each intra-annual ring position. Next we determined the most ecologically appropriate ways to divide annual rings into categories. These analyses resulted in a new system for placing fire scars into ring position categories.

Our new system contains four ring positions. These include: 1) *Dormant (D),* for the position at the end of the previous year's latewood and initiation of the current year's earlywood, 2) *Early (E),* for the first half of the earlywood, 3) *Transition (T),* for the second half of the earlywood and the first half of the latewood, and 4) *Late (L),* for the last half of the latewood. Our designations correspond to seasonal changes in rainfall: Dormant, Early, and Late occur almost exclusively during the dry season, while Transition encompasses the very end of the dry season and the entire wet season. Since the wet season at APAFR corresponds to the summer thunderstorm season, these designations also correspond to difference in lightning frequency. This four ring-position system thus corresponds to the annual dry-wet seasonal period at the APAFR.

We used observed patterns of cambial growth to formulate the first intra-annual fire scar position system that can be used to determine accurately the seasonal timing of fire scars in longleaf and slash pines in subtropical central Florida. Our intra-annual fire scar position system replaces the standard system of tree ring positions which is commonly used for fire history research, but was developed for temperate, western trees. Unlike the standard system our ring position designations correspond with seasonal changes in climate that are relevant to fire ignition and spread. We examined a wide range and a large number of trees over more than 2 years; our results on the seasonal timing of cambial growth of longleaf and south Florida slash provide a strong basis for our intra-annual fire scar position designation system. We propose this system to be best suited, practically and ecologically, for accurate seasonal dating of fire scars in our fire history study of APAFR and is likely to also be applicable to longleaf and south Florida slash pines throughout Florida. This intra-annual fire scar position designation system is central to determining intra-annual timing of past fires for the fire history of APAFR.

In addition three additional topics are explored in the Part 1 Appendices: in 1.4 we present a preliminary investigation of false ring occurrences, in 1.5 we examine variation in the quantity of seasonal growth between species, habitat types and size classes of trees, and in 1.6 we explore the environmental influences on seasonal timing of cambial growth.

Part 2. Fire History of the Avon Park Air Force Range

Fire scars contained in the annual rings of trees provide direct evidence of historic fires. Knowledge of past fire regimes is relevant to current fire management and management of biological communities and species of concern. No tree-ring based investigations of fire history have previously been completed for APAFR or for peninsular Florida. We collected cross-sections from as much of the oldest deadwood we could find and used the fire scars we found to: 1. determine the frequency and season of past fire regimes; 2. to determine how frequency and seasonal timing of fires changed over time in relation to human settlement and land use in the region; and 3. to develop concepts regarding the ecology of fire in this landscape based on our understanding of past fire regimes and changes in fire regimes over time.

Fire scars and distribution of fire-scarred trees. Fire scars occur in living trees and in dead wood such as stumps and snags. Old wood, living or dead, however, is not abundant at APAFR. We collected cross-sections from longleaf and south Florida slash pines recently downed by hurricanes, older stumps, and snags. The old trees and stumps needed to reconstruct early fire history were concentrated in a few areas of APAFR, especially the Echo Springs/Echo Range area at the south end of the central Bombing ridge, and the north end of the Ridge in the North Fence area. Fire scars were present in recently dead trees, snags, and stumps that were collected. A total of 740 fire scars were found from 151 dead trees. Fire-scarred trees were found across APAFR, but were clustered mainly in five sites that became our fire history sites. Most old trees, stumps, and snags occurred within the five fire history sites (113 of 151 total fire-scarred trees).

Master tree-ring growth chronology. To date the fire scars it was essential to have a master growth chronology. We used the sections of trees that we collected to develop a site specific master tree-ring growth chronology for the APAFR, which was essential to date annual rings and fire scars precisely. The dated series from 106 longleaf and 6 slash pines from all sites and habitats produced a 250-year chronology (1756 to 2005). We also created site-specific and habitat-specific chronologies and found that overall (range-wide) climatic influences on the growth of trees were stronger than site-specific or habitat-specific influences. We produced a strong master site chronology for the APAFR which enabled accurate dating and was the foundation of all tree-ring dating for the fire history reconstruction.

Fire frequency. We examined the frequency of fire, or fire interval, both range-wide and for the five fire history sites using the composite fire scar record. ***Range-wide*** fires recorded by tree rings occurred frequently across the APAFR over the period of fire record (1784-2005). At least one fire was recorded in all but 35 of the 222 years of the fire scar record. The range-wide fire interval was slightly longer than one year. Fires likely have been almost annual occurrences on the Range during the entire period of fire record. At all of the ***Fire history sites*** short fire intervals, mostly 1-3 years, occurred over the period of fire record (1784-2005). The mean fire interval (MFI) ranged from 2.5 to 3.7 years (3 year mean for all sites), and the Weibull median interval (WMPI) ranged from 2.0 years to 2.9 years (2.5 year mean for all sites). Fire intervals of 1 to 3 years were the most frequent at all five fire history sites. The composite fire scar record is often used to examine changes in fire interval at fire history sites over time but because of the fading fire record before the 1880s (insufficient numbers of samples to capture the fires that occurred in the early part of our fire record), it is very unlikely that the composite fire-scar record reflects the true fire interval for the early part of the fire record.

To describe changes in fire interval over time we used an examination of short-interval fire scars (1-3 year) within individual trees. Range-wide we found the length of these fire return intervals changed over the 222 year period of study. Annual and biennial fire intervals were common in the early portion of the fire record, and 3-year intervals became common in recent decades. A high proportion of annual fire intervals occurred before the 1930s, but afterwards annual fire intervals (at a set point in the landscape) were never common. Changes in fire interval over time for most of the individual fire history sites were similar to the range-wide results: 3-year interval fires increased over time and 1- year interval fires decreased.

Fire season. We were able to determine the time of year for almost all fire scars based on their inter-annual ring position (93% or 669 of 719). Over the entire period of record most fires were recorded either during the winter *dormant* (46%) or late spring/ summer *transition* (42%) periods. Fires occurred infrequently during the early spring *early* (5%) or fall and early winter *late* (7%) periods.

There were ***range-wide*** changes in the proportion of dormant and fire season fire scars over time. Transition scars dominated the early portion of the fire record (1784-1919), constituting >50% of all scar positions prior to 1920. A switch in preponderance of scars from transition to dormant position occurred between the 1920s and 1930s. The proportion of dormant scars was high (mean 66%) from 1930s-1980s. Dormant scar frequency peaked in the 1980s with 82% of fire scars occurring in the dormant ring position and only 11% in the transition position. A decline in dormant scars occurred during the 1990s (42%). The smaller ***fire history sites*** also showed a shift from predominance of transition fires to predominance of dormant fires. Four of the five fire history sites show a pattern of more transition fires early in the record and more dormant fires late in the record, with more dormant fire scars after the 1930s. Both range-wide and in 4 of the 5 fire history sites there were mostly transition fires before 1930 and mostly dormant fires after 1930.

Synthesis of fire patterns with land-use history. Land use patterns at the APAFR have changed markedly over the period of record recorded in the tree rings of longleaf and slash pine and these changes have influenced fire regimes. We designated different periods of land use based on human settlement patterns, land use and major historical events. We separated the period of record for fire scars into two Eras: pre-extractive (1787-1919) and extractive (1920-2005). We divided the pre-extractive era into four periods (Indigenous Decline, Seminole era, Seminole Wars, and Homesteader/Open Range) and the extractive era into two periods (Extractive and Bombing Range).

The frequency of fire changed in the different land use eras. Fires were frequent throughout the entire pre-extractive era, both during the time when Seminoles were present and later when the open-range/ homesteaders were present. As indicated by analyses of fire scars recorded by individual trees/point in the landscape, fuels were sufficient for fires to occur every 1-2 years; these short interval fires were dominant during all three periods of the Pre-extractive Era even during periods when people were likely absent from the landscape. After the Pre-extractive Era there was a shift from mostly 1-2 year interval to mostly longer 3-year intervals fires. Changes in the human use of the land contributed to this shift to slightly longer interval fires. Differences in land use in different locations across the range also may have contributed to slight differences in the fire return intervals in the different fire history sites.

The time-of-year of fire also changed in relation to human land-use. During the Pre-extractive Era fires left scars within annual rings indicating that fires occurred primarily during the transition season. The presence of some dormant time-of-year fires in the Pre-Extractive Era indicates that humans were influencing fire regimes. Nonetheless, most fires occurred during the time when lightning-ignited fires would have spread across APAFR landscapes. Our results are different than what would be expected from historical descriptions of fires in Florida. People are reported to have burned throughout the year during the pre-extractive era. The fire scar record, a more objective record than human observations, clearly indicates that fires on the APAFR during the Pre-Extractive Era occurred mostly during the transition season.

A pivotal change in intra-annual timing of fires came during the Extractive Era with an increase in dormant fires. Fires during the transition season decreased to less than 40% and fires during the dormant increased to more than 20% in the Extractive Era. In the Bombing Range Period (1940-2005) fires were primarily dormant and human-ignited. These human-ignited fires peaked in the Early Bombing Range Period (1940-1989). During the late Bombing Range Period (1990-2005) transition season fires increased and dormant fires decreased with the reintroduction of prescribed lightning season fires after a long tradition of dormant prescribed fires during the Early Bombing Range period.

The change to slightly less frequent fires and more dormant time-of-year burning since the 1930s likely has affected the plants and animals that evolved with a fire regime of more frequent, lightning-season fires. The plant communities now at APAFR probably reflect effects of almost 100 years of altered fire frequency and season. The recent history of less frequent and more dormant fires likely has resulted in less fire in wetlands with resulting greater accumulations of organic soils and a shift in toward more woody species in wetlands, increased woody cover in upland habitats such as dry prairie, pine flatwoods and sandhill, declines in plants and animals that are very finely tuned to evolutionary fire regimes that are likely to be rare and declining when fire regimes change. Our findings suggest that a move to more frequent prescribed fires of 1 and 2 year intervals, and more prescribed fire in the transition season would be most similar to natural fire regimes and most likely to benefit the native plant and animals of APAFR. This fire history study provides scientific data (on frequency and time of year of fires) that can be used to help guide ecologically-based fire management of APAFR and other fire-frequented habitats.

Part 1. Cambial growth phenology and intra-annual dating of fire scars in savanna pines at the Avon Park Air Force Range

Introduction

Fire histories based in annual rings produced by trees can help provide a scientific basis for the restoration and management of pine savannas. Fire history studies have only recently been conducted using longleaf pine (*Pinus palustris*) and slash pines (*Pinus elliottii*) in the Southeastern Coastal Plain. These studies have indicated short fire return intervals and have also examined the seasonality of fire (Huffman et al. 2004, Huffman 2006, Henderson 2006, Stambaugh et al. 2011).

The seasonal timing of past fires can be estimated quite accurately to the month based on the positions of the fire scars within the annual growth rings. Patterns of wood growth (cambial phenology) of living pines can be used to determine when early- and late-wood growth occurs, as well as when the dormant season begins and ends during a yearly growth cycle. The seasonal timing of fire scars in other trees can then be estimated using known seasonal patterns of growth. To examine seasonality of past fires, fire scars are placed into ring-position categories.

A standard system for classifying fire scar positions within growth rings has been used extensively in fire history studies. Developed for tree species and sites that have a short growing season with an abundance of earlywood and a long dormant season, this standard system designates five ring positions: *dormant* (no wood deposition), three positions within the earlywood (*early* for the first one-third, *middle* for the middle one-third, and *late* for the last one-third of the earlywood), and one position for *latewood* (Baisan and Swetnam 1990, Grissino-Mayer 2001). This system has been used extensively for determining seasonality in fire history studies and is the standard in the FHX fire history analysis software (Grissino-Mayer 2001). It has also been used in two of the three fire history studies of longleaf pine in the southeastern coastal plain (Henderson 2006, Stambaugh et al. 2011).

This standard system for describing the positions of fire scars in tree rings does not provide adequate resolution for delineation of the fire history based on annual rings of southeastern pines. These pines have a much longer growing season (e.g., 10 months in Florida, Langdon 1963, Harley et al. 2012) and produce larger amounts of latewood than the temperate species used to develop the standard system. For pines in Florida, the three categories of ring position designations for earlywood in the standard system are likely to encompass a much shorter period of growth than the one category that applies to the latewood growth. There is a need for a system of ring position designations for longleaf and slash pines in Florida that has relevant seasonal resolution and that reflects ecologically relevant categories.

To produce a relevant fire scar position system it is necessary to understand and quantify seasonal wood formation in longleaf and south Florida slash pines. Studies of seasonal wood formation are generally lacking for longleaf pine in Southeastern North America and are needed (Stambaugh et al. 2011). One previous study was found for longleaf pine. This preliminary investigation of seasonal growth of 8 longleaf pines in the western panhandle of Florida in 1927 and 1928 found that earlywood growth began around March 1st, latewood growth began in May or June and did not specify when growth ceased and dormancy began (Paul and Marts 1931). For south Florida slash pines (*P. elliottii* var. *densa)*, there have been two previous investigations that examined patterns of wood growth. Both of these studies occurred in south Florida; Langdon 1963, near Naples FL and Harley et al. 2012 in the Florida Keys. Harley et al. (2012) examined 6 mature trees, of about 35 cm dbh, in pine rockland for one year and found a period of dormancy from December through January, earlywood formation from February-June or July, and latewood formation from June or July-December. Langdon (1963) examined growth in10 young trees (average 15 years of age) in mesic flatwoods over 4 years and found a period of very little growth (3% of yearly growth) in December and January, and active wood growth from February through November.

A fire scar position system should encompass any differences in timing of cambial growth that may occur between trees. No previous studies, however, have investigated potential differences in timing of seasonal growth between longleaf and slash pines, among different sizes of these trees, or among trees growing in different habitats.

A fire scar position system should also encompass inter-annual variation in timing of seasonal cambial growth among trees. Quantity of growth in longleaf and south Florida slash pine is strongly influenced by precipitation (Larson et al. 2001, Ford and Brooks 2003, Henderson 2006, Henderson and Grissino-Mayer 2009), how varying amounts of precipitation might influence timing of cambial growth is not known. Fire is another potential influence on the timing of seasonal growth of longleaf and south Florida slash pines between years. Fire is an integral part of the ecology of these pines and of this central Florida region. How fire may influence the timing of cambial growth of longleaf and slash pines, however, is unknown.

Seasonal patterns of cambial growth of southern pines need to be studied on a range of sites to develop better categories related to seasonal wood deposition and fire scar positions in annual rings. Studies of cambial growth patterns in longleaf pine and south Florida slash pine in central Florida would be useful in understanding the seasonal initiation and cessation of growth, as well as variation in the timing of early and latewood growth of pines in this region. Measurements of these patterns should be useful in accurately estimating the seasonal timing of fires indicated by positions of fire scars within annual growth rings of pines. In addition a new system of standard fire scar positions should be developed based on these seasonal growth patterns.

We studied intra-annual wood deposition in annual rings from longleaf and slash pines, including a range of tree sizes and edaphic conditions, at the Avon Park Air Force Range (APAFR) in south-central Florida. We collected monthly growth from dendrometer bands and we took small wood core samples to determine the timing of transition from early to late wood deposition. We used these data first to compile seasonal phenology of stem wood growth and determine the months that correspond to intra-annual ring positions (earlywood, transition from earlywood to latewood, latewood, and dormant season). Second, we examined effects of environmental condition (habitat), as well as species and sizes of pines on the seasonal timing of cambial growth. Third, we examined intra-annual variation in timing of growth. Fourth, we described the climatic variables most relevant to fire initiation and spread (e.g., rainfall and lightning) for each intra-annual ring position. Finally, we developed a new system of within-ring position designations that we propose to be best suited, practically and ecologically, for accurate seasonal dating of fire scars in our fire history study of APAFR. This system for seasonal dating might be applicable to other fire history studies of longleaf and slash pines in the subtropical regions of the southeastern coastal plain.

Methods

Study site

Location. Study sites were located within the Avon Park Air Force Range (APAFR) along the central Florida ridge in the interior of the Florida peninsula. All sites were within the Highlands County portion of APAFR. The region containing the sites occurs at the southernmost extent of the range of longleaf pine and near the southernmost extent of the range of slash pine (Figure 1). In central and south Florida the south Florida slash pine (*Pinus elliottii* var. *densa*) replaces longleaf as the dominant pine. The ranges of longleaf pine and south Florida slash pine overlap in a small zone along the southern extent of the longleaf pine range which includes our study sites.

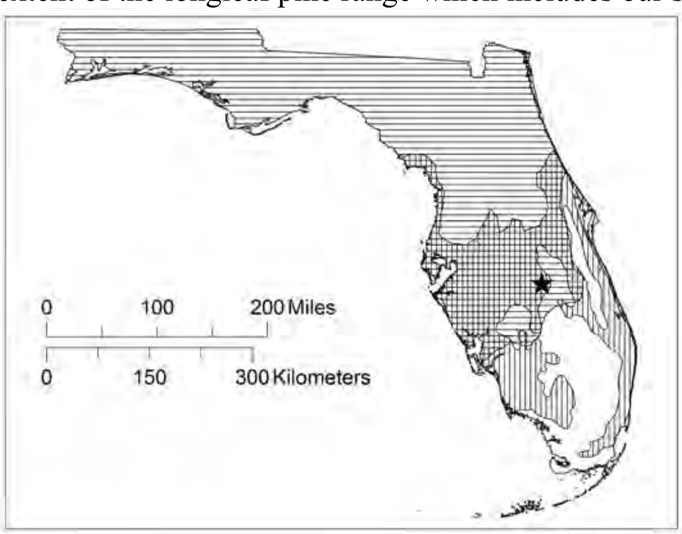


Figure 1. Location of the Avon Park Air Force Range (star) in Florida. The distribution of *Pinus palustris* (horizontal lines) and south Florida slash pine (vertical lines) overlap in the study region. Data on longleaf distribution taken from U.S. Geological Survey 1999 website of Little (1978) and south Florida slash pine from Hall and Braham (1998).

Site selection. To study seasonal cambial growth dynamics we selected sites that contained a range of sizes of longleaf and south Florida slash pines in dry, mesic and wet habitat types located along the southern part of the Bombing Range Ridge. We selected two replicate areas 1.5 to 2 ¼ miles (2.5-3.6 km) apart that contained the three different habitat types resulting in a total of 6 study sites (Figure 2). ***Dry sites*** were scrubby flatwoods and sandhills on sandy, well-drained soils with no saturated soils or above ground water throughout the year (Bridges 2000). These highest elevation sites currently have longleaf and slash pines, but historically were dominated by longleaf pines (Bridges 2006). Associated groundcover vegetation included wiregrass (*Aristida beyrichiana)*, shrubby xeric oak species, and associated herbaceous species with open, sandy patches (Orzell and Bridges 2006a). ***Mesic sites*** were seeps (Orzell and Bridges 1999, 2006a). These seeps occur on the landscape along slopes where groundwater seeps to the surface as it drains through the soil from well-drained uplands; soils are saturated, but without standing water during the wet season (Bridges 2000, Orzell and Bridges 2006b). Fire suppression and recruitment of trees and woody shrubs have reduced soil saturation in seeps as a result of transpiration. The most abundant groundcover species, cutthroat grass (*Panicum abscissum*), is a central peninsular Florida endemic species that occurs along slopes of central Florida Ridges (Orzell and Bridges 1999, 2006 a, b). ***Wet sites*** were hydric flatwoods that occur on soils that are not well drained and therefore have long hydroperiods, with water at or above the surface during the wet season and extending into the onset of the dry season. Hydric flatwoods can occur along lower slopes in low elevation sites that are dependent on landscape position, hydrological conditions and soils (Bridges 2000, 2006). Abundant species, in addition to pines, include wiregrass, cutthroat grass, and shrubs.

We grouped replicate areas in burn management zones so that each replicate set would burn at the same time and the two replicates would burn in different years. Because most areas in APAFR burn at least every 3 years, sites were selected so that one replicate was planned to be burned in 2006 and the other in 2007. For map of burns see Appendix 1.1.

Within each of the six sites, we selected 18 longleaf and 18 south Florida slash pines of a range of diameter classes within as small an area as possible (Map in Appendix 1.2). We stratified by tree size, selecting six of three different size classes (small, 5-20cm dbh, medium, 20.1-30 cm dbh, and large, >30 cm dbh). This resulted in a total of 216 trees that were used for cambial growth monitoring (for experimental design see Appendix 1.3 table). Whenever possible we selected trees that were in open or canopy-dominant positions to reduce effects of intraspecific competition on seasonal growth. After trees were selected we assigned a unique number and recorded species, initial dbh, and canopy position.

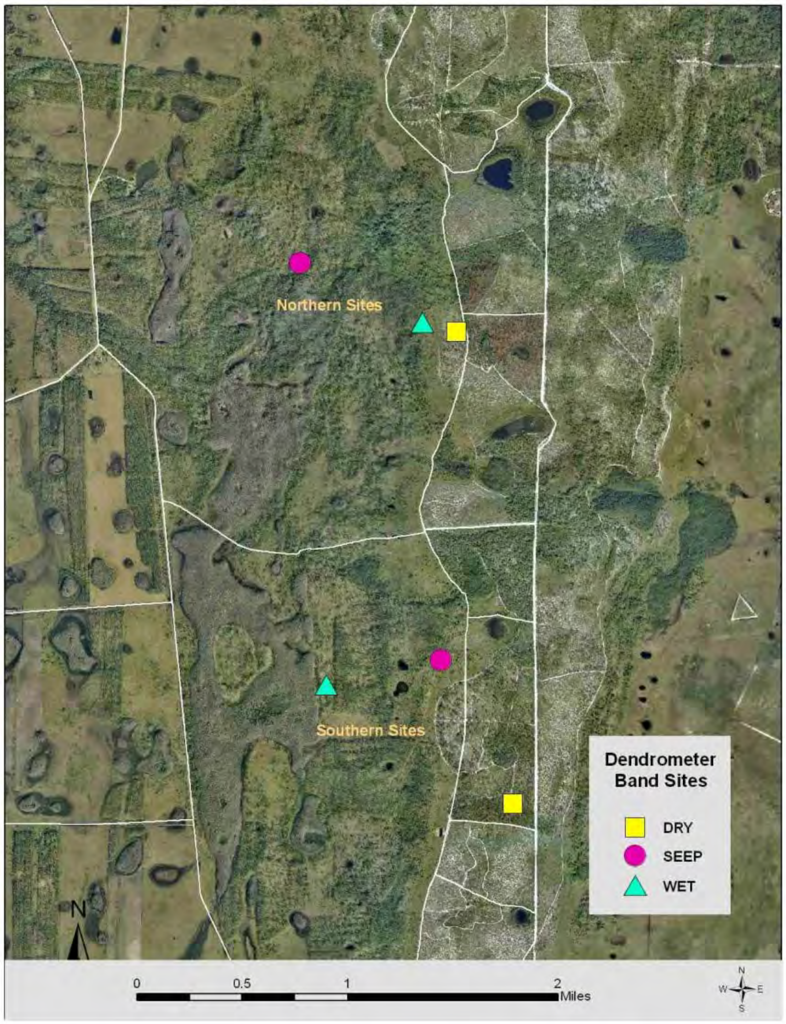


Figure 2. Location of study sites within the Avon Park Air Force Range. Replicates of dry (square), seep (circle), and wet (triangle) study sites were separated by approximate 2km.

Climate and Weather. Weather data were obtained from the meteorological station Avon Park 2W. This station, located near the study sites, has a period of record from 1879 to 2010. Monthly high temperature averages 28.8ºC (83.9ºF) annually and peaks in July and August at 33.3ºC (92ºF). Mean coldest temperatures average16.7ºC (62ºF) mean annually, and the coldest months are January and February, 10ºC (50ºF) and 10.6ºC (51ºF), respectively. Mean total annual precipitation recorded at Avon Park 2W is 132.94 cm (52.34 in).

The historic climate in central Florida has been highly seasonal. Long-term averages depicted in Figure 3 indicate a pronounced wet season that typically is initiated in May/June and extends through September, and a longer dry season typically extends from October/November through April. Rainfall in the dry season has been influenced by

ENSO (Slocum et al. 2010a). Transitions typically occur in May (dry to wet) and October (wet to dry). Thunderstorms that produce lightning are frequent from May to August, but are rare during the transition from wet to dry season and thereafter (Figure 3) (Platt et al. 2006, Slocum et al. 2010a).

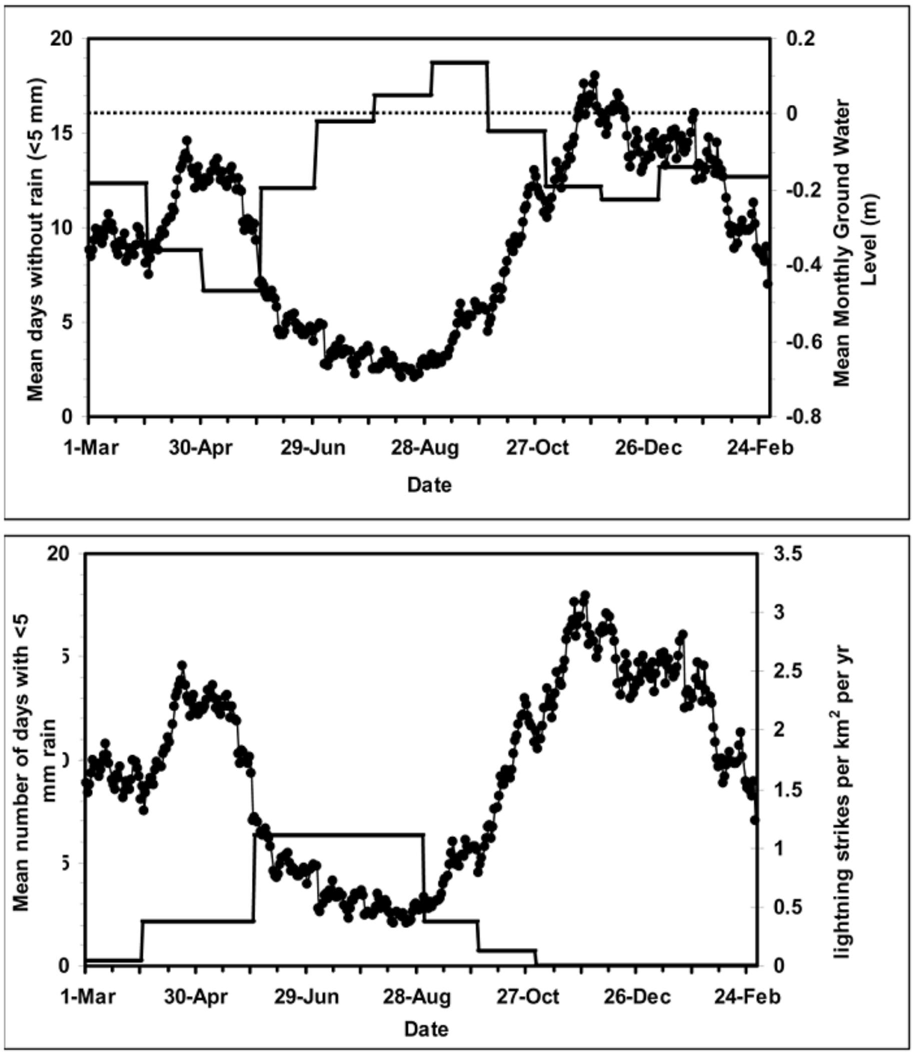


Figure 3. Climatic conditions of the Avon Park Air Force Range, Florida. Black circles in both graphs: mean number of successive days with <5mm rainfall recorded at Avon Park, FL for each day of the year during the period from 1944-1997. Upper: The histogram is the mean monthly ground water level at Tick Island (1974-2004), located in the pine flatwoods/dry prairie matrix of the eastern section of the Avon Park Air Force Range (Polk County, FL). Dotted line indicates ground surface. Lower: The histogram is the mean number of cloud-ground lightning strikes per km^2 from 1944-1997. Figure modified from Platt et al. (2006).

Annual precipitation varied among the three years of the study (2006 - 2008). Differences in monthly rainfall for the study period are presented in Figure 4. Total rainfall in 2006 and 2007 was below average. 2006 was a dry year with 79 cm. of rainfall, 62% of the annual mean of 128.1 cm. 2007 also had below average rainfall, with 95 cm which is 74% of average. 2008 was an average rainfall year with 129 cm of rainfall and near average rainfall for all months except May (Figure 4). Thus rainfall during the period of study resembled the overall long-term average more toward the end of the study, in 2007-2008 than in 2006 (Figure 4).

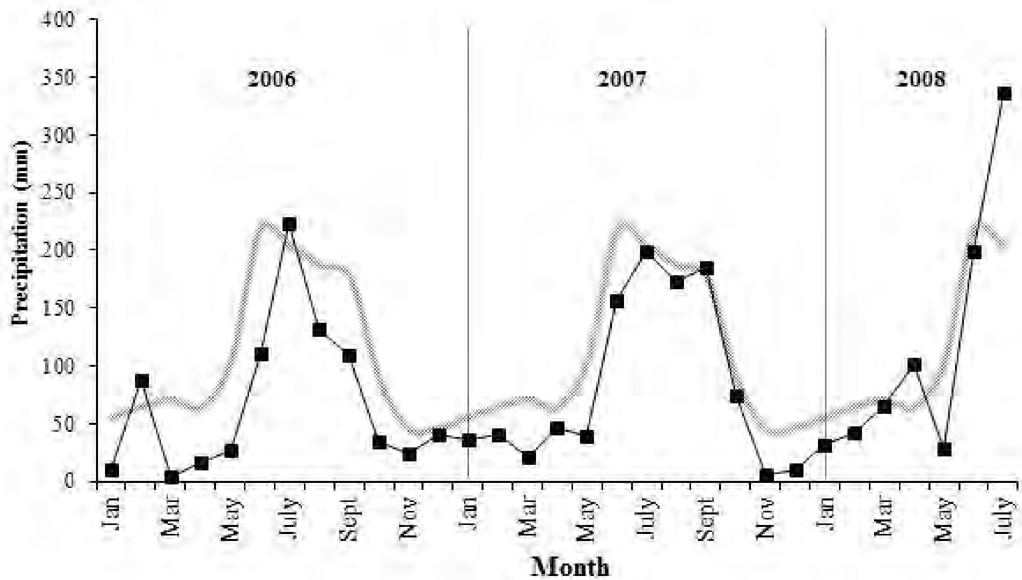


Figure 4. Monthly precipitation during the years of study (squares) compared to long-term averages (grey line) from 1892-2010. Data are from meteorological station Avon Park 2W.

Precipitation during the end of the dry season was lower than the long-term average for all three years of the study (2006 - 2008). The months of March, April and May occur at the end of the dry season and may influence seasonal cambial growth. Rainfall during this early spring period varied greatly between sampling years (Figure 5). The initial spring, 2006, was very dry; total rainfall March-May (4.7 cm) was only 20% of the mean rainfall for these months for the period of record (23 cm). Spring 2007 was also very dry with less than half (45%) of mean rainfall. Spring 2008 was only slightly below mean with 82% of mean rainfall (Figure 5). The onset of the wet season occurred on June 7th in 2006, May 31st in 2007 and May 31st in 2008 (M. Slocum pers. com.).

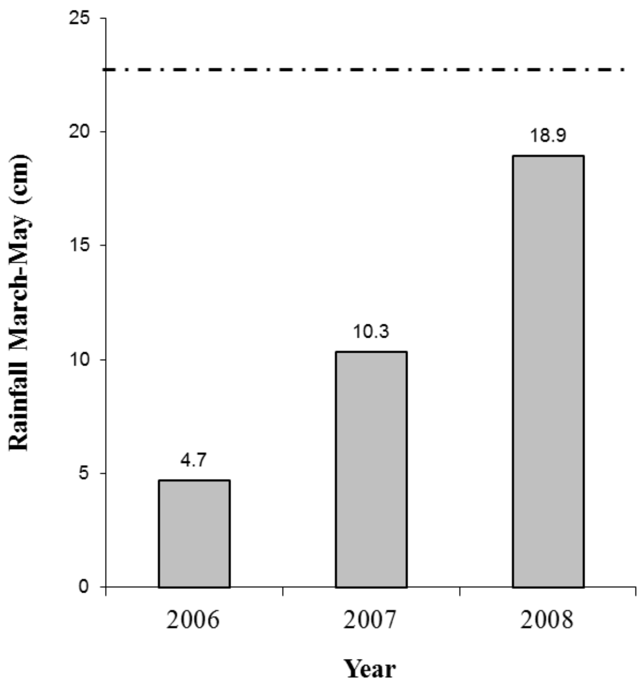


Figure 5. Rainfall during March, April and May varied among sampling years. 2006 was very dry; rainfall for this period was only 20 percent of the mean rainfall for these months for the period of record (23 cm indicated by dotted line). 2007 had more rainfall but was still well below the mean with less than half (45 percent) of mean rainfall. 2008 was only slightly below mean with 82 percent of mean rainfall.

Field sampling

Measuring cambial growth. To measure monthly cambial growth, we installed dendrometer bands on 216 study trees in October 2005. We adopted the dendrometer band design used by Keeland and Young (2007). First, we scraped away loose bark and measured the starting circumference of the tree. To construct the dendrometer band, a stainless steel band was placed around the trunk of the tree at breast height (Figure 6). The band is then looped back upon itself and inserted through a collar. A spring is inserted in the band that allows the band to move through the collar as the tree expands in circumference. A vertical scratch is made at the edge of the collar when the band is installed and as the tree expands the scratch moves away from the collar. To allow time for the tree to grow and take up any slack in the bands we began measurements after two months, in December. Dendrometer bands were checked from December 2005-April 2006; reliable, consistent, monthly tree growth readings for all trees did not begin, however, until May 2006. As a result, we used monthly readings over a 27-month period, May 2006 through July 2008 for analysis. The only missing data during this period of time occurred in October 2007, when access restrictions from military missions made it impossible to measure the trees.

Figure 6. Dendrometer band installed on pine.

We were consistent with field measurements. Growth readings from dendrometer bands were taken between the 24th through 30th of the month, with three exceptions resulting from access restrictions due to military activities. At each sampling, dendrometer bands on all trees were read over a one or two day period, such that there were on average 30 days between readings. The actual number of trees sampled at any site varied slightly month by month. Dendrometer bands sometimes malfunctioned and needed to be replaced, especially after fires, which often heated and destroyed the dendrometer band springs. Also, lightning killed six trees over the course of the study, and three trees died of other causes (Table 1). These sample trees were not replaced.

Table 1. Date and apparent cause of death for monitored trees that died during the course of the study. LLP=Longleaf Pine, SFS=South Florida Slash Pine.

Tree ID	Cause of Death	Species	Habitat	Initial dbh cm	Month/Year of Death
1-11	Lightning	SFS	Wet	24.5	July 2007
1-59	Lightning	LLP	Seep	41.2	July 2007
1-70	Lightning	LLP	Seep	37.2	July 2007
1-74	Lightning	SFS	Dry	37	June 2008
2-31	Lightning	SFS	Seep	16.4	July 2007
2-88	Lightning	LLP	Dry	15.8	May 2008
1-38	Unknown	SFS	Seep	34.9	Nov. 2006
2-31	Unknown	SFS	Seep	16.4	April 2007
2-43	Post Fire	LLP	Wet	22.3	May 2006

Growth readings were measured with calipers accurate to 0.1 millimeters. Accuracy of reading was estimated to be within 0.2mm. Measureable growth was defined as anything greater than 0.2 mm in circumference during any monthly reading period. This measurement margin of error was used to compensate for any increase or decrease in circumference that could have resulted from reader error or from swelling and shrinkage of bark when it is wet or dry.

Extracting wood samples. To determine seasonal initiation of latewood formation we collected short core samples (corelets) from 12 trees from each of our six dendroband sites. At each of our 6 study sites we sampled 6 longleaf pines and six slash pines, 2 from each size class. Size classes were: small (6-20 cm dbh) medium (20.1-30 cm dbh), and large ($\geq$ 30 cm dbh). Using an increment hammer, we collected corelets approximately 0.8m to 1.2m high on the trunk of these 72 trees during the late spring/early summer period when the transition from early to latewood occurs. Care was taken to take each sample more than 20cm away from any prior samples. During 2006 corelets were taken twice a month, starting in early May until late June, and then monthly until most trees were producing latewood. In 2007 and 2008 corelets were taken in late May, June, and July, and a partial set was taken in late April in 2008 (Table 2). In each year, individual trees were sampled until the first of latewood was produced. Corelets were directly glued onto core mounts with tracheids aligned vertically and taped in place; they were dried and then sanded with successively finer grits of sandpaper to 400 or 1200 grit. Sanded corelets were examined under a microscope to determine visually when the denser latewood cell development began.

Table 2. Dates of corelet sampling.

	Late April	Early May	Late May	Early June	Late June	Late July	Late August	Late September
2006		5/8/2006	5/20/2006	6/05/06	6/27/2006	7/27/06	8/29&29/06	9/25/006
2007			5/24-25/07		6/25&26/07	7/26/07		
2008	4/28/2008		5/27/2008		6/26/2008	7/26/2008		

Analysis

We examined monthly growth of all trees to determine timing and distribution of cambial growth throughout the year. We graphed mean growth in circumference for each month, as well as the proportion of total annual growth that occurred each month. The unknown portion for October 2007 was estimated using the monthly proportion of growth from known years. We graphed proportion of trees that were dormant in each month. We used three different measures, all of which had to be satisfied, to assign a month to the dormant category: 1) mean monthly growth in circumference was $\leq$ 0.4 mm; 2) the proportion of annual growth that occurred that month was $\leq$ 0.03; and 3) the proportion of trees with no measureable growth for that month was $\geq$ 50%. We used the percentage of trees that produced latewood in each sampling period to determine timing of the transition from earlywood to latewood. We then used the dormancy and earlywood-to-latewood transition dates we found to assign calendar months to different intra-annual ring positions (including earlywood, earlywood/latewood transition, latewood, and dormant positions).

We also explored whether there were differences in timing of cambial growth between species, trees growing in different habitat types, and sizes of trees by graphing mean monthly growth and monthly proportion of dormant trees. Because we were not able to get readings of tree growth in October of 2007 we estimated the October/November proportion of growth by dividing the November growth total proportionately based on proportions of October/November growth in 2006. It was not possible to determine proportions of dormant trees for October and November of 2007 based on November readings. We also explored differences in growth between years by graphing and comparing monthly proportion of dormant trees and growth between years.

We then used the final dormancy and earlywood-to-latewood transition dates we found to assign calendar months to different intra-annual ring positions (including earlywood, earlywood/latewood transition, latewood, and dormant positions). Using climate data from previous studies (Slocum et al. 2010a&b, Platt et al. 2006) we described seasonal differences in lightning and rainfall that correspond to these designated ring positions.

Finally, using the calendar months of different intra-annual ring positions and climate data we developed a system of fire scar position designations (early, transition, late, dormant) that is ecologically relevant for use in determining the seasonality of fire scars for the fire history study of sites at APAFR.

Results

Seasonal cambial growth (all trees)

Using our data on all trees, we describe the monthly timing of cambial growth and observe when the majority of all trees were dormant, initiated earlywood growth and initiated latewood growth.

The quantity of cambial growth varied monthly and between years. Mean monthly growth (mm circumference) for all trees varied from a low of 0.15 mm in January 2008 to a high of 2.53 mm in July 2008 (Figure 7). The amount of annual growth varied widely from year to year, with much slower annual growth occurring in 2006 than in 2007 and 2008 (Figure 7.). However, the monthly proportionate distribution of growth was similar in each year (Figure 8). Monthly proportions of total mean annual growth varied from 0.01 (January) to 0.16 (July) (Figure 8).

Rates of cambial growth varied through the year. Cambial growth was initiated in March. In March and April, 24% (2007) to 30% (2008) of total mean annual growth occurred (Figure 8). Growth then slowed in May, at the end of the dry season, to only 3-8%. Higher growth rates resumed in June, at the onset of the wet season, and continued through October, with monthly proportions ranging from 8-16% of total mean annual growth. June through October growth totaled 58% of annual growth in 2006, and 57% in 2007. In November and December, as the fall/winter dry season progressed, monthly growth slowed to only 3-5% of annual growth. Growth almost completely ceased in January and February, with monthly growth of only 1-2% of total annual growth (Figure 8).

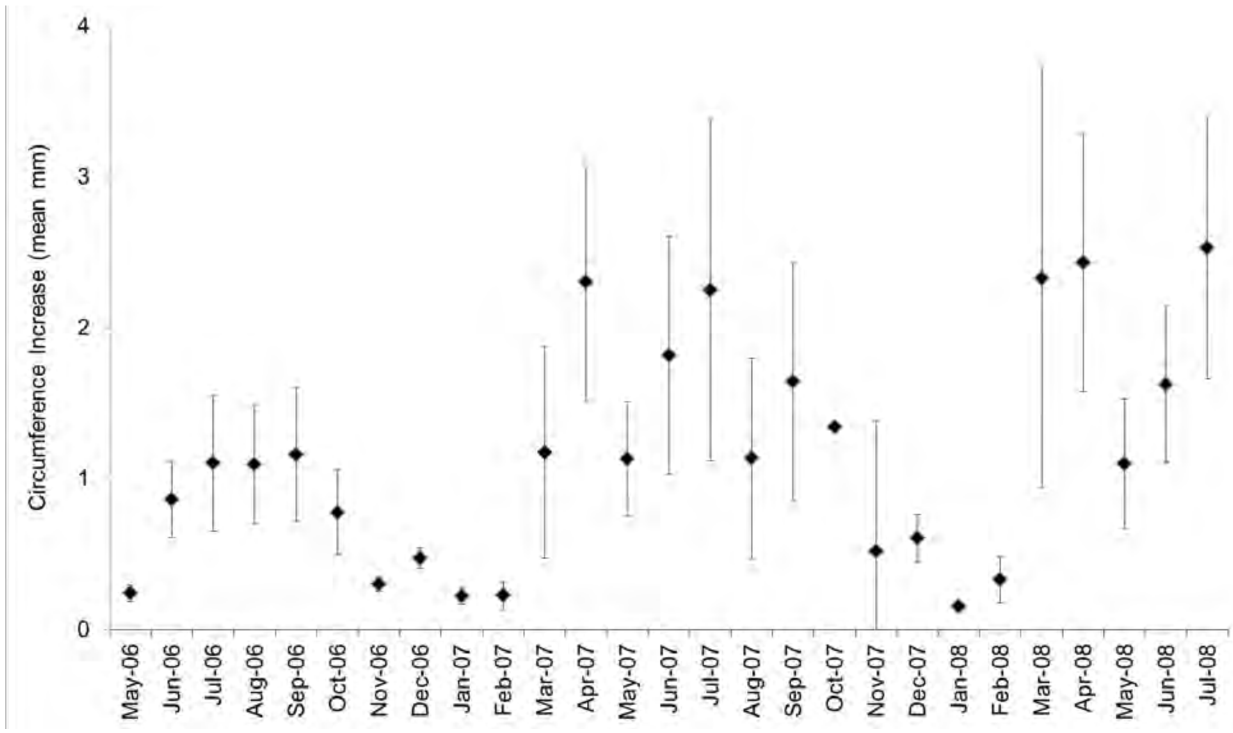


Figure 7. Monthly mean increase in circumference (mm) among all trees for period of study – bars represent variance.

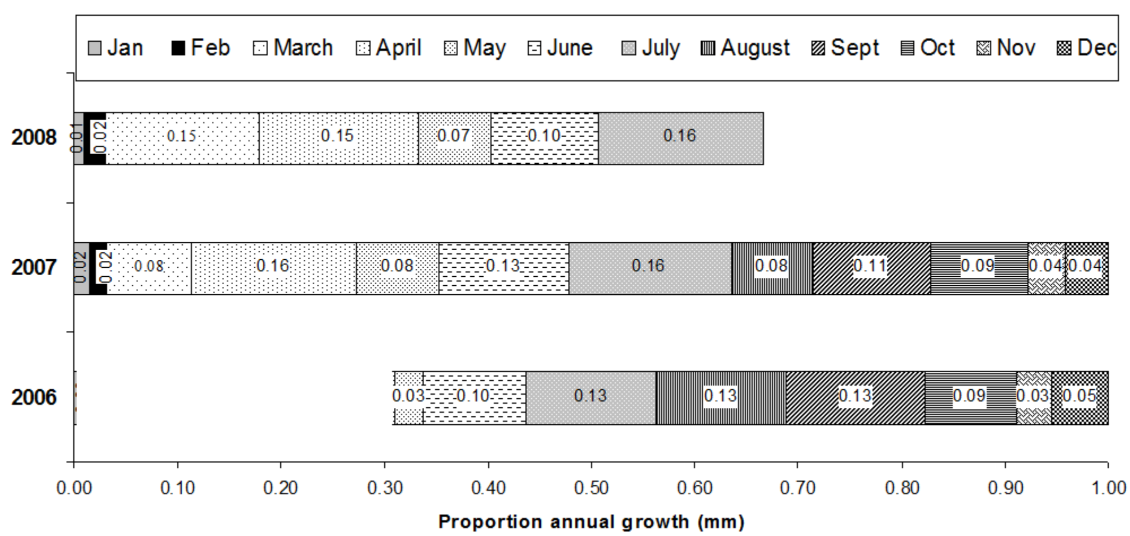


Figure 8. The proportion of total yearly increases in circumference (mm) represented by each month from May, 2006 through July, 2008. Months are arrayed sequentially along the abscissa such that monthly proportions of total yearly increases in circumference sum to 1.0. Data were averages based on all sizes of trees of both species in all sites.

Dormant periods. Dormant periods occurred seasonally. The winter dormant season occurred in January and February when cambial growth ceased or decreased to nearly imperceptible levels for most trees. Most trees at APAFR produced no cambial growth, or extremely little (1-2% of the total annual growth monthly), in the months of January and February (Table 3). In these two months, 58-77% of all trees exhibited no growth, and those trees that were not completely dormant grew, on average, only 0.15-0.33 mm circumference (Figure 4). In addition, shorter periods of dormancy occurred outside the winter months. A majority of trees were dormant in May and November of 2006, but no months of dormancy occurred outside the winter dormant season in 2007 or 2008 (Table 3). Dormancy outside of the winter dormant season may influence the formation of intra-annual density fluctuations or false rings further exploration of false rings is contained in Appendix 1.4.

Table 3. Three measures of monthly growth and dormancy for all pines with dormant values highlighted in blue. Measures and dormancy definitions are: 1) proportion of annual mean increase in circumference mm (dormant = 0.03 or less); 2) proportion of all pines with measurable monthly growth $\leq$ 0.2mm in circumference (dormant = months with greater than 50 percent trees with no growth), and 3) monthly mean growth (mm increase in circumference) (dormant = growth less than 0.4 mm). Data are from May 2006 through February 2008. * = missing data.

	Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1. Proportion of annual growth	2006					0.03	0.10	0.13	0.13	0.13	0.09	0.03	0.05
	2007	0.02	0.02	0.08	0.16	0.08	0.13	0.16	0.08	0.11	0.09	0.04	0.04
	2008	0.01	0.02	0.15	0.15	0.07	0.10	0.16					
2. Proportion with no growth (≤2mm circumference)	2006					0.62	0.21	0.18	0.15	0.09	0.28	0.53	0.27
	2007	0.67	0.75	0.29	0.01	0.12	0.05	0.02	0.29	0.11	*	*	0.29
	2008	0.77	0.58	0.07	0.01	0.21	0.02	0.01					
3. Mean Growth	2006					0.24	0.86	1.10	1.09	1.16	0.78	0.30	0.47
	2007	0.22	0.23	1.18	2.31	1.13	1.82	2.25	1.13	1.64	1.34	0.52	0.60
	2008	0.15	0.33	2.33	2.43	1.10	1.62	2.53					

Earlywood growth. The timing of earlywood growth was consistent between years, with a majority of trees producing earlywood in March. In March of 2007 71% of all trees were growing and 93% were growing in March of 2008. In April 99% of trees were growing in both years (Figure 9). There was a large increase in the amount of growth from the barely measurable .23 to .33 mm in February to 1.18 or 2.33mm in March (Table 3). For all years there was a large amount of growth in March and April followed by a decline in earlywood growth in May. This May decline in growth and increase in dormancy was more pronounced and reached dormant levels in 2006. Earlywood growth continued until the initiation of latewood growth.

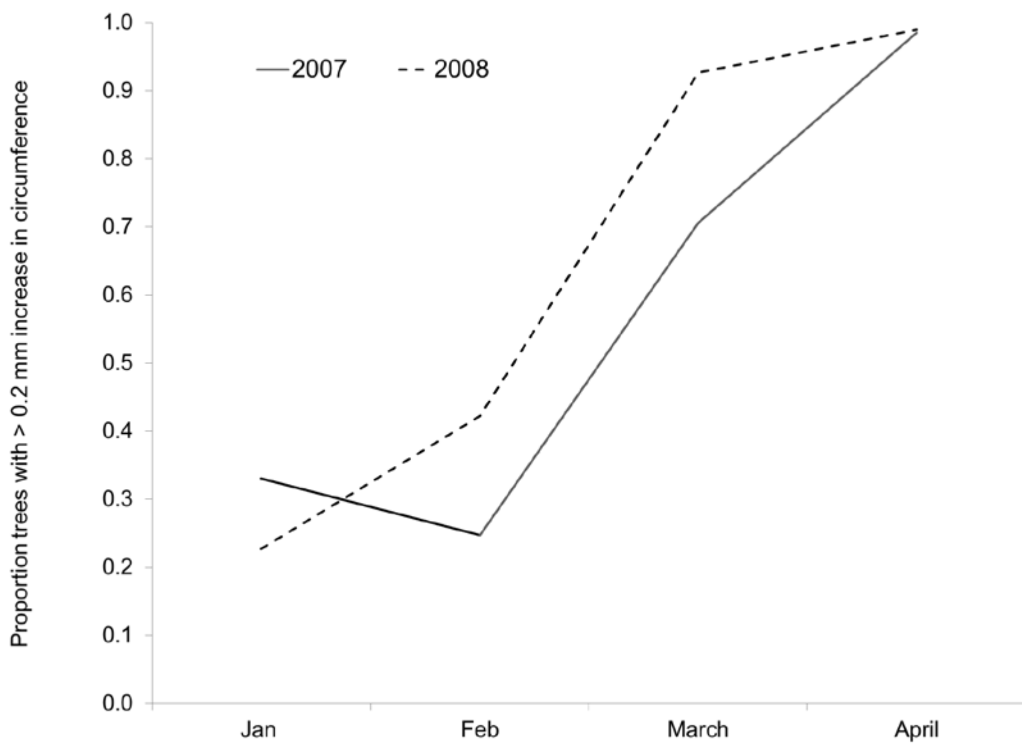


Figure 9. Proportion of all trees with growth (increase in circumference of >0.2 mm) for each month from January through April in 2007 and 2008.

Latewood growth. The timing of latewood initiation was consistent among most trees with some variation between years. Most trees made the transition from earlywood to latewood formation in June. In 2006, 2007 and 2008, 54%, 86% and 91% of trees respectively were producing latewood by late June (Figure 10). A smaller percentage of trees made the transition after June. In 2007 and 2008, transition to latewood production was complete for all trees by late July. In 2006, the transition to latewood occurred over a longer period of time (Figure 10). Nonetheless, 54% of trees had completed the transition to latewood production by late June, and 88% of trees completed the transition to latewood production by late July. Because a majority of trees began producing latewood sometime between late May and late June we designated middle June as the transition from earlywood to latewood growth.

Latewood growth continued for most trees through December. Growth was greatly reduced in November and December (only 3-5% of annual growth for each month). November and December could be considered a semi-dormant season, when trees are growing very slowly. We included these months as part of the latewood growth period, however, since there was a small amount of latewood growth in the great majority of trees during these months. Few trees were growing in January. Thus, latewood production season is designated as mid-June through December.

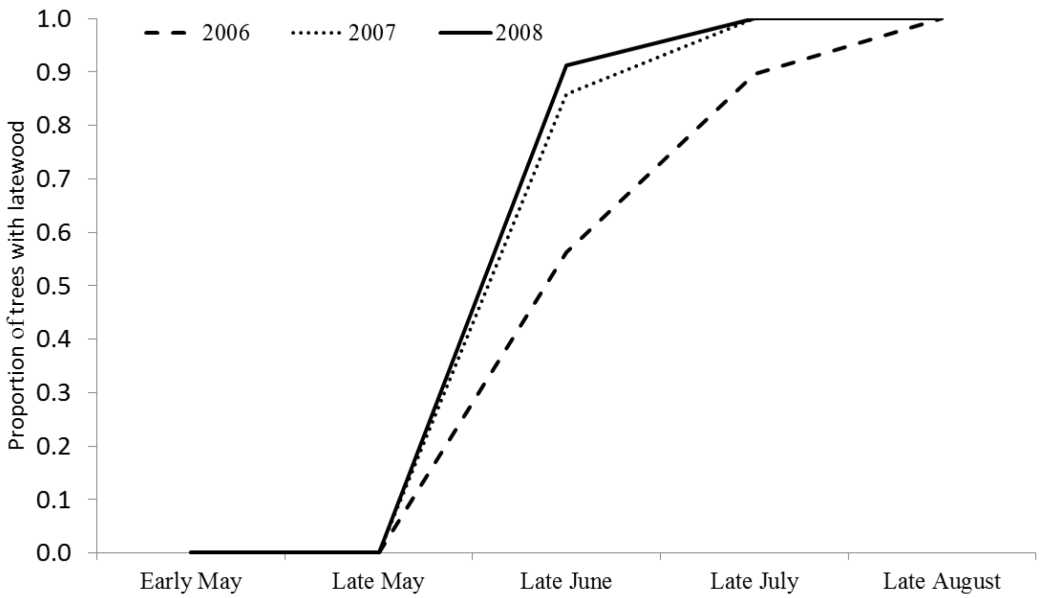


Figure 10. Proportion of all trees with latewood growth for each month of transition from earlywood to latewood growth (May-August) 2006-2008.

In summary, most study trees had a dormant period in January and February, produced earlywood growth from March through mid-June, and latewood growth from mid-June through December.

Variation in seasonal timing of cambial growth.

We examined whether there were differences in the seasonal timing of cambial growth between trees growing in different habitats, between longleaf pine and slash pine and between different sizes of trees. First, we used monthly rates of dormancy to examine variation in timing of initiation of yearly earlywood growth and cessation of latewood growth. We then examined any variation between trees in the timing of the transition from earlywood to latewood growth. An analysis of the quantity of seasonal growth among trees is presented in Appendix 1.5.

Habitat. There were no large differences in the timing of the initiation of earlywood growth and the cessation of yearly latewood growth for most trees in relation to habitat. Initiation of growth in the spring (March) of 2007 was similar between trees growing in different habitats (Figure 11). In 2008 the timing of earlywood initiation was also similar between habitats but 21% more wet site trees began growth in February than dry site trees. The timing of cessation of latewood growth in January also was similar between trees growing in different habitats. Often fewer wet site trees were dormant than dry and seep site trees. The largest differences in rates of dormancy between trees in different habitats occurred during especially dry periods of the growing season. For example in May, which is the usually the driest month of the year, 20% of dry and seep site trees, but only 0-5% of wet site trees were dormant in 2007 and 2008. This difference, however did not affect the timing of early and latewood growth.

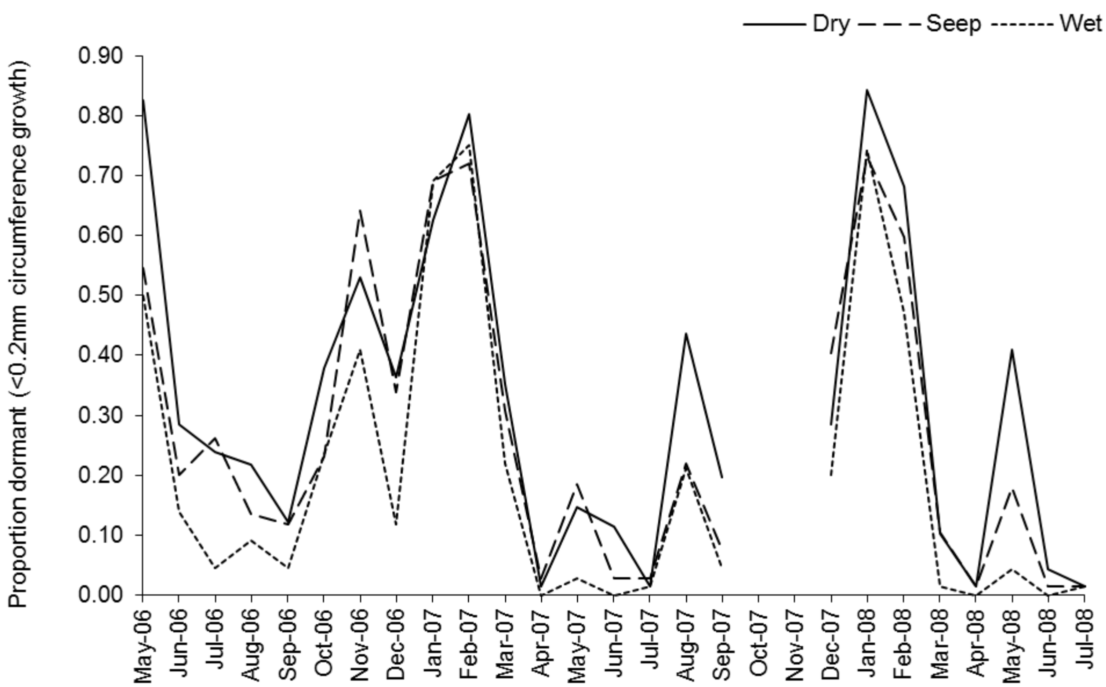


Figure 11. Proportion of trees dormant each month over the period of study in three habitats (dry, seep and wet sites).

Species. There were no major differences between longleaf pine and south Florida slash pine in the timing of cambial growth initiation or the timing of dormancy. Patterns of initiation of growth in March and cessation of growth in January were similar between species (Figure 12). There were some differences in rates of dormancy. A slightly higher proportion of longleaf pine (7%) were dormant than South Florida slash pine over the entire study period (Figure 12). The highest rates of dormancy for longleaf pine (>10% greater than slash pine) occurred during two times of year: the winter dormant season and the month of May. In January of 2007, 11% more longleaf pines were dormant than south Florida slash pines; in December 2007, January and February 2008 the differences were 16%, 14% and 15% respectively. In May (at the end of the dry season), 12% to 21% more longleaf pines were dormant than south Florida slash pines. These differences, however, do not affect the timing initiation and cessation of cambial growth which was similar between species.

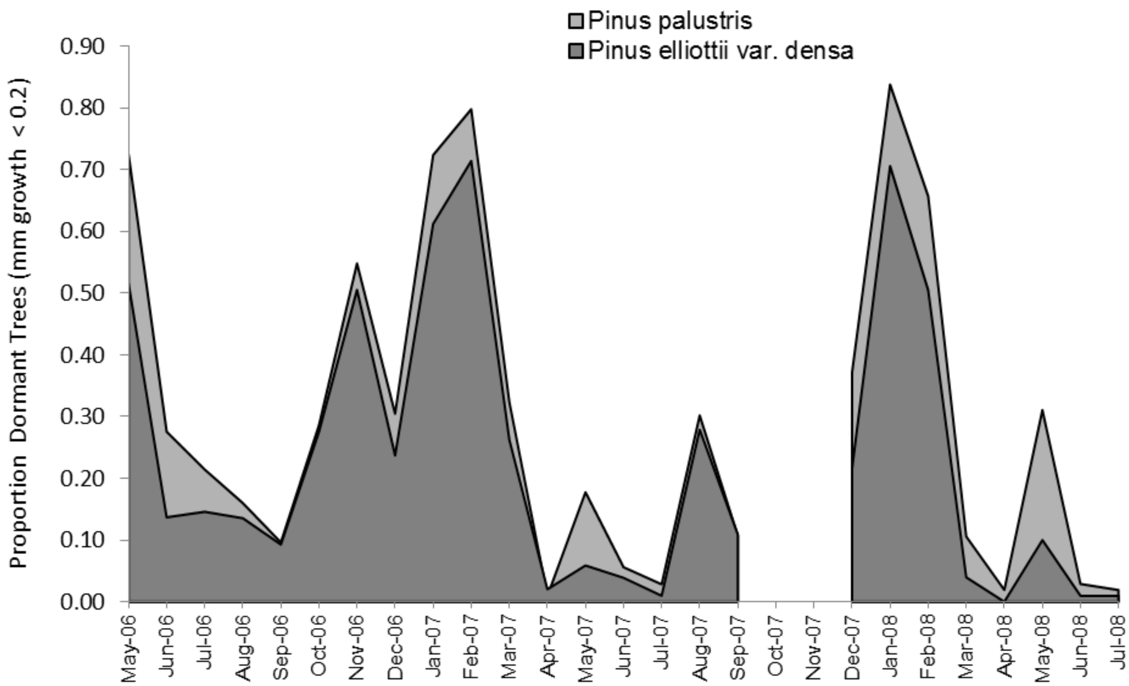


Figure 12. Proportion of trees of South Florida slash pine (*Pinus elliottii* var. *densa*) and longleaf pine (*Pinus palustris*) dormant each month over the period of study.

Species x habitat. General patterns in the timing of cambial growth initiation and the timing of dormancy were similar between longleaf and south Florida slash pines in dry, wet and seep habitats, with some minor differences. Longleaf pine generally had slightly higher rates of dormancy than south Florida slash pines (Figure 13). Minor differences in timing of cambial growth included a higher proportion of longleaf than south Florida slash pines ceased growth in December, especially in the wet and seep sites, and on wet sites a greater proportion of longleaf pines (30%) than south Florida slash pines (14%) were dormant in March, 2007.

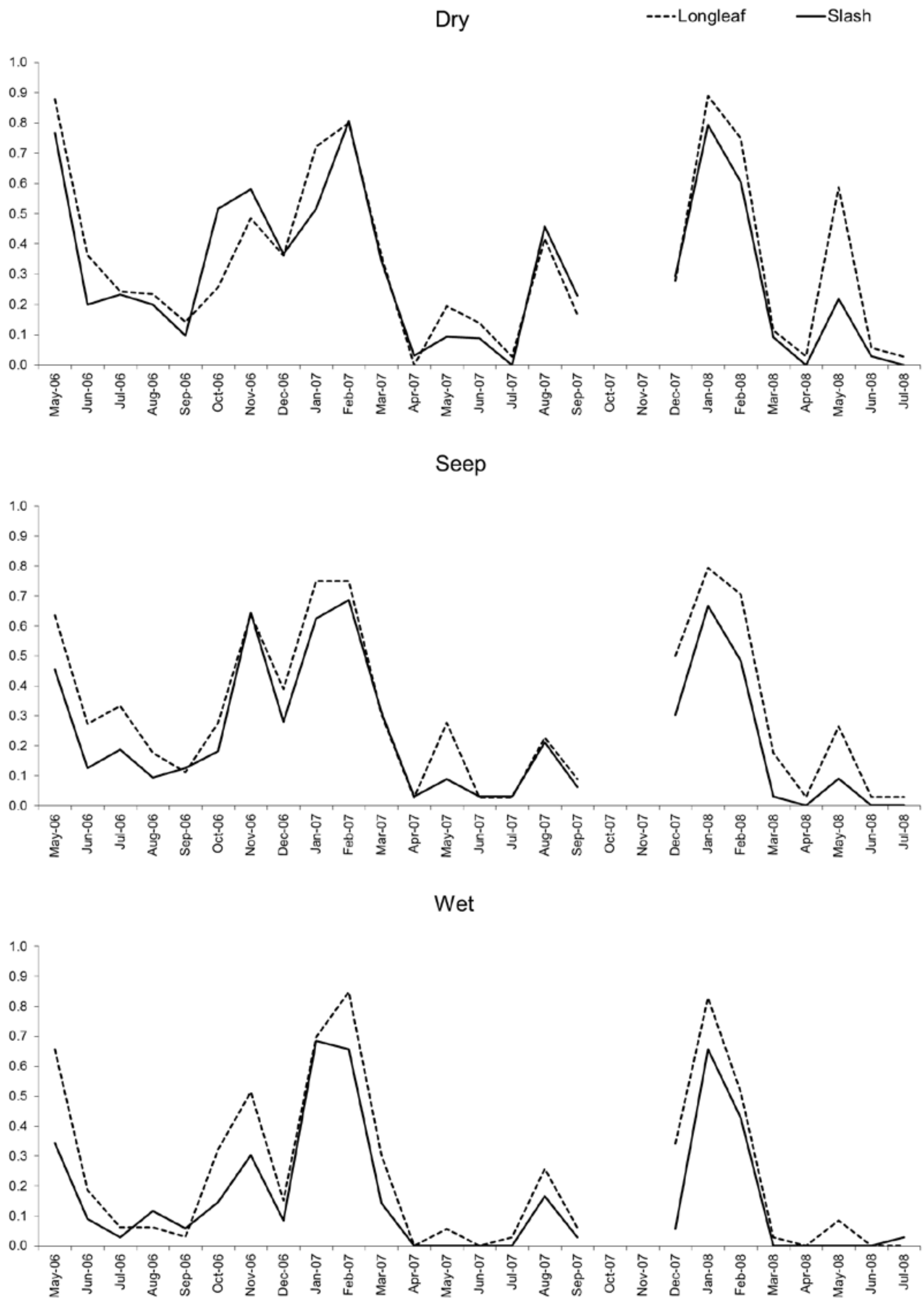


Figure 13. Proportion of trees dormant each month over the period of study of longleaf pine (*Pinus palustris*) and south Florida slash pine (*Pinus elliottii* var. *densa*) in dry, seep and wet habitats.

Size class. There were some differences in the timing of cambial growth initiation between different size classes of trees. Large and medium size class trees had similar timing of seasonal growth and dormancy (Figure 14). Small trees, however, were dormant during the growing season less often and were dormant within the dormant season for a shorter duration than larger, older trees. Small trees were similar to other size class trees in the timing of the start of dormancy and the transition to latewood but were earlier to initiate earlywood growth in the spring.

Timing of dormancy varied between small trees and other size classes. All size classes of trees had similar high rates of dormancy during January. The greatest difference in dormancy between small and medium/large trees was in February; 51% of small trees were dormant in 2006 versus 86% medium and 90% of large trees in 2007. In February of 2008 only 38% of small trees were dormant versus 67% of medium and 70% of large trees. In March 2007 only 9% of small trees were dormant versus 38 and 41% of medium and large trees. Most small trees are dormant in January but a greater number of small trees begin earlywood growth in February, earlier than most large and medium trees. Also, fewer small trees are dormant during growing season months when there are small spikes of dormancy in other trees, this is especially evident in August 2007 and May 2008 (August 2007: 25% of medium and 56% of large trees were dormant, but only 06% of small trees were dormant, May 2008: 28% medium 29% large and 6% small).

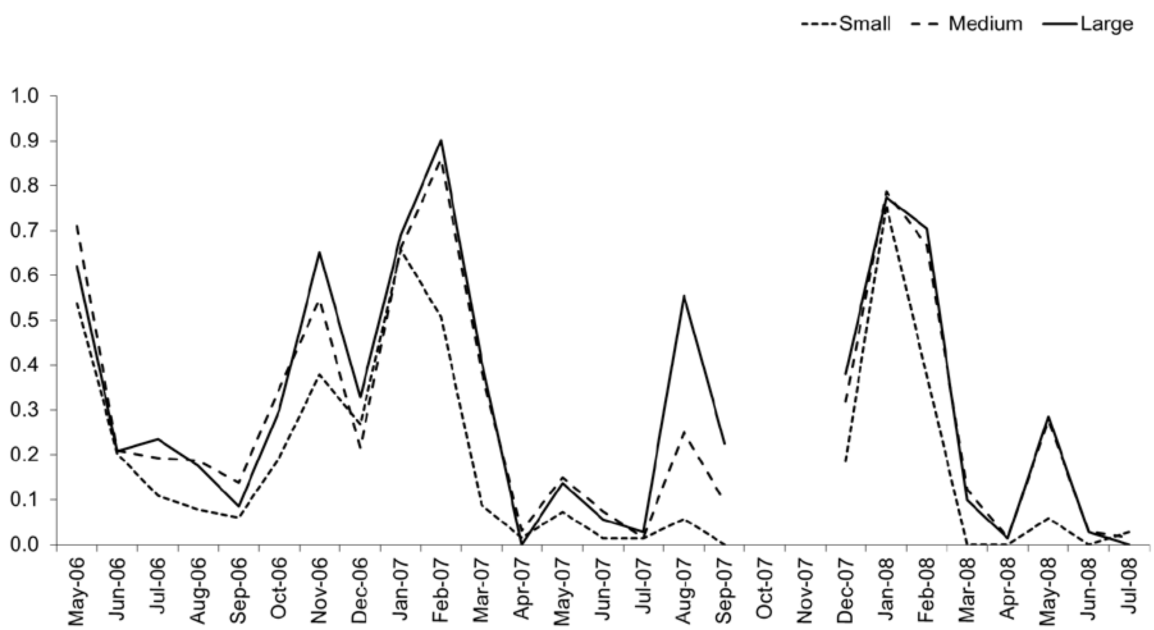


Figure 14. Proportion of trees dormant each month over the period of study for small, medium and large size class pines. Horizontal line indicates when more than 50% of the trees exhibited no growth in a given month.

Species x size class. The timing of growth and dormancy were similar between longleaf and south Florida slash pines of different size classes, with some minor differences. The greatest difference was that medium sized slash pines were dormant for a shorter duration during the winter dormant months of January and February than medium sized longleaf pines. For most months a greater proportion of medium and large longleaf pines were dormant than medium and large slash pines (Figure 15). For small trees a slightly greater proportion of small slash pines were dormant than longleaf from May through October 2006 and from March through October of 2007.

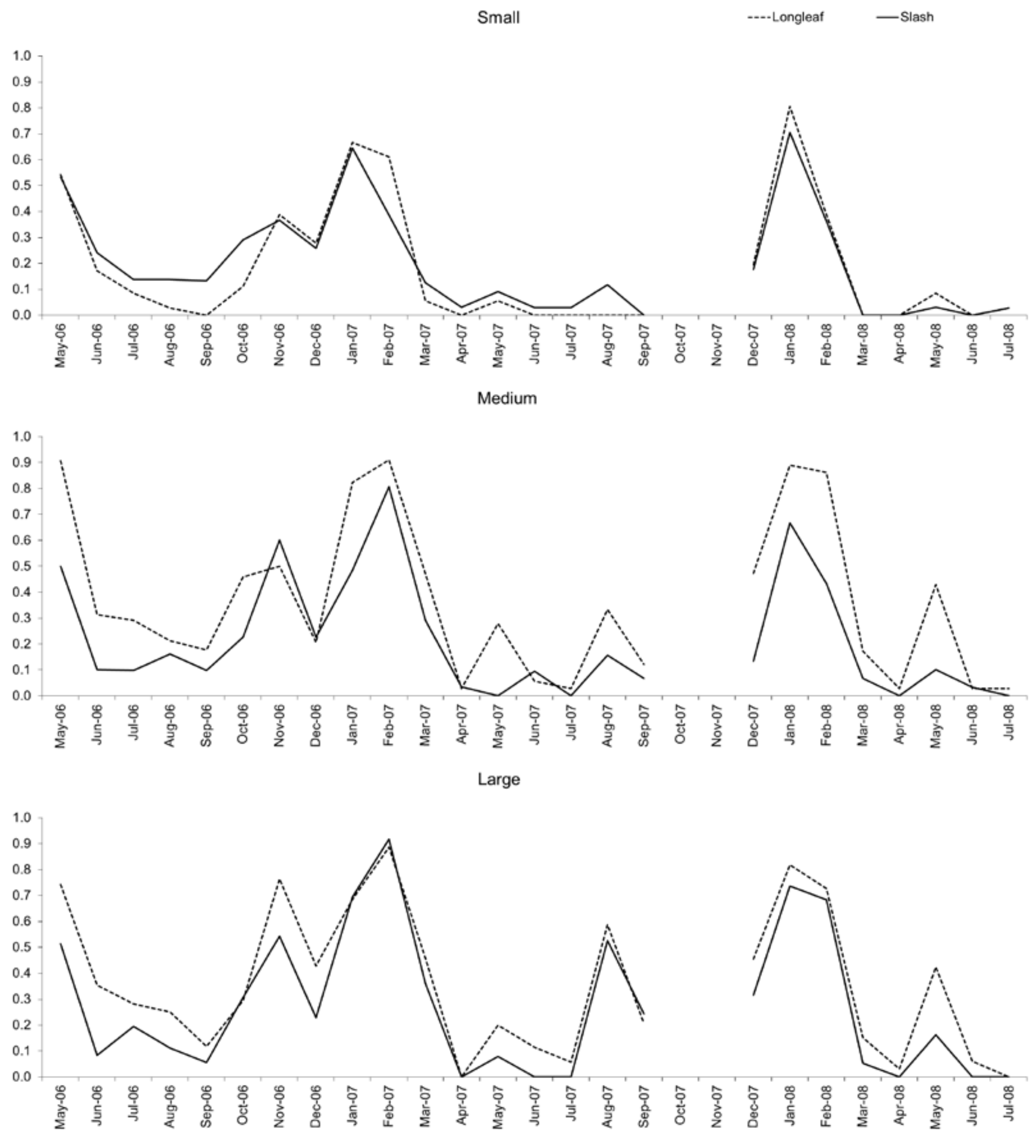


Figure 15. Proportion of trees dormant each month over the period of study of longleaf pine (*Pinus palustris*) and south Florida slash pine (*Pinus elliottii* var. *densa*) in small, medium and large size classes.

Variation in earlywood to latewood transition. The timing of the transition from earlywood to latewood did not vary greatly between species and habitats of trees. Most trees produced latewood between late May and late June (54% in 2006, 86% in 2006 and 91% in 2008). We examined the final 9 to 14% of trees that were the last to transition to latewood growth in each year (12% of trees after July 2006, 14% after June 2007, and 9% after June 2008). In the dry year of 2006, 71% of trees that were the last to begin latewood production were from dry sites, all of the remaining trees were in overtopped or subdominant canopy positions and there was a mix of longleaf and slash pines (55% and 45%). In contrast, in 2007 and 2008, 94% of trees that were the last to begin latewood growth were from wet and seep sites (wet 50% and seep 44%), 50% were in overtopped or subdominant canopy positions and 80% were south Florida slash pines.

Fire and timing of cambial growth. Fire did not appear to change the timing of cambial growth for most trees. Site 2 trees were burned with a prescribed fire on April 24, 2006 just as measurements of trees were beginning. Site 1 trees were burned on June 4, 2007. Growth and dormancy rates were not different between sites during the year following the 2007 burn. Growth and dormancy were only slightly different during the year following the 2006 burn, with slightly higher dormancy rates (Figure 16) and slightly lower growth rates for the burned site trees (Figure 17). The 2006 burn had large amounts of crown scorch on some of the measured trees in the wet and seep sites which may account for the slightly lower growth and higher dormancy of trees following fire in 2006.

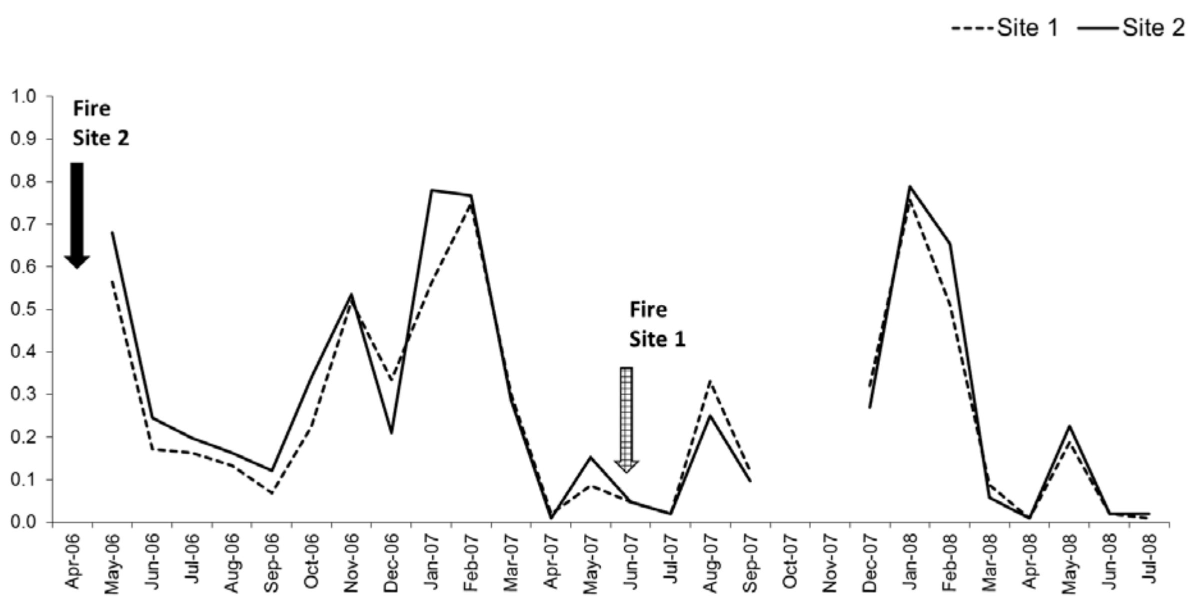


Figure 16. Proportion of trees dormant in site 1 and site 2 each month over the period of study. Arrows indicate fires. Site 1 was burned on June 4, 2007 and Site 2 that was burned on April 24, 2006.

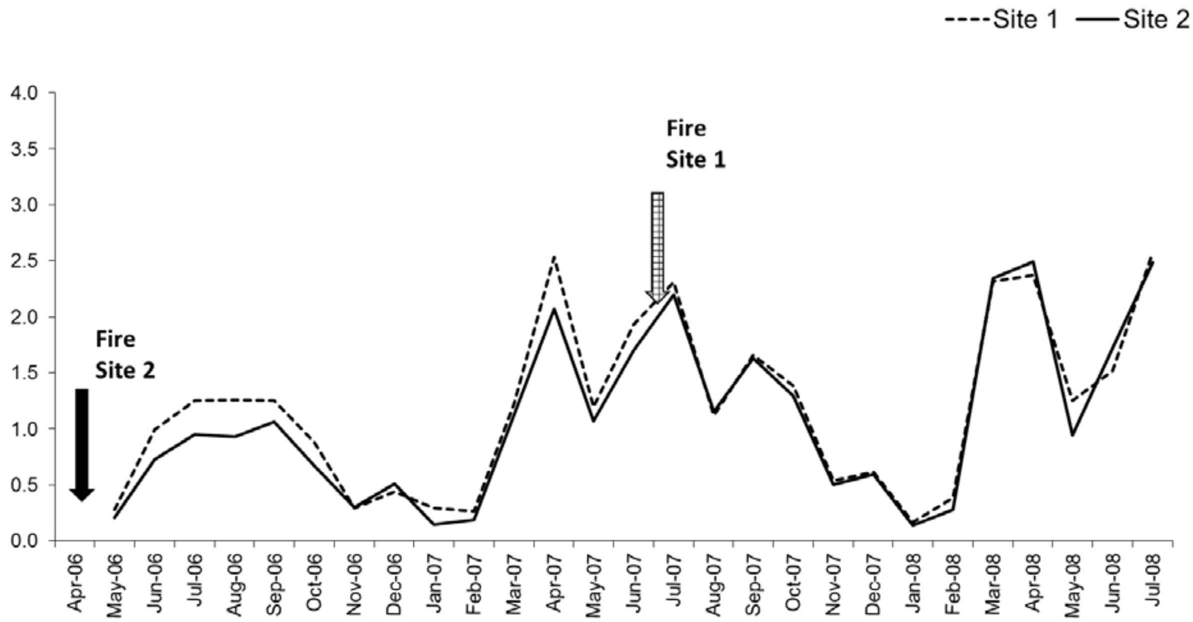


Figure 17. Mean monthly increase in circumference (mm) over the period of study for site 1 (burned on June 4, 2007) and site 2 (burned April 24, 2006). Arrows indicate fires.

Summary of intra-annual and inter-annual variations in timing of cambial growth.

The initiation of earlywood growth, initiation of latewood growth and cessation of latewood growth were similar for longleaf and slash pines, trees in different habitats, and of different size classes. The largest difference in timing we found was between small trees versus large and medium size class trees; a slightly larger proportion of small trees started earlywood growth in February rather than March.

The timing of the initiation of earlywood growth, initiation of latewood growth and ending of yearly growth was the same between years for the majority of trees. There were two differences in timing of cambial growth between years: 1) latewood growth was initiated later for many trees in 2006, and 2) initiation of earlywood occurred later for a portion of trees in 2007.

We found that the species, size of tree and habitat and year of growth did not have strong influences on patterns of timing of cambial growth. The generally synchronous timing of cambial growth that we found confirms that the earlier assignment of months to ring positions using all trees was applicable to longleaf and south Florida slash pines growing in different habitats and of different sizes (with less precision in regards to small trees) and was also applicable across years of varying rainfall and fire.

Monthly timing of intra-annual growth positions and corresponding climate.

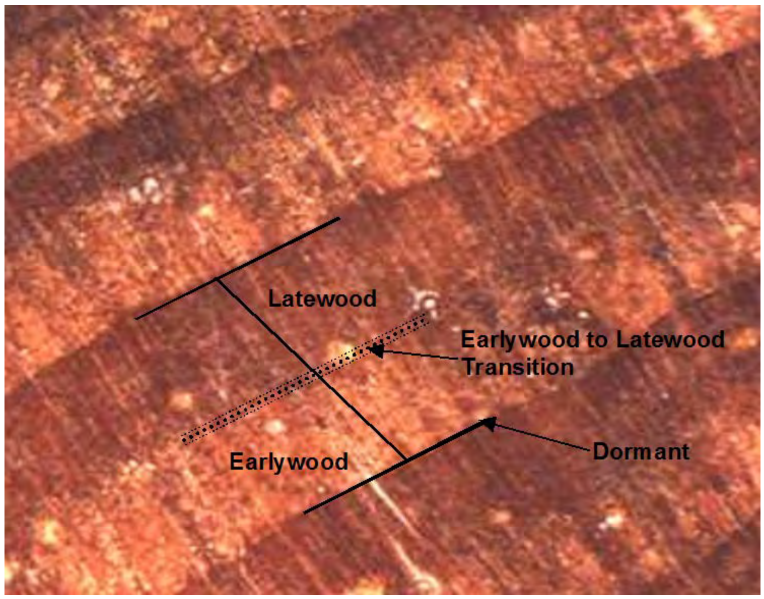
Having established the months that correspond to different ring positions we can now describe the climatic variables most relevant to fire initiation and spread (e.g., rainfall and lightning) for each intra-annual ring position. This information will be used later in this report to design an intra-annual fire scar position designation system that has meaningful categories relevant to seasonal climate and fire weather. A graphic presentation of these ring positions within an annual growth ring and a table of the months and climate corresponding to each position are presented in Table 5. For graphic representation of monthly rainfall, lightning, and depth to water table (a measure of drought) refer to Figure 3.

Periods of wet season/dry season and lightning frequency vary predictably throughout the year and are different during the winter dormant season and earlywood growth. The winter dormant season occurs in the middle of the dry season when lightning strikes, which are associated with thunderstorms, are extremely low to nonexistent making the likelihood of lightning-ignited fires extremely low (Table 5). Earlywood growth spans the period from the driest part of the year, at the end of the dry season, through the beginning of summer thunderstorm rains. Rapid earlywood growth begins during the dry season (March-April) and then declines in May as the dry season reaches its peak and both surface and groundwater levels are usually at their lowest point of the year. Earlywood growth continues until shortly after the onset of the thunderstorms of the summer wet season (historical mean date of onset of the wet season is May 22nd, Slocum et al. 2010). There is little lightning during most of the earlywood growth period before the onset of the wet season. During the final period of earlywood growth, when the season's first lightning occurs and becomes frequent, the landscape is at its driest and has the greatest potential for fires to spread and burn large areas (Slocum et al. 2010a & b).

The timing of the transition from earlywood to latewood occurs at a crucial time for fire weather. The onset of the wet season occurs at the end of the driest time of the year, when extended drought results in lowered surface water levels and dry wetlands. Lightning is at peak levels of frequency. The combination of these two elements of dryness and lightning make this period the most likely time for lightning-ignited fires (Slocum et al. 2010a & b).

Latewood growth occurred both during wet months with lightning and during dryer months without lightning. Latewood growth began during or soon after the onset of wet season, and extended through December, including almost the entire wet season and the first three months of the dry season. Lightning is still frequent in the early part of latewood growth (July-August). It declines in September and October to low levels, and by the end of latewood growth in November and December there is practically no lightning (Table 5).

Table 5. The four basic ring positions (dormant, earlywood, transition from earlywood to latewood, and latewood) located on one annual growth ring of longleaf pine. For each ring position we present the corresponding months of growth, rainfall season, and relative lightning frequency.



Inter-annual Portion of Ring	Corresponding Months	Number of Months	Rainfall	Lightning Frequency
Dormant	January-February	2	Dry season	None
Earlywood	March through mid-June	3.5	Dry season to beginning of wet season	Very little ascending to peak
Earlywood to Latewood Transition	June		Dry season through beginning of wet season	Peak
Latewood	Mid-June through December	6.5	Wet season to dry season	Peak dropping to none

Intra-annual fire scar position designation for Florida

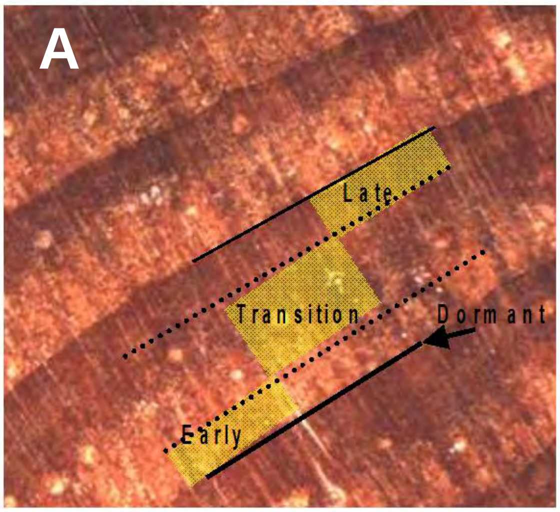
We present a system for intra-annual divisions of the growth rings of longleaf and south Florida slash pines that is based on our understanding of seasonal growth of longleaf and south Florida slash pines at APAFR and knowledge of seasonality of rainfall and lightning in peninsular Florida.

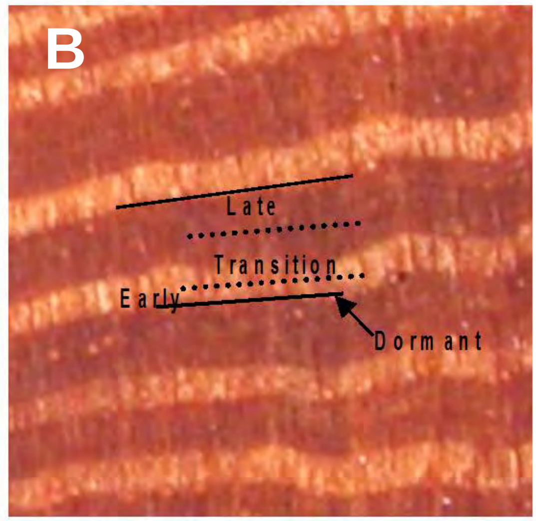
Our aim was to make ring divisions that correspond to seasonality of lightning occurrence. We developed a system, presented in Table 2-1, that consists of four ring positions: 1) *Dormant (D),* for the position between previous year's latewood and current year's earlywood, 2) *Early (E),* for the first half of the earlywood, 3) *Transition (T),* for the second half of the earlywood and the first half of the latewood, and 4) *Late (L),* for the last half of the latewood (Table 6).

To determine which months correspond with our "early, transition and late" designations we divided early and latewood growth in half based on the proportion of mean monthly growth of our measured trees. Half of the earlywood growth for both years measured ended in late April. We consider the first half of April to be "early" and the latter half of April to be "transition." Half of the latewood growth for both 2007 and 2008 ended at the end of August. The proportion of wood that was produced during the transition designation (mid-April through August) was 52% of the mean annual growth for 2007. Forty-eight percent of the annual growth was during the dormant, early, and late portion of the year.

Our designations correspond well with seasonal changes in rainfall: Dormant, Early, and Late occur almost exclusively during the dry season, while Transition encompasses the very end of the dry season and almost the entire wet season (Table 6). Since the wet season at APAFR corresponds to the summer thunderstorm season, these designations also correspond to difference in lightning frequency. There is little to no lightning storm activity in the Dormant, Early and Late designations. The Transition designation encompasses the onset of the wet season (when lightning storms become frequent) throughout the entire peak season of lightning strikes.

Table 6. The four position designations of the Florida intra-annual fire scar position designation system (**dormant**, **early**, **transition**, and **late)** seen on one annual growth ring of longleaf pine with wide earlywood growth (A) and one with narrow earlywood growth (B). For each ring position designation we present the corresponding months of growth, rainfall, and relative lightning frequency.





Designation of Ring Positions	Location in Ring	Number of Months	Corresponding Months	Rainfall	Lightning Frequency (scale of 0-3)
Dormant	Between latewood of previous year and current year's earlywood)	2	January-February	Dry Season	None 0
Early	First 1/2 of earlywood	1.5	March- and early April	Dry Season	Low 1-2
Transition	Final 1/2 of earlywood through first 1/2 of latewood	4.5	Late April-May-June-July-August	Wet Season and very end of dry season	High 2-3
Late	Final 1/2 of latewood	4.0	Sept-Oct-Nov-Dec	Dry season and very end of wet season	Some in Sept & Oct. then very low 0-2

Discussion

Intra-annual fire scar position designation for Florida

We used observed patterns of cambial growth to formulate the first intra-annual fire scar position system that can be used to accurately determine the seasonal timing of fire scars in longleaf and slash pines in subtropical central Florida. Our system divides the growth ring into designated positions that are relevant both to seasonal patterns of cambial growth, and to seasonal climate that is relevant to fire.

Our intra-annual fire scar position system replaces the standard system of tree ring positions which is commonly used for fire history research but was developed for temperate trees. Unlike most temperate trees, subtropical southern pines have a long growing season and a relatively long period of latewood growth. The standard system divides earlywood (3.5 months of growth for trees at APAFR) into 3 separate designations and groups latewood production (6.5 months) into just one ring designation. Our system more evenly divides the entire growing season into 3 separate designations that also correspond to important seasonal changes in climate.

Unlike the standard system our ring position designations correspond with seasonal changes in climate that are relevant to fire ignition and spread. Because of this it is possible to use our fire scar position system to infer whether past fires occurred during the climatically-driven fire season when lightning-caused ignitions are frequent (our *Transition* designation), or during times when lightning is absent or very infrequent and any ignitions would more likely have been human-caused (the *Early*, *Late* and *Dormant* designations). We also can relate the seasonal occurrence of historical fires to the wet/dry season seasonal cycles that exert strong influence on likelihood of fire spread in savanna landscapes of central and southern Florida (e.g., Beckage et al. 2003, Slocum et al. 2003, 2010a).

Variability among trees

Species and habitat did not have strong influences on patterns of timing of cambial growth; hence, our system can be applied to both longleaf and south Florida slash pines growing in different habitats. Our system is also applicable to all sizes of trees, with slightly less accuracy for small trees which often begin earlywood growth a month earlier than other trees. The pattern that we found of reduced periods of dormancy in small trees, and earlier initiation of growth in the spring, has been found previously for small slash and longleaf pine (Larson et al. 2009) and many other species of trees (Vieira et al. 2008, De Luis et al. 2009). It is notable that two different species of pines (longleaf and south Florida slash pine) had nearly identical patterns of timing of growth. Longleaf and slash pine also have remarkably similar patterns of height and crown growth (Jack et al. 2002, Gonzalez-Beneke et al. 2011,) and likely are responding to similar environmental cues to intra-annual growth.

Although the two fires that occurred during course of study was not a sufficient number to make definitive conclusions about fire and timing of growth, we did not observe any large differences between burned and unburned sites in the timing or the amount of cambial growth. Fire may influence the timing of cambial growth, mainly by slowing or temporarily stopping growth (Sutherland et al. 1991). Since fires are frequent in this landscape the intensity of fire is reduced and large effects of fires on growth are less likely than in locations that have less frequent, higher intensity fires.

Variation among years

Drought may influence the timing of cambial growth. The growth of longleaf pine is usually very sensitive to rainfall, and even more so to long term rainfall patterns reflected in drought indexes; less rain generally results in slower growth in longleaf pine throughout the Southeast (Meldahl et al. 1999, Henderson and Grissino-Mayer 2006). South Florida slash pine was found to be sensitive to rainfall in flatwoods sites, and rainfall in the early spring period was especially important to growth (Ford and Brooks 2003).

The variation in timing of cambial growth that we found between years was likely related to drought. The three differences in timing of cambial growth that we found among years were all associated with 2006, a year of well below average rainfall and an extremely dry spring.

1. Later transition to latewood for some trees in 2006: The timing of the transition to latewood is often more variable than the initiation and cessation of seasonal growth (Vargas-Hernandez and Adams 1994) and rainfall is known to influence the timing of latewood initiation (Larson et al. 2009). We hypothesize that the lack of rainfall, especially in the early growing season, and the delayed onset of the rainy season in 2006 resulted in the delayed transition to latewood for some trees in 2006.

2. Dormancy outside the winter dormant season in 2006: The only months when most trees were dormant outside the winter dormant season occurred in May and November 2006.

3. Later initiation of earlywood for some trees in 2007: Earlywood growth in longleaf pine and south Florida slash pine is more strongly influenced by previous year’s rainfall than the current year’s rainfall (Ford and Brooks 2003, Henderson 2006, Henderson and Grissino-Mayer 2009). The slower initiation of earlywood growth by some trees in 2007 may have been influenced by the low rainfall in 2006.

Because the majority of trees initiated earlywood and latewood during the same month across years, the differences we found would not affect the general application of our intra-annual ring position system. However, for a portion of trees, the timing of earlywood and latewood production may be delayed slightly in exceptionally dry years. Inter-annual dating of fire scars therefore may be slightly less precise in dry years.

An analysis of the influence of rainfall and other climatic influences on the timing of earlywood and latewood growth should be examined in the future. Appendix 1.6 of this report presents a preliminary examination of climatic influences on growth.

Seasonal Growth Patterns

We expected to find differences in the timing of cambial growth at different latitudes and between species of pine. Our study was located in central Florida, close to midway in latitude between the northernmost and southernmost sites of several previous studies (Table 7). One previous study was conducted on longleaf pine to the north (Paul and Marts 1931) and two studies were conducted on south Florida slash to the south (Langdon 1963, Harley et al. 2012). Each examined a small number of trees (Table 7).

Latitude did not appear to have a strong influence on timing of cambial growth based on these studies. The timing of dormancy that we found in January and February was similar to the northern longleaf site (Paul and Marts 1931) and both the timing of the start of earlywood growth (March) and latewood growth (June) that we found were more similar to the southernmost south Florida slash site (Harley et al. 2012). Langdon (1963) found a shorter period of dormancy and earlier timing of initiation of earlywood in his study of small trees, which was similar to our results for small trees.

We examined a wide range and a large number of trees over more than 2 years, therefore our results on the seasonal timing of cambial growth of longleaf and south Florida slash provide a strong basis for our intra-annual fire scar position designation system. Based on the strength of our system and the similarity of our results to these other smaller studies, our system is likely to be applicable to longleaf and south Florida slash pines throughout Florida.

Conclusion

This intra-annual fire scar position designation system, which was developed based on study of cambial growth of pines at APAFR, is central to the overall goals of our study of the fire history at the APAFR. In subsequent portions of this report, we use our dating system to construct seasonal patterns of fires for different time intervals during the fire history of the APAFR.

Table 7. Summary of previous studies of cambial growth in longleaf and south Florida slash pines, including Huffman and Platt from this report. Cambial growth dates (earlywood and latewood start, latewood end and period of dormancy) and study information (species, location, number of trees, age/size of trees, length of study and method of measuring cambial growth) are presented.

Author/Year	Species	Location	Additional Information	Method	Earlywood start	Start Latewood	Latewood end	Dormancy
Paul &Marts 1931	*Pinus palustris*	Northwest Florida (now Eglin AFB) 30°48'N	8 mature trees, >100 yrs old, sandhill, 2 yrs.	Dendrometer bands/monthly	March 1	***1927:*** *May 10* ***1928:*** *June 1 -50%, July 3 -100%*	Not designated, note that on Dec. 10 some trees still growing	(December?) January - February
Harley et al. 2012	*Pinus elliottii* var. *densa*	South Florida Big Pine Key 24°42'N	6 mature trees (mean 75 yrs/ 35 cm dbh); pine rockland; 1 yr	Anatomical; monthly	Mid-February to Mid-March	***2010:*** *June 15 - 67%; July 15 - 100%*	December 50%; January 100%	Mid-December 50% Mid-January 100%
Langdon 1963	*Pinus elliottii* var. *densa*	Southwest Florida, near Naples 26°24'N	10 small/young trees (mean 15 yrs/16 cm dbh); mesic pine flatwoods; 4 yrs	Dendrometer bands/2 weeks	Early February	*Not examined*	December - January	December - January (3% annual growth)
Huffman & Platt 2012 (This report)	*Pinus elliottii* var. *densa* & *Pinus palustis*	Central Florida, Avon Park AFR, 27°35'N	207-216 small - large, in 3 habitat types dry to wet; 2 yrs, 3 mo.	Dendrometer bands/monthly	March	***2006:*** *June 27 - 54%, July 27 -84%,* ***2007:*** *June 26 - 86%, July 26 - 100%* ***2008:*** *June 26 -91% , July 26 - 100%*	January	January-February

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Part 2. Fire History of the Avon Park Air Force Range

Introduction

Fire is widely recognized as an important ecological process in southeastern pine savannas and prairies. Many plant species are endemic to these ecosystems (Sorrie and Weakley 2006), indicating evolution in these fire-frequented environments (Frost 1998, Platt 1999, Myers and Rodriguez-Trejo 2009, Noss 2012). Nonetheless, characteristics of past fire regimes remain unclear. Because these habitats were altered directly and indirectly before fire regimes were characterized the natural ranges of fire frequency, seasonal timing of fires, and the extent to which natural fires burned across landscapes are unknown, and sometimes controversial, components of hypothesized natural fire regimes.

Currently humans directly determine fire regimes on remaining natural savannas. Humans have been influencing fire regimes extensively for longer periods of time in different regions. The effects of humans on characteristics of fire regimes in the southeast been only recently been explored using scientific data comparing the results of natural and human ignitions (Slocum et al. 2007). Still, the relative influence of natural (lightning/climate) and human controls on fire regimes remains disputed. Scientific data on fire history prior to European settlement would be useful for exploring characteristics of fire regimes, especially those characteristics that might be important as part of restoration and management programs. Likewise, fire history subsequent to initial European settlement could provide data indicating how humans have altered the natural fire regimes post settlement.

Fire scars contained in the annual rings of tree rings provide direct evidence of historic fires. Fire scars are formed when a portion of the cambium of a tree is killed by fire, but the tree survives and wound wood grows over the area of dead cambium (Gill 1974). Often fire scars appear as small, internal distortions of annual growth rings. A fire history is produced by dating fire scars using dendrochronological techniques of cross-dating, and then compiling information from fire scars from a series of trees from a defined area to produce a reconstruction of past fires at that site. Analyses of fire history based on fire scars have been lacking for southeastern pine savannas.

In this report, we provide scientific data on historical fire regimes in pine savannas at the Avon Park Air Force Range (hereafter APAFR). We describe the methods and the results of our quest to find the oldest trees and stumps, and we constructed a master tree growth chronology to date fire scars. We then used those data to compile historical fire regimes at the APAFR. Our fire history focused on two important aspects of past fire regimes: fire frequency and intra-annual (or seasonal) timing of fire. Frequency is a very important aspect of fire regimes and differences in fire intervals over time may result in important differences in the structure and composition of biotic communities (Glitzenstein et al. 1995, 2003). Likewise, the intra-annual timing of fire has important influences and many pine savanna species show strong and varying responses to fire at different times of year (Streng et al. 1993, Brewer and Platt 1994, Fill et al. 2012).

We had three primary objectives of our research. The first focus of this study is to determine the frequency and season of past fire regimes. We have already studied the monthly growth of longleaf and slash pine at APAFR and constructed a system of fire scar designations that is tailored to central Florida. Thus, it is possible to infer the extent to which past fires occurred during the climatically-driven fire season when lightning-caused ignitions are frequent or during times when lightning is absent or very infrequent and any ignitions would more likely have been human-caused.

The second focus is to determine how frequency and seasonal timing of fires changed over time in relation to human settlement and land use in the region. Climatic-driven fire regimes should be indicated by fire frequency and season recorded in the earliest recorded fires, prior to extensive European settlement. The human history of APAFR during the last several centuries has included periods during which different cultures occupying the site had different land use activities. People are known to have used fire extensively throughout the year for different purposes in Florida and the Southeast (Eldredge 1911, Pyne et al. 1996, Van Lear et al. 2005). Although there has been much speculation on how human modified climatically-driven fire regimes during different historical periods, documented records of such changes do not exist. We used our frequency and intra-annual timing data, grouped into sequential time periods, to explore effects of climate and human modifications on fire regimes over time.

Third, based on our understanding of past fire regimes and changes in fire regimes over time, we developed concepts regarding the ecology of fire in this landscape. These concepts should be useful in guiding fire management of the range, as well as in other managed areas. We explored the frequency and intra-annual timing of past fires to understand both the type of fires that produced the plant communities currently on the APAFR, and those further in the past that may shed light on what the fire interval may have been over evolutionary time scales. This understanding is especially important since both frequency and the time of year of fires is now almost completely determined by land managers conducting prescribed fires.

Methods

Study site

The Avon Park Air Force Range is the largest remaining natural upland landscape in the ridge region of south-central Florida. APAFR is a 42,430 ha military installation in south-central Florida (27˚35' N, 81˚16' W), established during World War II for air-to-ground training and related military missions. The installation has 23,000 ha of some of the most diverse fire-maintained landscapes remaining in the region (Orzell, unpublished data). Located north of Lake Okeechobee between the Kissimmee River and Lake Arbuckle Creek in Polk and Highland Counties, the Range is a mosaic of fire-dependent plant communities that transition from well-drained uplands (oak and sand-pine scrubs, sandhills) down slopes containing mesic pine flatwoods and scrubby flatwoods into lower elevation dry prairies, cutthroat seeps, herbaceous wet prairies. Floodplain marshes and cypress wetlands occur at the lowest elevations in lowlands and drainages (Bridges 2000, 2006). APAFR is currently managed for multiple uses, primarily for military training, but also for forestry, cattle-grazing, and recreational uses. In addition it is also managed for the high conservation values of one of the last large intact natural landscapes in the central Florida ridge region that is rich in endangered, rare and declining species of fire-dependent plants and animals. Fires occur frequently; prescribed fires, ordinance fires from military training operations, and lightning fires all have been regularly recorded over the approximately 4 decades that records have been kept at APAFR (Slocum et al. 2010b).

The historic climate in central Florida is highly seasonal. Patterns of precipitation indicate two seasons, wet and dry, within the year (Chen and Gerber 1990, Slocum et al. 2010b, Platt et al. 2006). Long-term averages (Figure 1) indicate a pronounced wet season of 4-5 months that typically is initiated in May/June and extends through September. During this wet season, rainfall occurs every few days, with intervals between rainfalls on the average being less than a week (Figure 1). The longer dry season, during which intervals between successive rainfalls typically lasts more than one week and often extends to about two weeks, extends from October/November through April (Figure 1). Surface and ground water levels, at their lowest just before the start of the summer wet season, usually in May, peak toward the end of the wet summer rainy season in August and September (Figure 1). Rainfall in the dry season is influenced by the El Niño-Southern Oscillation (ENSO) (Slocum et al. 2010a, Slocum & Orzell 2013). Lightning is also seasonal (Platt et al. 2006, Slocum et al. 2010a). Thunderstorms that produce lightning are frequent from May to August, averaging around one cloud-ground lightning strike per square kilometer annually, but rare during the transition from wet to dry season and thereafter until the next spring (Figure 1).

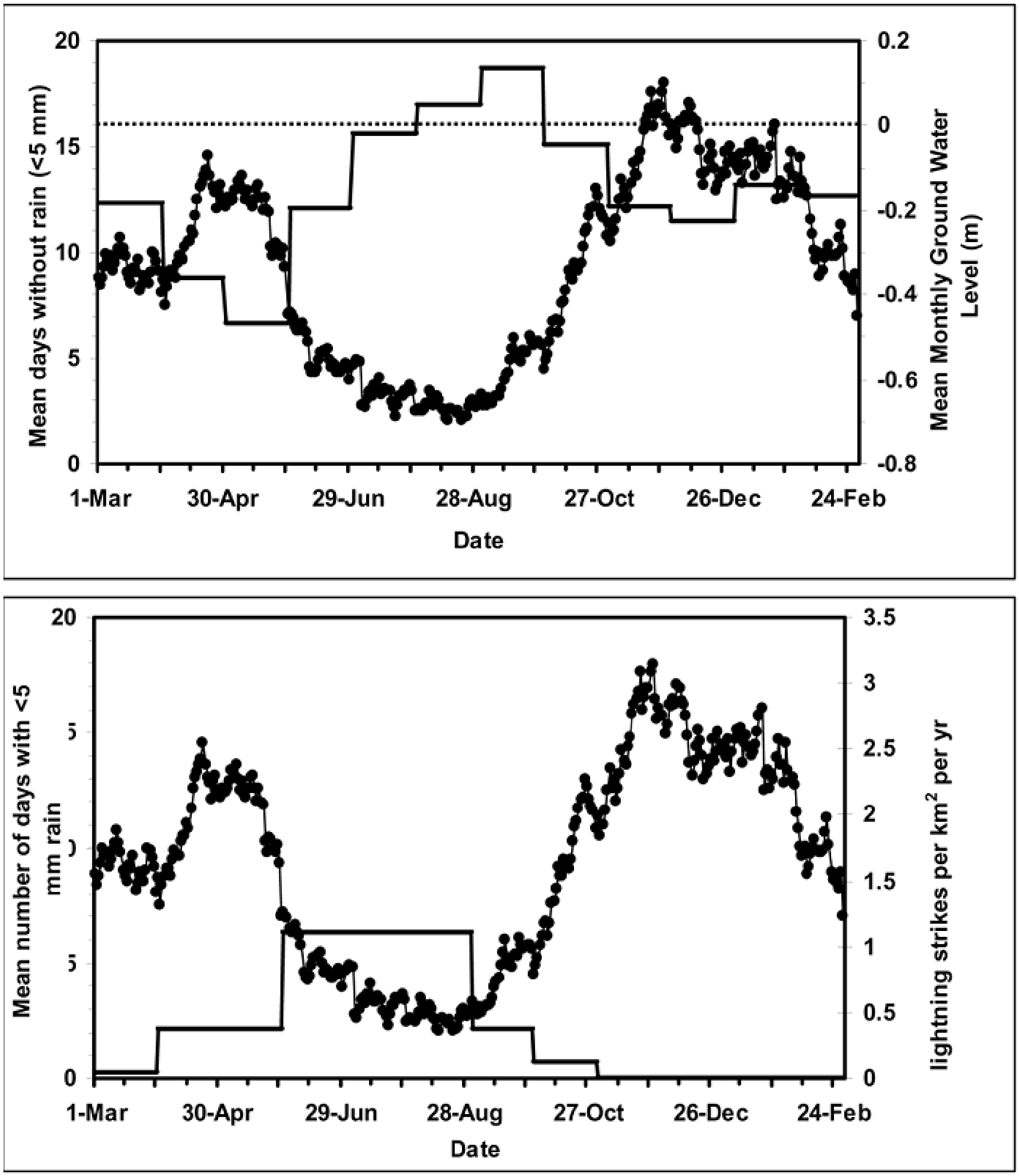


Figure 1. Climatic conditions at the Avon Park Air Force Range, Florida. Black circles in both graphs: mean number of successive days with <5mm rainfall recorded at Avon Park, FL for each day of the year during the period from 1944-1997. Upper: The histogram is the mean monthly ground water level at Tick Island (1974-2004), located in the pine flatwoods/dry prairie matrix of the eastern section of the Avon Park Air Force Range (Polk County, FL). Dotted line indicates ground surface at the well. Lower: The histogram is the mean number of cloud-ground lightning strikes per km^2 from 1944-1997. Figure modified from Platt et al. (2006).

Historical fire regimes at the Avon Park Air Force Range have not been explored. Records of current fire management have been kept since 1978. Before this time, little knowledge exists of characteristics of fire regimes, other than some anecdotal recollections of the prior century, and some aerial photos of fires on the landscape beginning in mid-20th century. Research on relationships of climate to fire regimes at APAFR has greatly increased our understanding of natural and human controls of fire regimes during the past several decades (Slocum et al. 2010 a, b, Slocum and Orzell 2013, Platt et al. 2014). No direct studies of fire history, however, are available.

Land use patterns at the APAFR have changed markedly over the period of record recorded in the tree rings of longleaf and slash pine. This period of record extends from the 1700s to the present. We designated different periods of land use based on human settlement patterns and major historical events of the periods using the report on the history of APAFR (Jones et al. in 2007) as well as various other historical sources (Mealor and Prunty 1976, Devane 1983, Myers and White 1987, Covington 1993). A summary of this information is presented in Table 1. This region of peninsular Florida historically was never densely populated. Prior to 1500, this region was occupied by indigenous people who likely concentrated along waterways; evidence of their presence consists of archeological sites, such as mounds on the lake and river shores. After the Spanish discovered Florida, populations of indigenous peoples declined and they likely were gone, or very nearly gone, by the time that the Seminoles were pushed further south into the region in the late 1700s to early 1800s (Covington 1993). The Seminoles had agriculture and open range-grazed cattle, and they also were concentrated along waterways. Early settlers and cattlemen expanded cattle grazing operations after the Seminoles were driven out of the region from the 1830s-1850. Cattle-grazing has been the primary human use of the site for the past 200 years or more and it remained open range until the late 1940s. The old growth timber of the area was cut between 1925 and 1930. We have separated the period of record for fire scars into two Eras: pre-extractive and extractive, based on the patterns of land use (Table 1). We divide the pre-extractive era into four periods (Indigenous Decline, Seminole era, Seminole Wars, and Homesteader/Open Range). The extractive era consists of two periods: Extractive and Bombing Range. A more detailed summary of the land use history is presented in Appendix 2.1.

Table 1. Chronological periods of time from 1500s to the present at the Avon Park Air Force Range. Two eras, the pre-extractive (1500-1919) and extractive (post 1919), are designated based on patterns of land use and the logging of the old growth pines. Within each of these eras, shorter periods are designated based on human populations and their land-use patterns.

Era	Period	Time Period	Major land-use patterns
Pre-Extractive	**Indigenous Decline**	1500- 1700s	Indigenous people likely concentrated along waterways, Major population declines in 1500s, practically absent by early 1700s.
	Seminole	Late 1700s until ~1850	Seminole Indians, along waterways, had cattle/agriculture
	Seminole Wars	1837 and 1849-1851	Military campaign again Seminoles, construction of short-term forts and removal of Seminoles from region
	Open Range/Homestead	1859-~1939	Homesteader Era, focused on raising cattle. Few settlers before 1865 end of Civil War, more settlers after Civil War, peak population of 30 families, very few left by 1939
		1860s -1880s	Cattle provided beef for Confederacy, cattle drives in spring/early summer. After Civil War cattle shipped to Cuba.
		~ 1900	Land purchased by Consolidate Naval Stores Co., mapped and timber inventories 1918 – 1921
Extractive	**Extractive**	1919-1928	Intensive turpentine operations
		1925-1930	Intensive logging of old growth pines
		1918-1939?	Consolidated Cattle Co./ introduced 25,000 cattle/sheep in 1919
	Bombing Range	1939	Land purchased by War Department
		Late 1940s	End of open range for cattle. WWII military training operations.

The large size of the APAFR is likely to result in heterogeneous fire regimes within the site. Therefore, we defined smaller fire history sites within the Range based on the ability to collect sections from trees and stumps within these more localized areas. Hereafter these areas will be referred to as "fire history sites" or "sites" as opposed to the larger "Range". These fire history sites are areas that are small enough so that a similar fire history among trees within a site was likely (Figure 2). We defined five fire history sites based on the distribution of fire scarred trees, current roads, and habitat types. The sites ranged from 192 to 743 hectares in size (Table 2). All have a mix of upland and wetland pine savanna habitat types. The predominant upland habitat types in the Tomlin Gulley, Eight-Mile and North Fence sites is mesic flatwoods, the Echo Springs site is primarily scrubby flatwoods and the Echo Range site is primarily mesic flatwoods and cutthroat savannas. In Appendix 2.2 maps with aerial photographs for each of the five major fire history sites, and five minor fire history sites that were not used in this report because of insufficient numbers of scarred trees or length of fire chronology, are presented.

Figure 2. Locations of the five fire history study sites (white-shading) that were used in this study. Yellow line indicates boundary of APAFR.

Table 2. Size of fire history sites in hectares and acres.

	Fire History Site	Size Hectares	Size Acres
1	Echo Springs	214	529
2	Tomlin Gulley	650	1606
3	North Fence	743	1836
4	Echo Range	354	876
5	Eight-Mile	192	474

Wood collection

Fire scars occur in living trees and in dead wood such as stumps and snags. Old wood with fire scars is the key to fire history reconstructions. Old wood, living or dead, is not abundant at APAFR. We attempted to locate and collect cross-sections from downed trees, snags, and stumps of longleaf pine and south Florida slash pine throughout the Range. The first phase of collecting wood began after Hurricanes Jeanne and Charley felled many trees throughout the range. In conjunction with APAFR personnel, between November, 2004, and August, 2005, we scouted for the oldest trees and those having external evidence of fire scars after the hurricanes (Figure 3). Generally, trees that looked the oldest (flat-topped, large, etc.) or that had visible fire scars were sampled. A single cross-section of the trunk was collected using a chainsaw from each of 191 trees during this first phase of collecting. For each tree sampled, we recorded the species, GPS location, shape of crown, whether the tree was uprooted (tip up, Figure 3A) or snapped off by the wind (snap off, Figure 3B), height of section taken, dbh of tree, and any evidence of scarring. A photograph was taken of nearly every tree.

Figure 3. Phase 1 collection focused on recently dead trees killed by hurricanes Jeanne and Charlie, (A) Wayne Taylor cutting a basal cross-section from a longleaf pine tipped-up during Hurricane Jeanne. This tree has a large, externally-visible fire scar. The site is mesic flatwoods. Other trees felled during the hurricane are visible in the background. (B) Preparing to collect a cross-section from a Longleaf pine in a cutthroat seep habitat with trunk snapped off by hurricane Jeanne.

The old pines needed to reconstruct early fire history are not common at APAFR and are concentrated in a few areas. The 191 recently dead trees from which we collected sections were concentrated in four areas along the north-south central “Bombing Range Ridge” (Figure 4). Of these trees, only 12 were 150 years or older. The five oldest trees that we found that were killed by the hurricanes (recently dead trees) were between 171 and 214 years old in 2004. The very oldest hurricane-killed trees were located in stands of old trees in Echo Springs and the North Fence areas (Table 3). Trees older than 150 years were also located in the Tomlin Gulley (Figure 5) and Eight Mile areas, but not in other locations, except for one old tree in Orange Hammock.

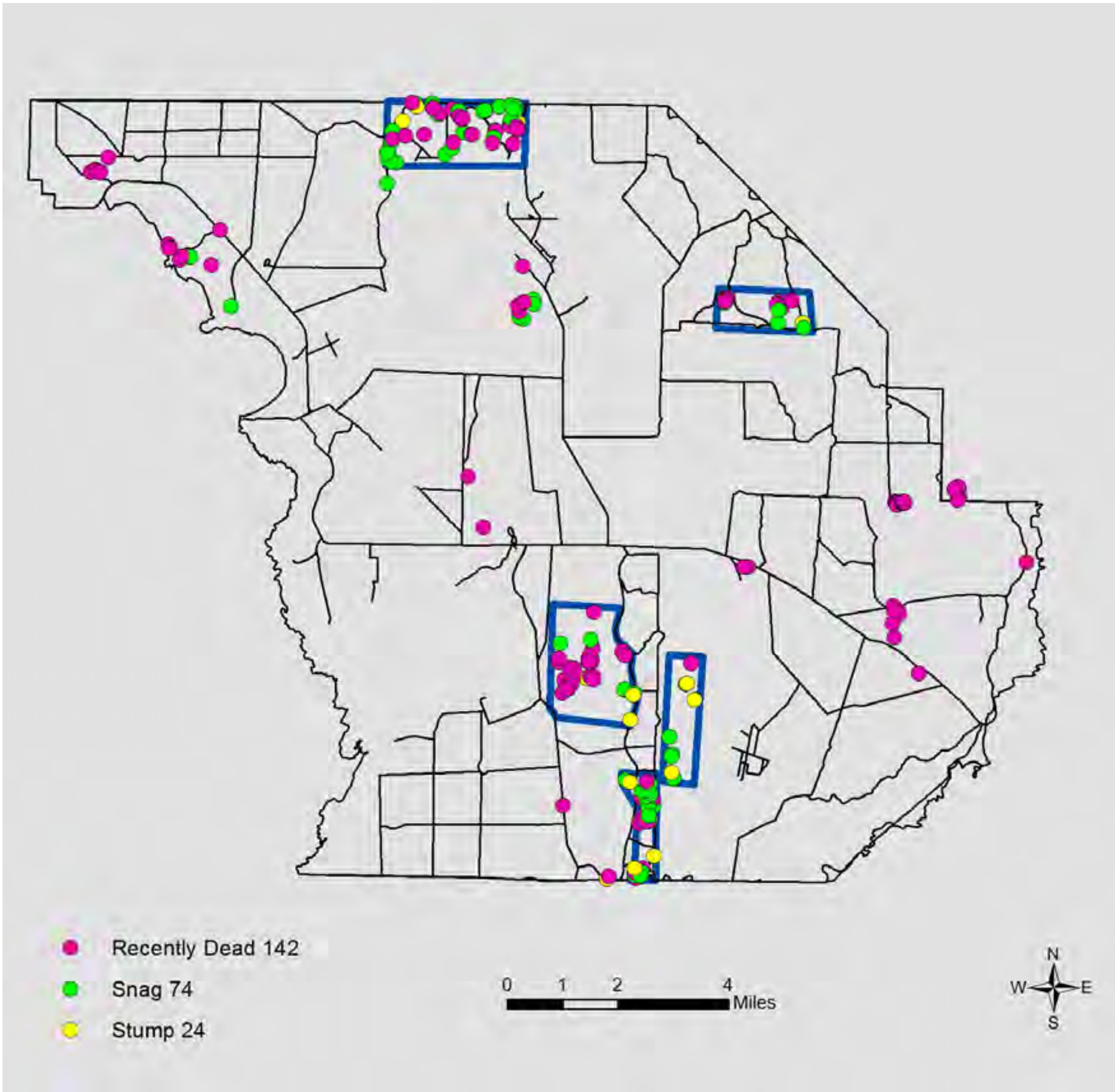


Figure 4. Locations and types of trees (recently dead, snag or stump) for the 240 longleaf and slash pines sampled throughout APAFR. Older trees, and therefore samples, were concentrated at the north and sound ends of the central "Bombing Range Ridge" that runs north-south through the range. The five fire history sites are outlined in blue. Lines within APAFR boundary indicate roads within the Range that are used in current fire management.

Table 3. The dates of oldest trees sampled from six different regions of APAFR. Age is indicated by the year of the innermost dated ring. Included for each region are the oldest trees of two categories: recently dead trees and long dead trees (stumps and snags).

Site	Recently dead pines	Long dead pines
Echo Range	1935, 1936, 1940	1756, 1810, 1812
North Fence	1790, 1820, 1829	1758, 1786, 1790
Eight Mile	1838, 1842, 1854	1836
Echo Springs	1804, 1822, 1833	1794, 1810, 1821
Tomlin Gulley	1845, 1850, 1863	1813
All other sites	1835, 1870	na

Figure 5. Old-growth Longleaf pine flatwoods at the Tomlin Gulley site. This is one of the few remaining sites on APAFR where there are many trees over 100 years old. Note the flat-topped growth form that is typical of these old longleaf pines.

Old stumps and snags are also rare and historically valuable. Both stumps and old snags were concentrated in the Echo Springs/Echo Range area at the south end of the central Bombing ridge, and the north end of the Ridge in the North Fence areas (Figure 4). Stumps contributed most of the oldest wood found in this study (Table 3). Stumps were remains of dead trees less than .5 meter tall, and snags were trees >0.5 m tall that were dead long enough to lose any branches (Figure 6). Information recorded for each stump or snag section included: GPS location, type (stump/snag), and height at the top of the sections taken. Multiple sections were often taken to try to capture as many fire scars as possible.

We also used some sections collected prior to initiation of the study in 2004. Sections from the stumps of nine trees were collected in February, 2001, in the southern Echo Springs area after old longleaf pines had been cut as prescribed in a scrub jay habitat management plan. Many old longleaf pines, including one of the oldest trees used in this study, were cut in Echo Springs in 2000 in what was the largest of the 3 major old longleaf stands in the Range. Six of the sections had fire scars and were used in this study, but do not have GPS locations (and thus are not on maps); these trees were taken from the area bounded by Echo Springs Road/South Fence and Echo Range.

Wood samples were prepared for microscopic examination. Cross-sections containing at least one fire scar (n=151) were processed in the lab to produce a fine surface suitable for microscopic examination. Cross-sections were allowed to dry, and then planed and sanded, using progressively finer sandpaper (80-600 grit up to 1200 grit) to produce a surface that revealed cellular structure of the wood.

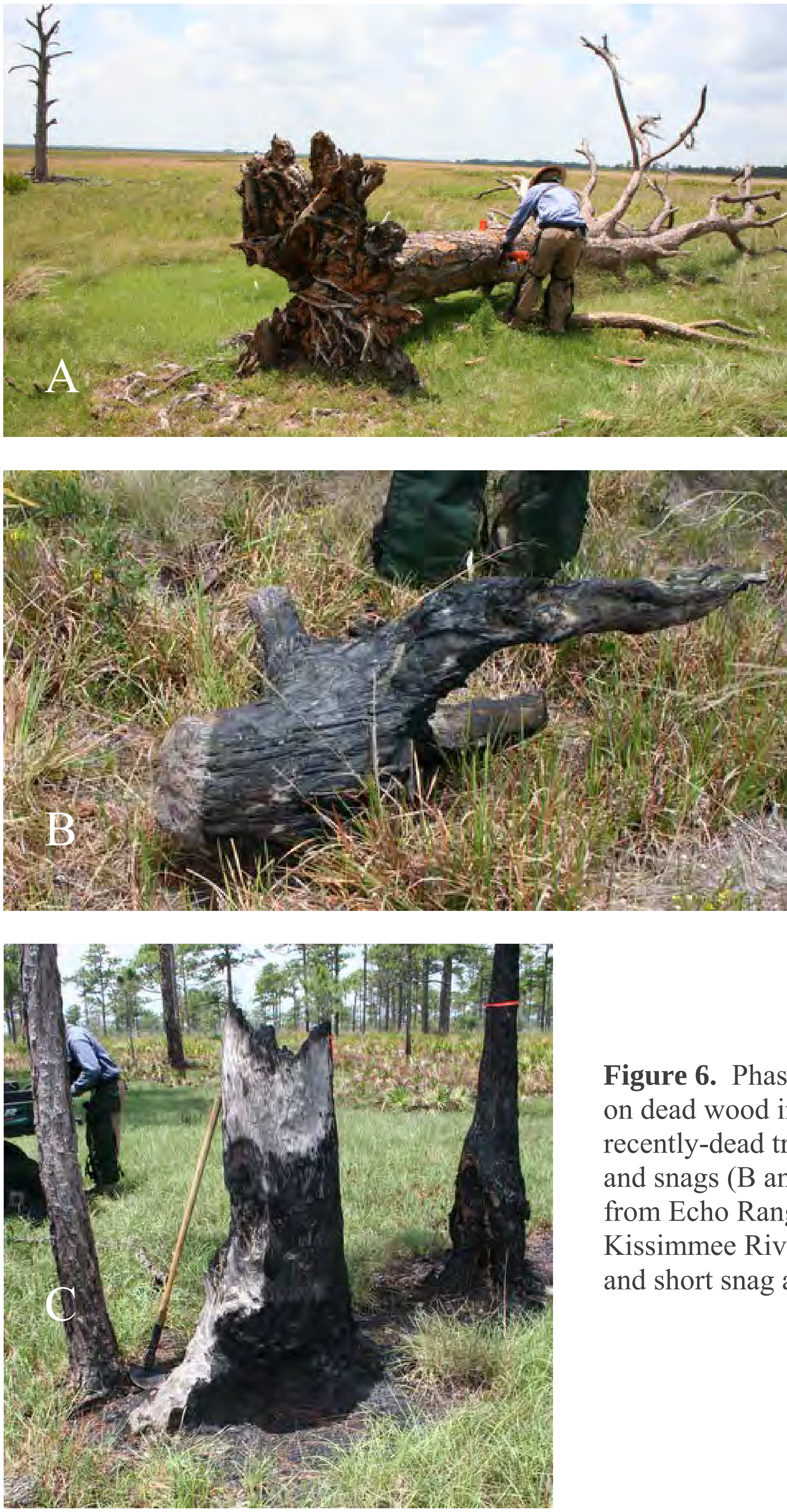


Figure 6. Phase 2 collection focused on dead wood including additional recently-dead trees (A), and old stumps and snags (B and C). All of these are from Echo Range near the edge of the Kissimmee River marsh, the stumps and short snag are in a cutthroat seep.

Growth chronologies

We used the sections collected from trees to develop a site specific master tree-ring growth chronology for the APAFR, which is necessary to precisely date tree rings and fire scars. The two dominant species of pines that occur at APAFR, longleaf pine (*Pinus palustris*) and South Florida slash pine (*Pinus elliottii* var. *densa*) had fire scars that could be used for fire history reconstruction. Both species, however, present challenges for dendrochronology work. Longleaf pine, the dominant tree of APAFR historically, and the most common older tree at the range, is at the southernmost limit of its range in south central Florida. Longleaf pines growing in the subtropical climate of southern peninsular Florida produce rings that have many unclear ring definitions (mostly false and partial rings) leading to difficulty in interpreting rings. A master chronology using longleaf pine is essential to interpret these rings but to our knowledge no chronologies of longleaf pine have previously been completed in this region. The purpose of the chronology is to determine the master pattern of large and small rings that occur in response to overall climate so that any false or missing rings in an individual tree will not result in inaccurate dating.

We used standard dendrochronology methods (Stokes and Smiley 1996) to produce a cross-dated chronology. The most promising sections (i.e., with clearest rings) were selected. Graphic representations of the patterns of large and narrow rings were made (skeleton plots) for each section and compared to those from other trees. The rings of these sections were dated, marked, and measured using a microscope and Velmex sliding stage micrometer. The computer program COFECHA (Grissino-Mayer 2001a) was used to detect and assist in correcting any errors in measurement and cross-dating. The abundance of false and "pinching" rings (those that were visible over a portion of the diameter of a section but disappeared and merged into other rings in the other part of the section) made it difficult and time-consuming to develop the master chronology.

We used the computer program ARSTAN to standardize tree-ring series to remove the age trend and to minimize effects of autocorrelation in the time series (Cook 1985). Each tree-ring series was detrended with fitted negative exponential curves. Three types of index chronologies were created using the program ARSTAN: standard, residual, and ARSTAN.

The chronology is constructed primarily from longleaf pines but also included south Florida slash pines. To construct the chronology a total of 106 longleaf pine (*Pinus palustris*) and six South Florida Slash Pines (*Pinus elliottii* var. *densa*) were used. The six south Florida slash pines that were included correlated very well with the predominately longleaf pine master chronology.

We first developed a master site chronology using all of the trees that had the strongest correlations and then constructed separate chronologies based on the trees from individual fire history sites or from different habitat types. For the habitat-based chronologies trees were separated into three habitat types based upon where they were growing: scrubby flatwoods (dry, well-drained sites), mesic flatwoods (mesic, poorly-drained sites) or cutthroat seeps (seasonally-wet, poorly drained sites). We determined if there were differences in tree growth responses that would make stronger chronologies (and therefore make trees easier to date) using habitat specific or fire history site-specific growth chronologies.

Fire scars

Each fire scar was dated and several types of scars were used. Rings within all cross-sections with fire scars were measured and dated to year using our site chronology and standard dendrochronological techniques of visual and statistical cross-dating using COFECHA (Holmes, 1983). Several types of fire scar categories were used: external curl, internal curl, and distortion. These types of fire scars are illustrated and described in Figure 7. Curl or distortion scars are anomalous patterns to subsequent wood growth known to be caused by fire damage to the cambium (Morrison and Swanson 1990). "Curl" scars are characterized by areas of vascular cambium that were killed by fire and subsequent tissue grew over the dead area forming the curls (Figure 7). External curls have a surface that is exposed (Figure 7A); internal curls are areas within the tree where a section, often very small, of vascular cambium was killed and tissue grew completely over the wounded area so it was not visible from the external surface of the tree (Figure 7B, 7C). "Distortion" scars are characterized by areas of vascular cambium that does not appear to have been completely killed but has been injured. Subsequent growth is distorted and generally thicker than in the rest of the uninjured part of the ring as it grows over the damaged area (Figure 7D). Also, discoloration, either dark or light colored, is typically associated with the scar and often the subsequent wood, as indicated in Figure 7. The few old stumps that were found were a rich source of old non-exposed fire scars (Figure 8).

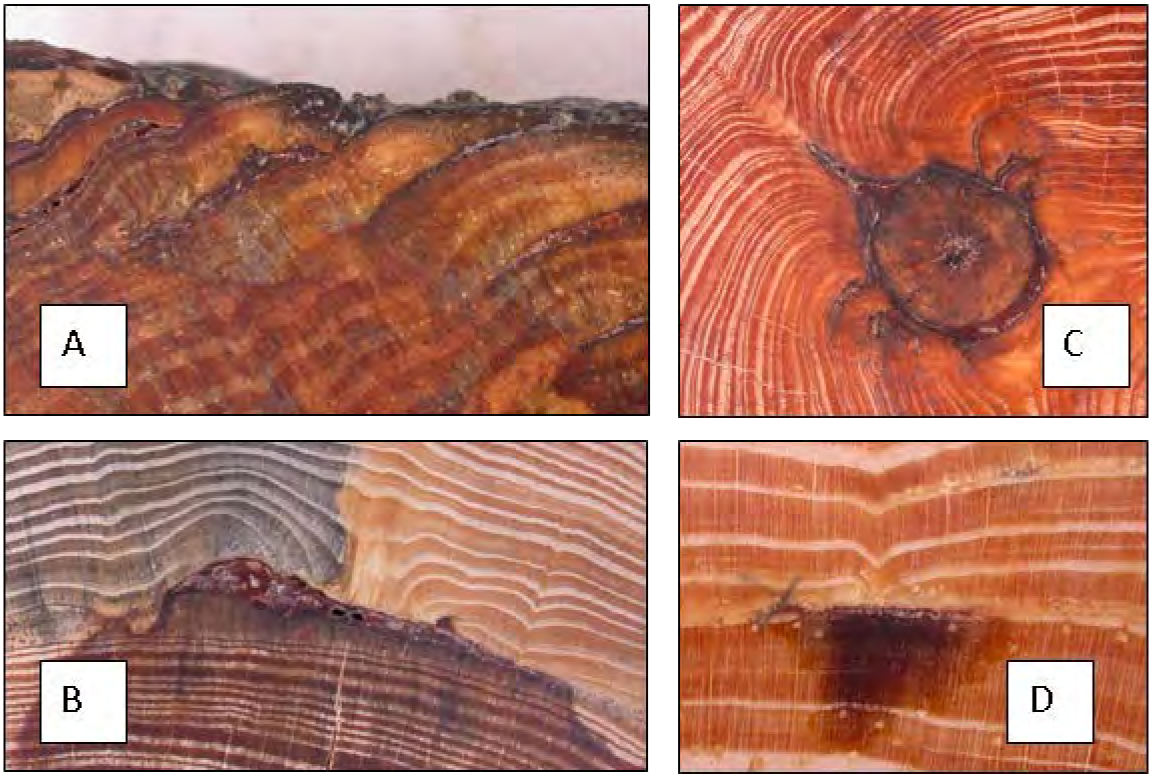


Figure 7. Illustration of "external curl" (a) and "internal curl" (b, c) and "distortion" (d) categories of fire scars. External curls (A) are scars that are visible from the external surface of the tree. Different variations on internal scars, those not visible from the external surface of the tree, are shown in B and C. C shows a relatively rare example of fire scars that occurred on the tissue that was wrapping around a branch. D is an internally healed scar that did not produce "curls", but where a very small area of cambium was killed, resulting in distorted subsequent growth.

Figure 8. This cross-section (North Fence 05) is an example of one the stumps that were a rich source of very old non-exposed fire scars, not visible until the section is cut. These stumps helped extended the fire history back in time.

Fire frequency

Dates were assigned to fire scars relative to their position in the dated tree-ring series. Fire scar dates were assigned to the first year of response to cambial injury. We compiled all dated fire scars we found to create a fire chronology. We used FHX2 software (Grissino-Mayer 2001b), the standard software used in fire history studies, to construct composite fire chronologies and generate summary statistics on fire intervals.

We used the interval between fires (years) as the measure of fire frequency. We used two standard composite interval statistics to describe fire intervals: the Mean Fire Interval (MFI) and the Weibull Median Probability Interval (WMPI). The MFI is the mean of all fire intervals for a specified area. The WMPI is the estimated interval at which there is a 50% probability of a longer or shorter interval, based upon all of intervals analyzed. In fire frequency data WMPI is considered more appropriate than MFI as a measure of central tendency due to non-normal distribution of intervals around the mean (Grissino-Mayer 2001b, Kitchen 2012).

We examined these measures of fire intervals at two different spatial scales: range-wide, within each of our five specified fire history sites. Fire intervals can be examined at different spatial scales and may vary depending on the size of the area being considered. A large area, such as the entire APAFR, may have many separate fires over a period of time but they may not burn all points within the greater area. Since many fires occur across the range in any one year site specific fire intervals might vary across smaller, more defined areas, especially since the older trees were concentrated in widely separated areas. The five major fire history sites were small enough so that a more similar fire history among trees was likely. We constructed composite fire chronologies and generated summary statistics on fire intervals for the APAFR as a whole and for each of the 5 major fire history sites within the Range.

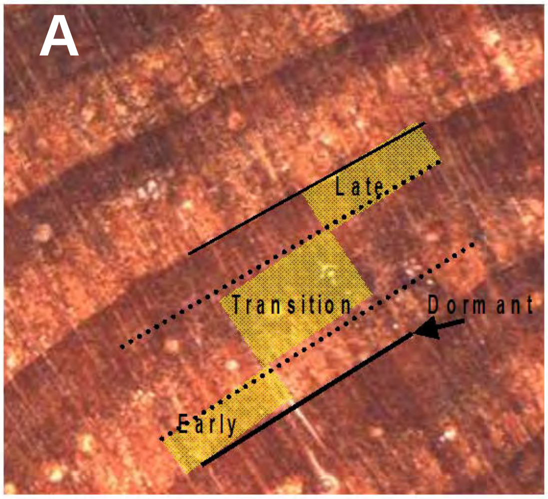
We could not accurately examine change in fire interval over time using these two spatial scales. Because of the fading fire record (the record of fires for the early time period was sparse relative to more recent time periods), the early and later time periods were not comparable in terms of recorded fire frequency. Examining changes in frequency of fire over time would result in decreases in intervals between fires over time primarily because of the fading fire record.

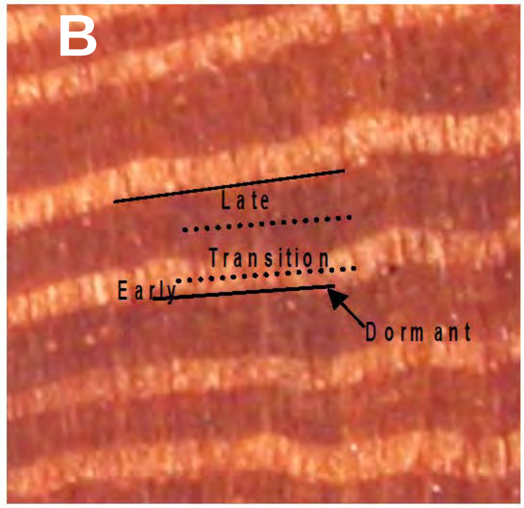
We examined short-interval fire scars within individual trees to examine change in fire interval over time and compensate for the fading fire record problem. Individual trees provide a record of some of the fires that occurred at a single point in the landscape. Because of the strong resistance to cambial damage in longleaf and slash pines, most trees do not record all, or even most, of the fires that pass near them. When a tree is scarred initially it often becomes more sensitive to scarring by subsequent fires and then records a series of successive fires. After they heal they stop recording low intensity fires. For periods of time, however, these sensitive recorder trees indicate many short-interval fire scar sequences. We examined short-interval scar sequences of 1, 2 or 3 years using the data in sensitive recorder trees. For each tree we determined the number of one-, two- or three- year fire intervals that were recorded by the trees during each decade. Using all trees we determined and graphed the proportion of 1, 2, or 3 year fire intervals for each decade of the fire history record. We used these data to examine changes in frequency of short interval fires over time for the entire range and for each fire history site.

Fire time-of-year

To determine the intra-annual timing of fires we assigned a scar position category to each fire scar that was clear enough to locate the position. Fire time of year refers to the location of scars within annual rings. The categories and corresponding monthly timing for the position of scars were determined by a separate study of the cambial growth of pines at APAFR which is summarized in Table 4 and treated in detail in part 1 of this report. This timing is not coincident with seasons as determined via climatological studies of rainfall (Slocum et al. 2010a) or more traditional seasons based on temperatures.

Table 4. The four position designations of the Florida intra-annual fire scar position designation system (**dormant**, **early**, **transition**, and **late)** seen on one annual growth ring of longleaf pine with wide earlywood growth (A) and one with narrow earlywood growth (B). For each ring position designation we present the corresponding months of growth, rainfall, and relative lightning frequency (from Part 1 of this report).





Designation of Ring Positions	Location in Ring	Number of Months	Corresponding Months	Rainfall	Lightning Frequency (scale of 0-3)
Dormant	Between latewood of previous year and current year's earlywood)	2	January-February	Dry Season	None 0
Early	First 1/2 of earlywood	1.5	March- and early April	Dry Season	Low 1-2
Transition	Final 1/2 of earlywood through first 1/2 of latewood	4.5	Late April-May-June-July-August	Wet Season and end of dry season	High 2-3
Late	Final 1/2 of latewood	4	Sept-Oct-Nov-Dec	Dry season and very end of wet season	Some in Sept & Oct. then very low 0-2

We compiled and graphed the time of year of fire scars and then examined changes in the time-of-year of fires over time. First, we determined the number of all scars and then determined the percentage of occurrences of each scar position. We graphed the proportion of all scar positions by decade and then examined changes over decadal intervals in the position of scars over the period of record - focusing on the differences between different eras of the human history of the range. We also examined differences in the within-year-timing of fires over time among the five fire history sites.

Results

Growth chronologies: Results & Discussion

Master growth chronology. We produced a master site chronology for the APAFR that was the foundation of all tree-ring dating for this project. The dated series from 106 longleaf and 6 slash pines from all sites and habitats produced a 250-year chronology (1756 to 2005) (Table 5). Two important statistics for tree ring chronologies are the series sensitivity and series inter-correlation. Mean sensitivity measures the relative change in ring-width from one year to the next in a series of trees, the higher the sensitivity the greater the variation in ring widths. The mean sensitivity of the APAFR chronology (0.42) (Table 5) is among the most sensitive among Southeastern savanna pine chronologies which ranged from mean sensitivities of 0.26 to 0.45 (Foster and Brooks 2001, Henderson 2006, Bhuta et al. 2009, Henderson and Grissino-Mayer 2009, Stambaugh et al. 2011). The 0.42 sensitivity of our APAFR trees is similar to the 0.39 mean sensitivity of the South Florida Slash pine from the Florida Keys (Harley and Grissino-Mayer 2011) and the 0.42 from longleaf pines in Louisiana (Stambaugh et al. 2011). The series inter-correlation measures the strength of the signal that is common to all trees at the site (climate) and is a measure of the strength of the chronology. The 0.46 series inter-correlation and is strong and compares favorably with longleaf and slash pine chronologies from other sites in Florida and the Southeastern Coastal Plain that vary from .40 (Tampa, Florida, Foster and Brooks 2001) to 0.56 (Louisiana, Stambaugh et al. 2011). The standardized chronology shows the year to year variation in growth of the APAFR pines over time (Figure 9). The replication (sample depth) is very strong for most of the record but the lack of replication in the earliest part of the record from 1750 to 1810 means that this part of the record should be viewed with some caution (Figure 9). The APAFR master chronology enabled accurate dating of rings of the trees used in the fire history reconstruction.

Table 5. Summary statistics for Avon Park Air Force Range master tree ring chronology (from Cofecha).

Summary Statistics:

Total number of trees in chronology	112
Longleaf Pine *Pinus palustris*	106
South Florida Slash Pine *Pinus elliottii* var. *densa*	6
Length of master series (1756-2005)	250 years
Total dated rings in chronology	9201
Series intercorrelation	0.46
Series sensitivity	0.42
Mean age	82.4 years

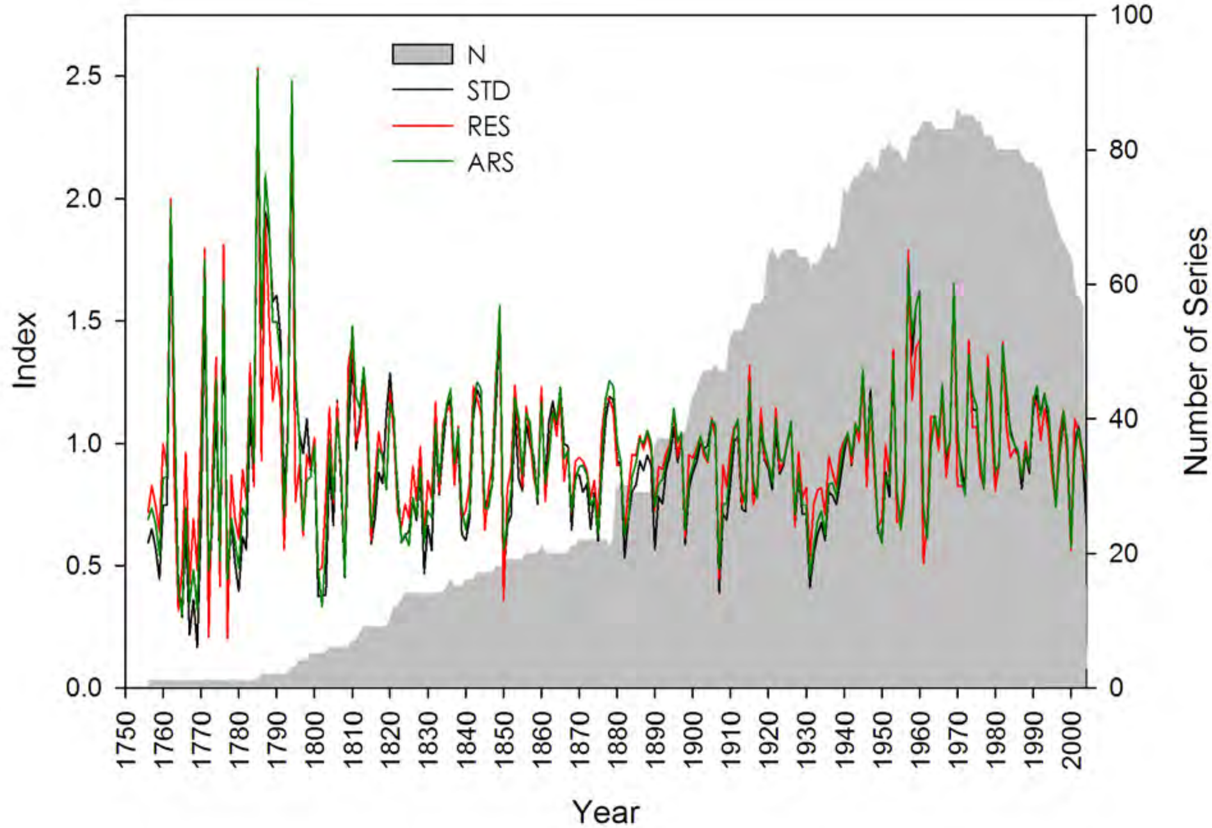


Figure 9. A 250 year tree longleaf and South Florida slash pine tree ring chronology from APAFR. Sample depth (number of sample trees recording fires at calendar year) is plotted on the right y-axis. Lines indicate the ARSTAN standard tree ring growth chronology (green line), standard chronology (black line), and residual chronology (red line). Left axis is the ring-width index.

Habitat and fire history site-specific growth chronologies. Overall (range-wide) climatic influences on the growth of trees were stronger than site-specific or habitat-specific influences. When trees from all habitat types were examined together in the master chronology the series inter-correlation was 0.46, higher than when trees were separated by habitat type (xeric uplands 0.43, mesic slopes 0.43 and cutthroat seep 0.38). Both series inter-correlations and sensitivity differed little among the three habitat types (Table 6). Cutthroat seeps had a slightly lower series inter-correlation, but also had fewer trees in the chronology relative to the xeric and mesic sites. Series inter-correlations were also slightly lower when trees from each of the 5 fire history sites were examined separately than when they were grouped together (Table 6). Chronology strength (series inter-correlation) did not increase when trees were examined separately either by habitat or site. Therefore, the master chronology rather than a site or habitat-specific chronology was used to date all trees and fire scars in this study.

Table 6. Summary statistics for Avon Park Air Force Range master tree ring chronologies based on habitat type and location (fire history study sites) (from COFECHA).

	Trees in Chronology	Time covered	Years	Mean Years	Series Inter-correlation	Mean Sensitivity
All Sites/Trees	112	1756-2005	250	82.4	0.46	0.42
Habitat Type						
Xeric uplands	46	1786-2005	220	81.8	0.43	0.41
Mesic slopes	47	1756-2004	249	86.4	0.43	0.42
Cutthroat seep	17	1794-2003	210	70.5	0.38	0.43
Fire Study Site						
Echo Springs	28	1794-2005	212	96.4	0.44	0.43
Tomlin Gulley	21	1813-2003	191	69.1	0.45	0.41
North Fence	18	1786-2003	218	93.1	0.42	0.42
Echo Range	14	1756-2003	248	72.1	0.37	0.43
8-mile	5	1799-2003	205	99.4	0.30	0.42

Fire scars and distribution of fire-scarred trees

Fire scars were present in recently dead trees, snags, and stumps that were collected. A total of 740 fire scars were found and dated (to year, and season when possible) from 151 trees (recently dead, stumps and snags). The remaining trees that were collected, but not used, had no fire scars; all were <100 years old. Fifteen trees used in the fire history study were South Florida slash pine; 136 were longleaf pine. Each cross-section and its scars are presented graphically in Figure 10. The earliest fire scar recorded in this study occurred in 1784. Fire scars generally increased in abundance with each subsequent decade. This trend can be seen clearly in the generally increasing number of scars per decade (Figure 11). This is not evidence of more fires occurring in recent times, but illustrates the well-known phenomenon of a rapidly fading fire record (Swetnam et al. 1999). This effect of a fading fire scar record is especially pronounced at APAFR because of the paucity of old trees and frequent fires often destroyed exposed fire scars and dead wood.

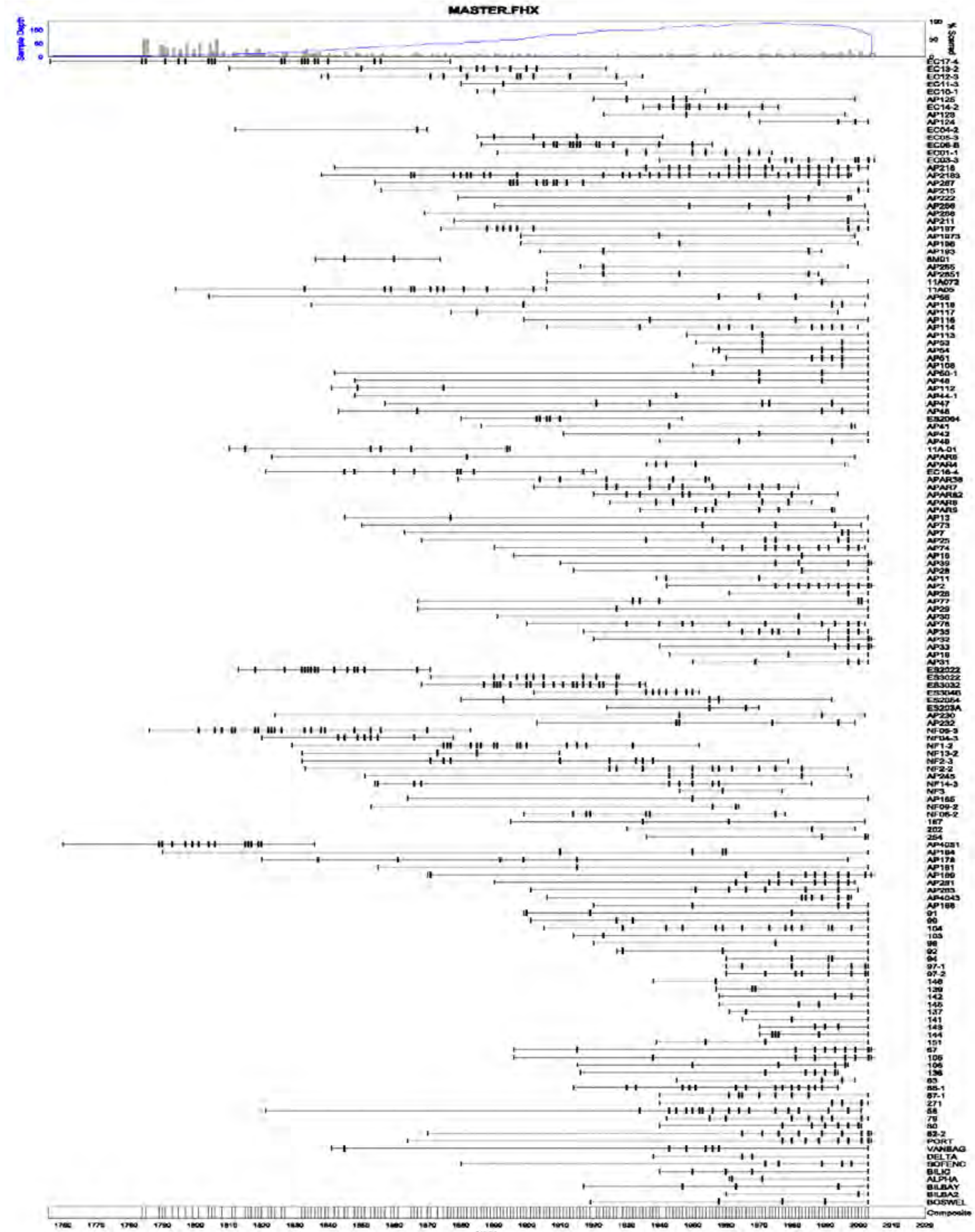


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Figure 10. Fire scars in 151 trees at the Avon Park Air Force Range. Each horizontal line represents a tree; Identification number is at right. Each vertical hatch mark represents a fire scar. The sample depth (blue line) and percent of recorder trees with fire scars (small grey bars) are shown on the top portion of graph. The range-wide fire composite is presented at the bottom. All years with fire scars are indicated with a vertical line.

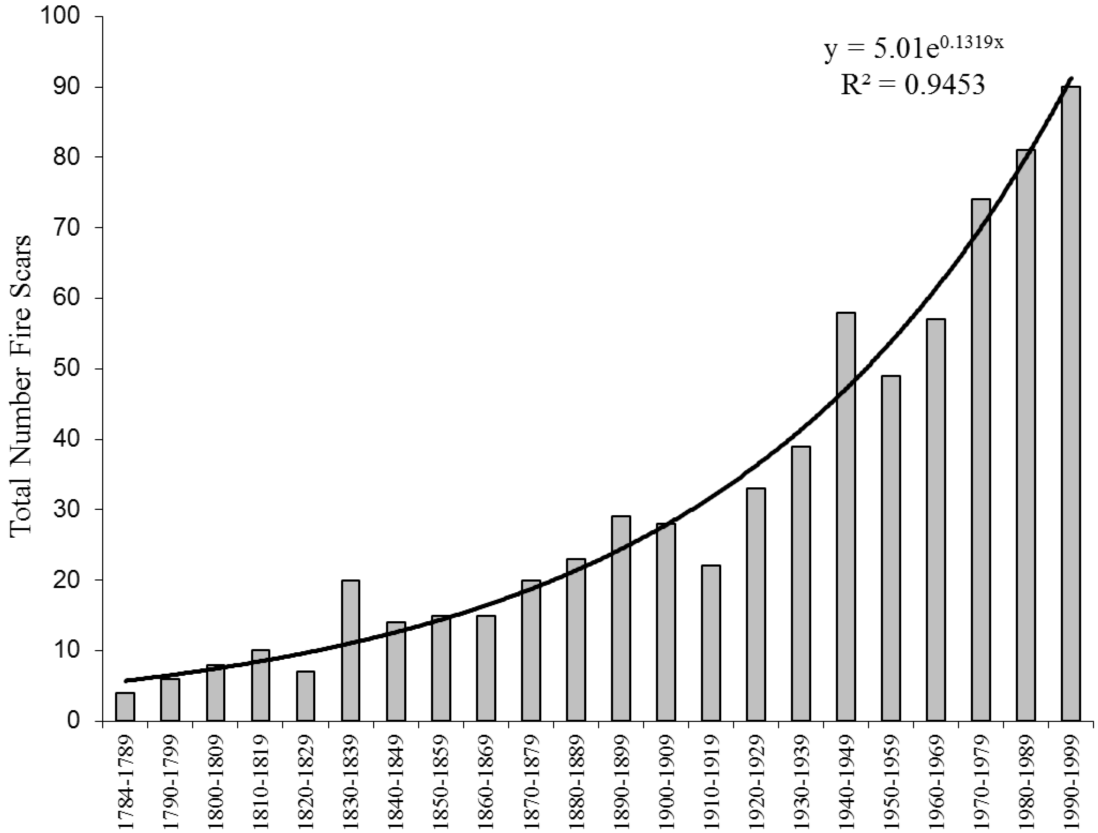


Figure 11. The total number of fire scars per decade recorded from 151 fire scarred trees at APAFR (1784-1999). An exponential regression line shows the trend of fewer scars further back in time.

Fire-scarred trees were found across APAFR but were clustered mainly in five fire history sites. Most old trees, stumps, and snags occurred within the five fire history sites (113 of 151 total fire-scarred trees) (Figure 12). Total numbers of fire-scarred trees in the fire history sites ranged from 14 on the Echo Range site to 33 on the Echo Springs fire history site (Table 7). Each of these five fire history sites had more than 10 trees or stumps with fire scars (range 14-33 per site) and a site chronology that goes back in time more than 150 years (range 155-221 years). Most of the fire-scarred trees outside of fire history sites occurred in five other named locations (Figure 12). These 5 other locations have 8 or fewer scarred trees and only record time periods after 1900 (Table 7). These locations did not have sufficient sample depth and length of fire history period to serve as fire history sites.

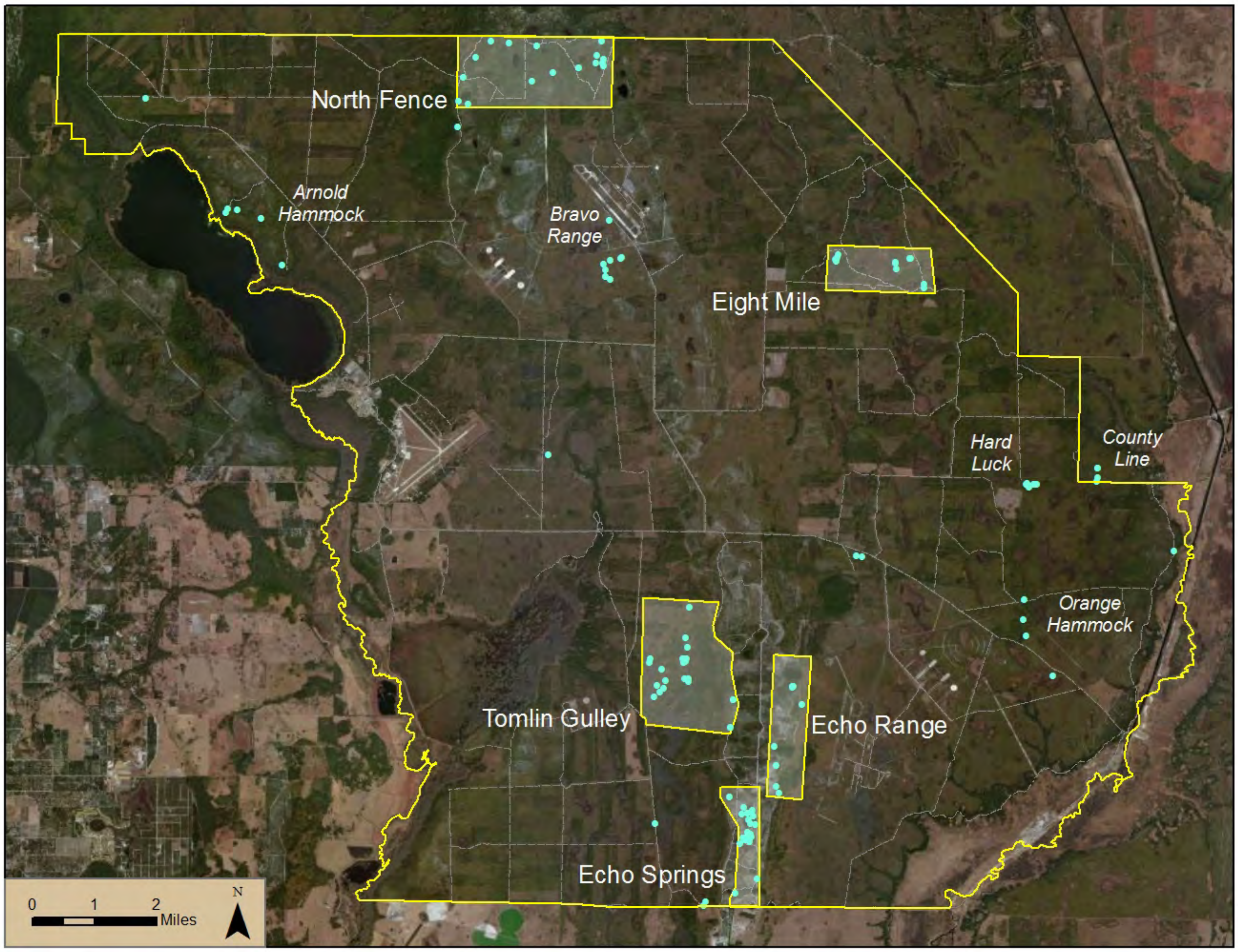


Figure 12. Map of fire history study sites and distribution of fire-scarred trees on APAFR**.** The five fire history sites (yellow outline, white shading) and five additional named locations (without outline) include 142 of the 151 fire-scarred trees and stumps (indicted by blue circles) collected and used in this study. APAFR boundary is indicated by yellow outline.

Table 7. Number of fire scarred trees and length of fire history period for the five fire history sites and five other named locations sampled trees at APAFR.

Fire History Site	Number Samples	Range of Scar records	Length of Fire History Period (Years)
Echo Springs	33	1815-2003	189
Tomlin Gulley	26	1817-2003	187
North Fence	25	1789-2002	214
Echo Range	14	1784-2005	222
Eight-Mile	15	1845-2000	156
Other Locations	**Number Samples**	**Range of Scar records**	**Length of Fire History Period (Years)**
Bravo	8	1957-1998	42
Hard Luck	9	1900-2002	103
Arnold Hammock	4	1915-2003	89
County Line	4	1930-2001	72
Orange Hammock	4	1934-2003	70
Not in a named location	9	1943-2003	61
TOTAL	151	1784-2005	222

Fire frequency

Range-wide. Fires recorded by tree rings occurred frequently across the APAFR over the period of fire record (1784-2005). Range-wide, at least one fire was recorded in all but 35 of the 222 years of the fire scar record (Figure 13). The range-wide fire interval was slightly longer than one year (1.19 years MFI, 1.13 years WMPI, Table 8). One or 2-year intervals comprised 97% of all range-wide fire intervals over the period of fire record (86% one-year and 11% 2-year); only 3% of intervals were more than 2-year (Figure 14). Almost all intervals longer than one year occurred in the early portion of the fire record, before 1875 (Figure 13), that period in which fewer fire scarred trees were available for study. These longer intervals likely reflect scarcity of samples early in the fire record. Fires likely have been annual occurrences on the Range during the entire period of fire record.

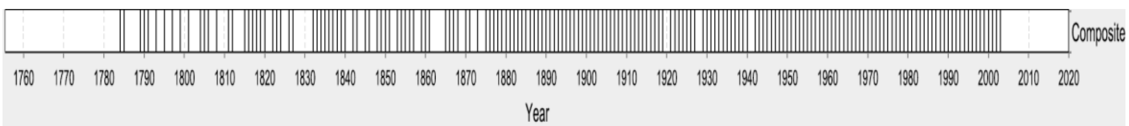


Figure 13. Composite Fire Chronology for Avon Park Air Force Range enlarged from bottom of Figure 10. Each vertical line represents a year with one or more fire scars indicating that a fire occurred within the range that year. The period of fire record was 1784-2005.

Table 8. Summary statistics for the Avon Park range-wide fire chronology, including five different measures of fire frequency or interval. The mean fire interval and Weibull median interval, highlighted in gray, are the most widely-used measures of fire interval.

Beginning year	1784
Last year	2005
Length of fire chronology	222
Total number of samples	151
Total number of recorder years	14374
Total number of fire scars	740
Percentage of years MFI	1.4
Total Intervals	184
Mean Fire Interval	1.19
Median Fire Interval	1
Fire Frequency	0.84
Weibull Modal Interval	1.01
Weibull Median Interval	1.13

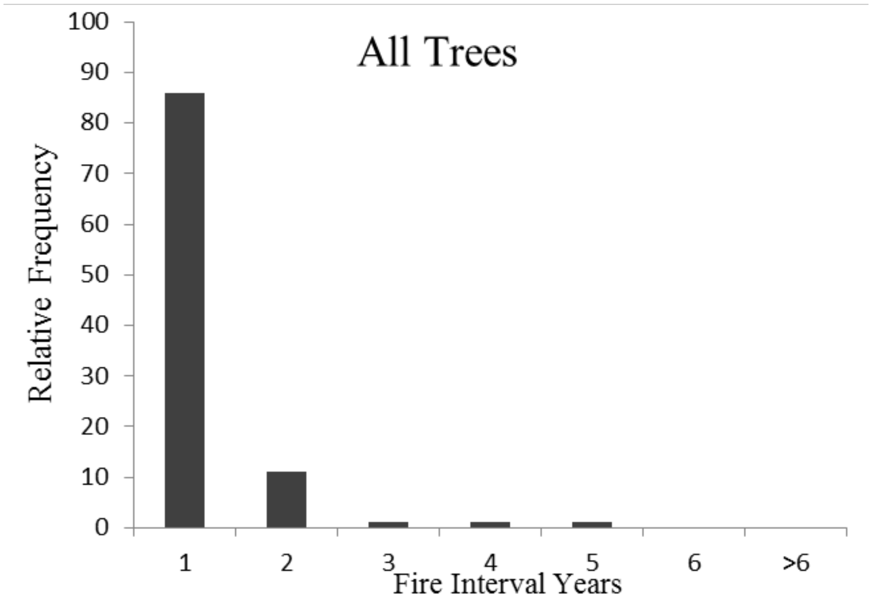


Figure 14. The distribution of different length fire intervals for APAFR over the period of fire record (1756-2005). The relative frequencies are derived using all trees range-wide.

When examining the fire intervals that occurred at single points (individual trees) rather range-wide, the length of fire return intervals changed over the 222 year period of study. Annual and biennial fire intervals were common in the early portion of the fire record, and 3-year intervals became common in recent decades. Our analysis of short-interval (1-3 year) fire scars on individual trees showed that a high proportion of annual fire intervals occurred before the 1930s, but afterwards annual fire intervals were never common. The reverse is true for 3-year intervals, which were uncommon before 1900 and became dominant (50% or more) for 5 of the six decades after the 1930s (Figure 15). Trends over time are shown in Figure 16. Over time there was an increase in 3-year fire intervals (R^2=0.7602), and a decrease in one-year intervals (R^2=0.4493). The abundance of 2-year fire intervals did not show a strong trend (R^2=0.1777) (Figure 16). Two year intervals were common for most decades until but they were rare (.0 to .06) in 3 of the 4 last decades.

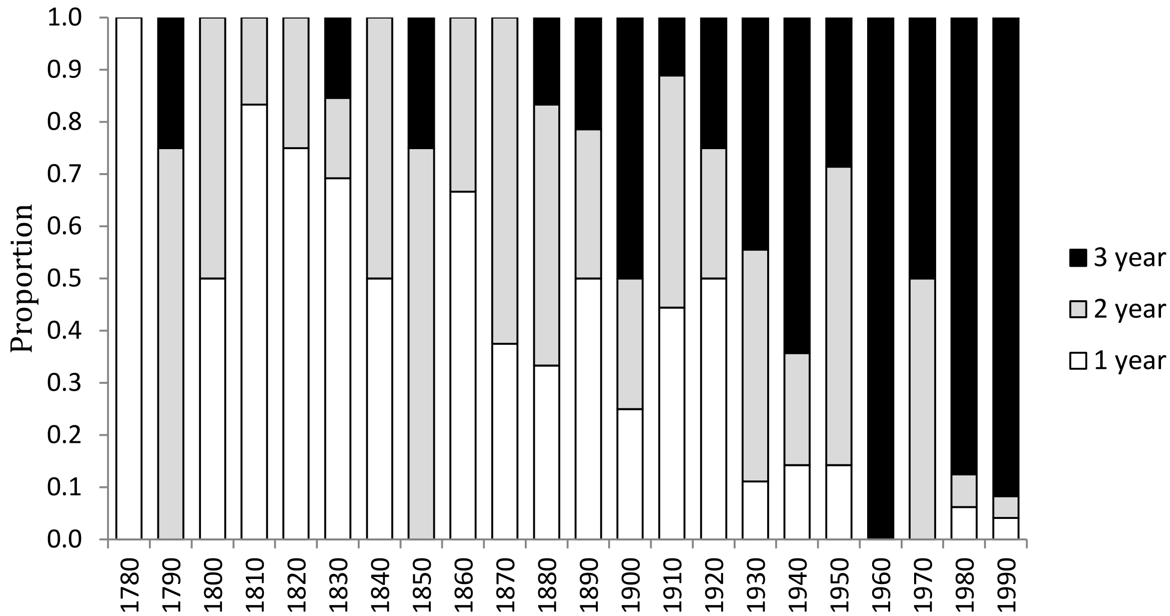
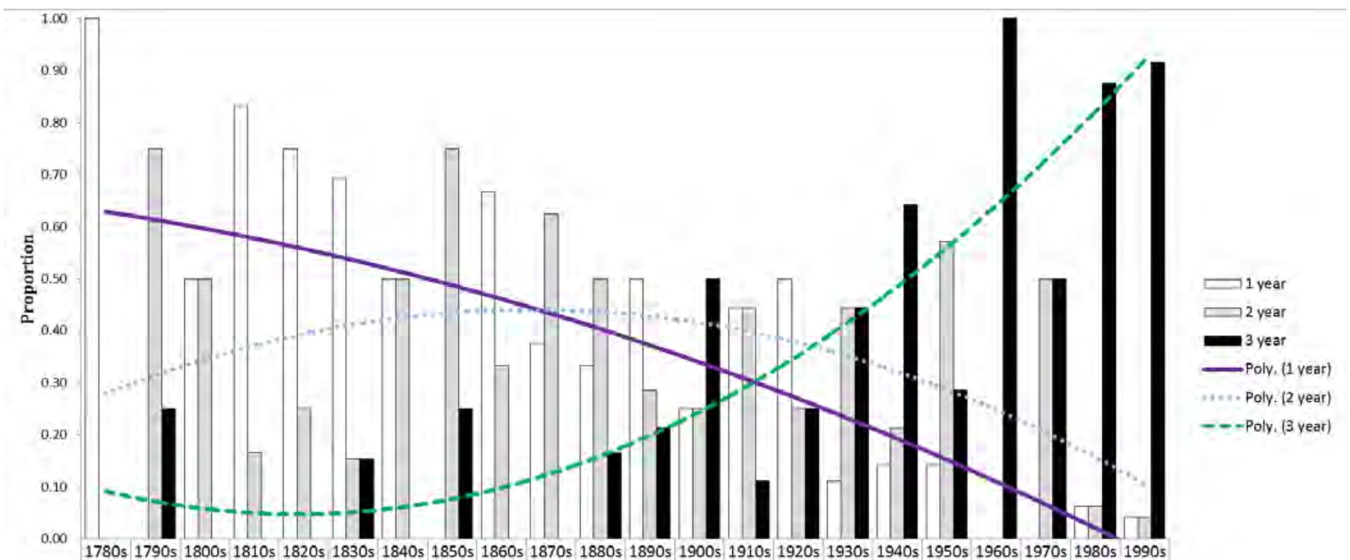


Figure 15. The proportion of 1-, 2-, and 3-year fire intervals recorded on all individual trees for each decade of the period of fire history record. Black indicates 3-year interval, grey 2-year interval and white bars are 1-year interval fire scars.



	1780s	1790s	1800s	1810s	1820s	1830s	1840s	1850s	1860s	1870s	1880s	1890s	1900s	1910s	1920s	1930s	1940s	1950s	1960s	1970s	1980s	1990s
1 year	1.00	0.00	0.50	0.83	0.75	0.69	0.50	0.00	0.67	0.38	0.33	0.50	0.25	0.44	0.50	0.11	0.14	0.14	0.00	0.00	0.06	0.04
2 year	0.00	0.75	0.50	0.17	0.25	0.15	0.50	0.75	0.33	0.63	0.50	0.29	0.25	0.44	0.25	0.44	0.21	0.57	0.00	0.50	0.06	0.04
3 year	0.00	0.25	0.00	0.00	0.00	0.15	0.00	0.25	0.00	0.00	0.17	0.21	0.50	0.11	0.25	0.44	0.64	0.29	1.00	0.50	0.88	0.92

Figure 16. The proportion of 1-, 2- or 3-year fire intervals for each decade is represented by bars for the period of fire scar record. Trend lines (2nd order polynomial) show increase in 3-year fire intervals (R^2 =0.7602, green dashed line) and decrease in annual fire intervals over time (R^2 =0.4493, solid purple line). Two year intervals did not have strong trend (R^2 =0.1777, blue dotted line).

Fire history sites. Fires were frequent for the 5 fire history sites. The fire composite graphs (Figures 17-21) show all the trees and fire scars from each site. At the bottom of each graph the composite fire chronology indicates all years that had fire scars at each site.

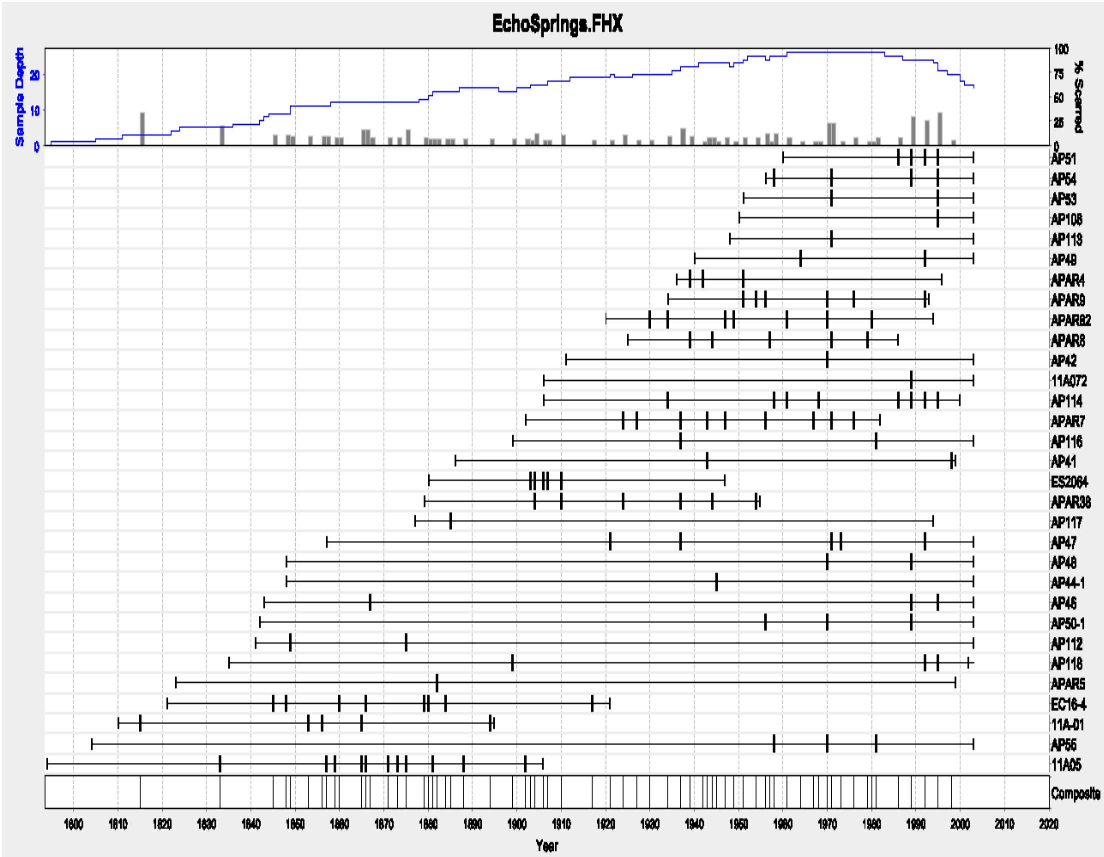


Figure 17. Echo Springs fire scar chronology including all fire-scarred trees from the Echo Springs site. Each horizontal line represents a tree with identification at right and each vertical hatch mark represents a fire scar. The sample depth and percent of recorder trees with fire scars are shown on top portion of graph. At the bottom is the fire composite where all years with fire scars are marked with a vertical line. Each vertical line represents a year with one or more fire scars indicating that a fire occurred within the site that year. The period of fire record was 1794-2003.

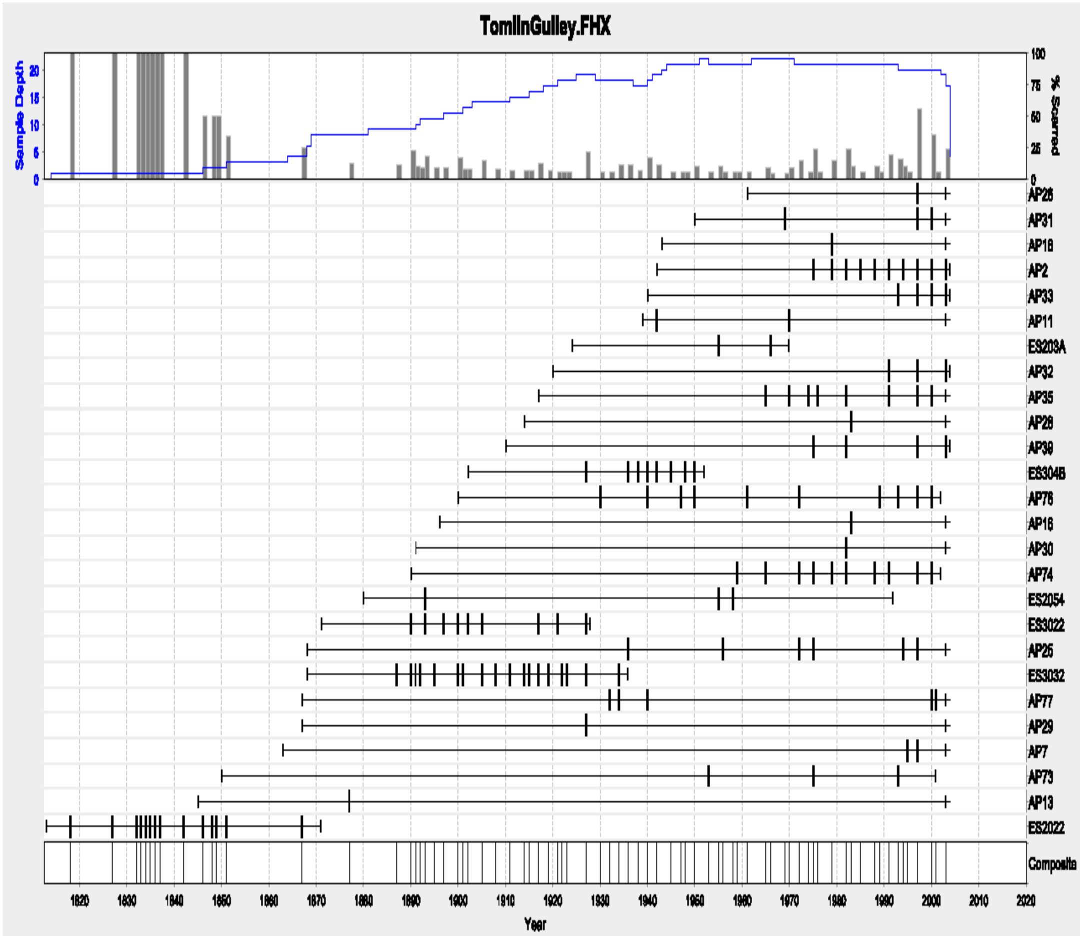


Figure 18. Tomlin Gulley fire scar chronology including all fire-scarred trees from the Tomlin Gulley site. Each horizontal line represents a tree with identification at right and each vertical hatch mark represents a fire scar. The sample depth and percent of recorder trees with fire scars are shown on top portion of graph. At the bottom is the fire composite where all years with fire scars are marked with a vertical line. Each vertical line represents a year with one or more fire scars indicating that a fire occurred within the site that year. The period of fire record was 1813-2004.

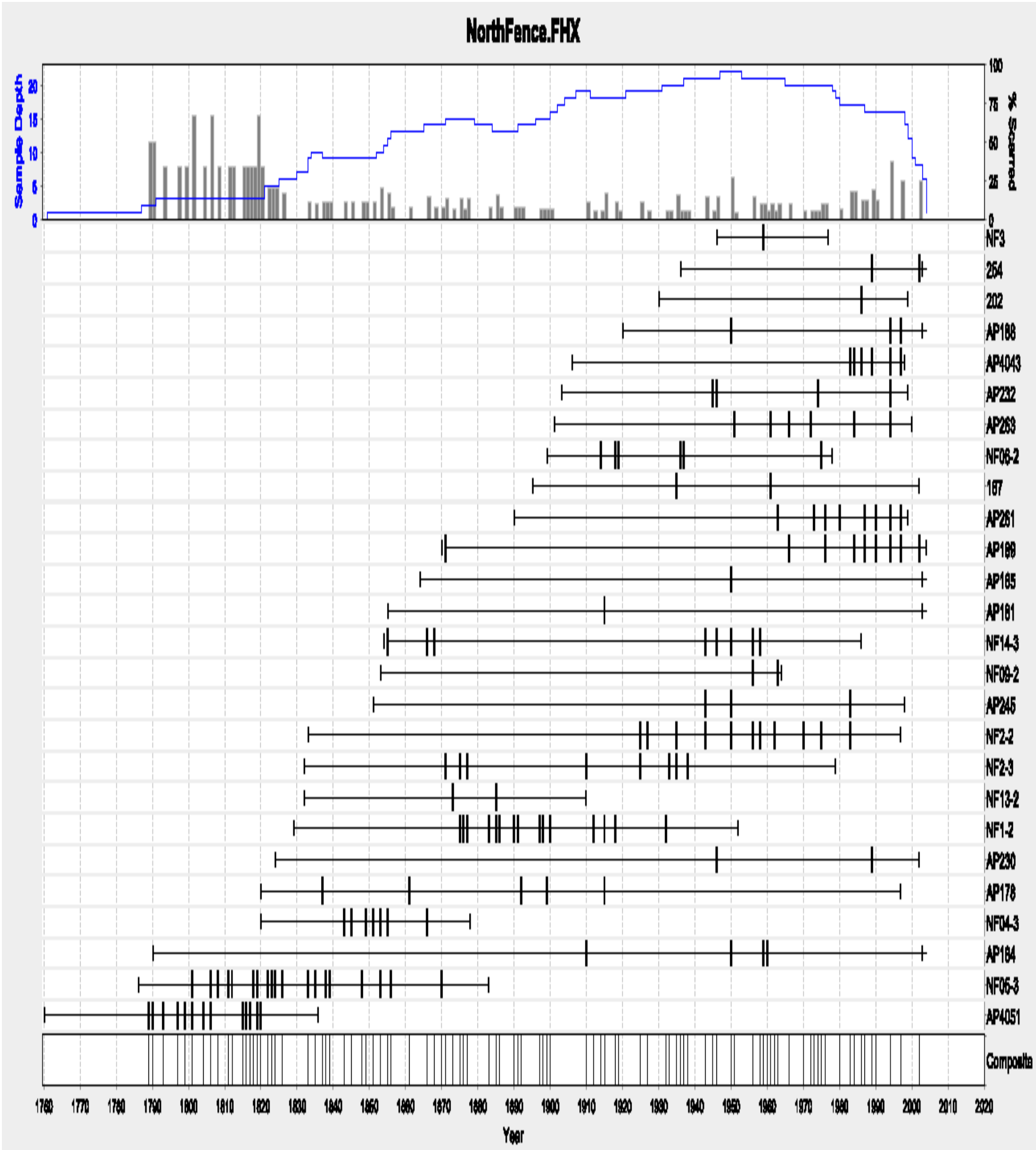


Figure 19. North Fence fire scar chronology including all fire-scarred trees from the North Fence site. Each horizontal line represents a tree with identification at right and each vertical hatch mark represents a fire scar. The sample depth and percent of recorder trees with fire scars are shown on top portion of graph. At the bottom is the fire composite where all years with fire scars are marked with a vertical line. Each vertical line represents a year with one or more fire scars indicating that a fire occurred within the site that year. The period of fire record was 1760-2004.

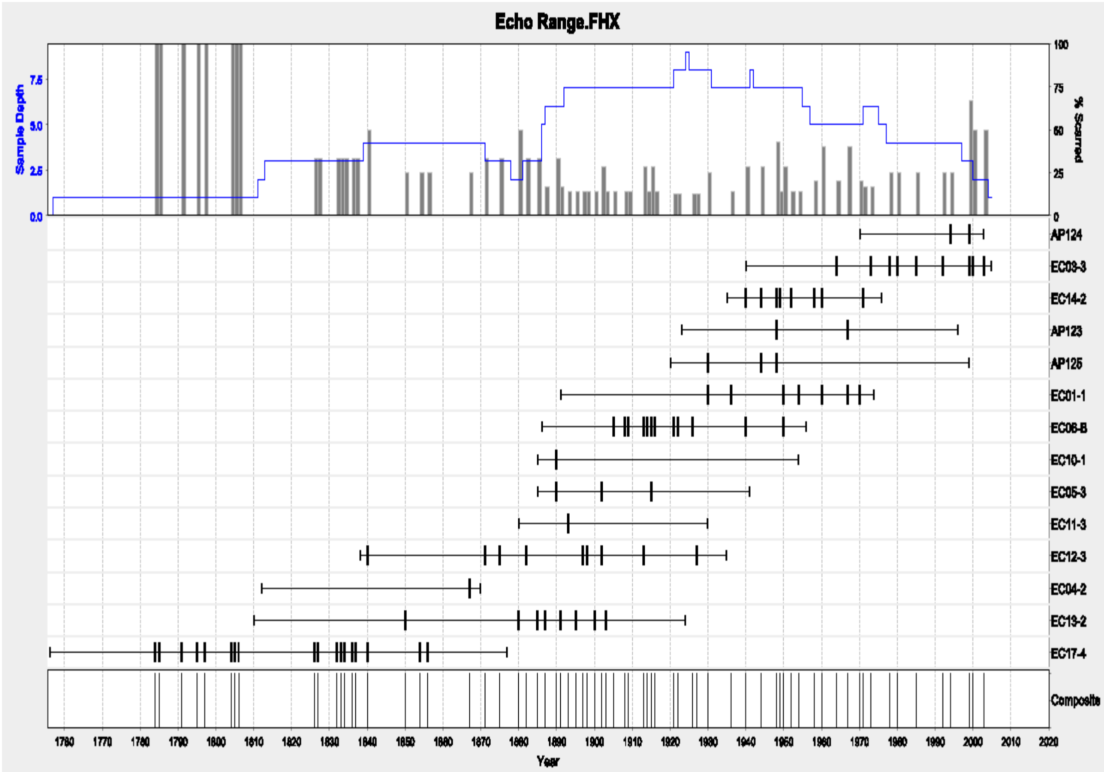


Figure 20. Echo Range fire scar chronology including all fire-scarred trees from the Echo Range site. Each horizontal line represents a tree with identification at right and each vertical hatch mark represents a fire scar. The sample depth and percent of recorder trees with fire scars are shown on top portion of graph. At the bottom is the fire composite where all years with fire scars are marked with a vertical line. Each vertical line represents a year with one or more fire scars indicating that a fire occurred within the site that year. The period of fire record was 1756-2005.

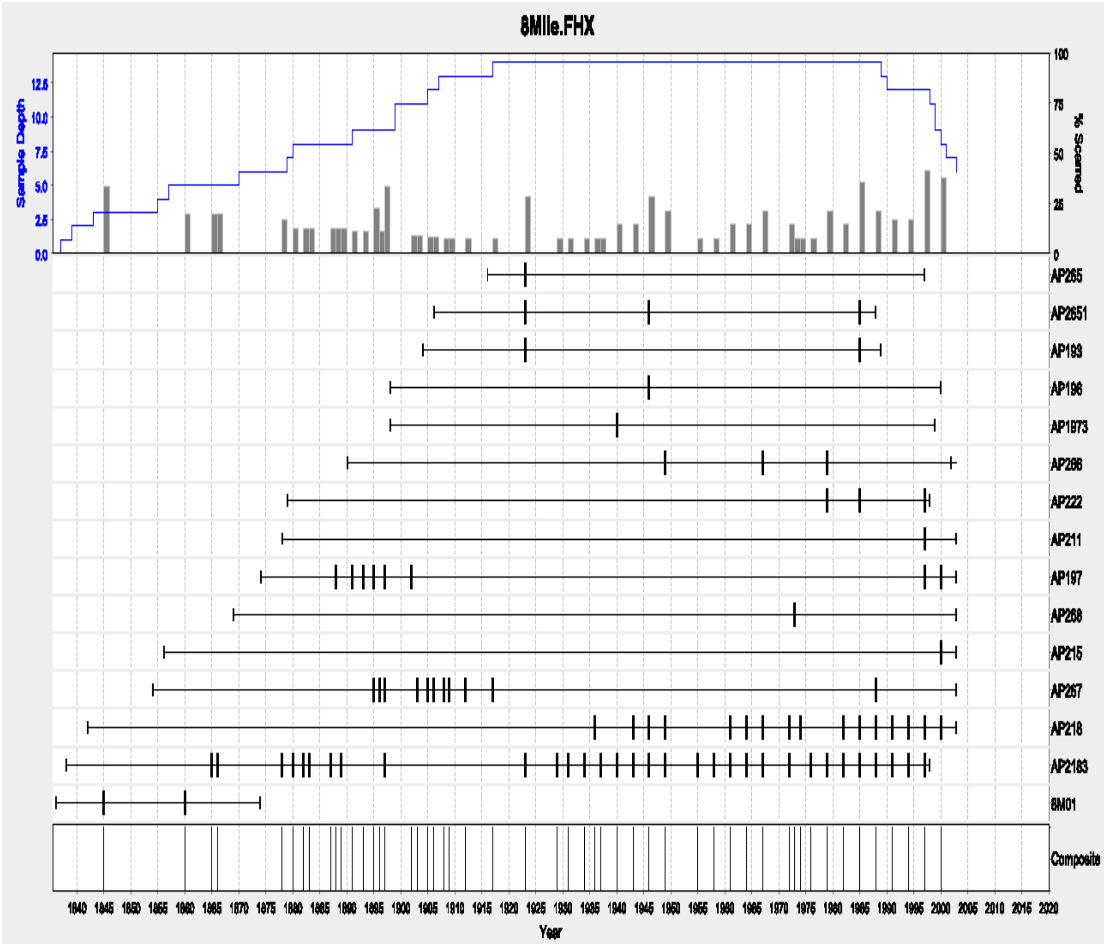


Figure 21. Eight Mile fire scar chronology including all fire-scarred trees from the Eight Mile site. Each horizontal line represents a tree with identification at right and each vertical hatch mark represents a fire scar. The sample depth and percent of recorder trees with fire scars are shown on top portion of graph. At the bottom is the fire composite where all years with fire scars are marked with a vertical line. Each vertical line represents a year with one or more fire scars indicating that a fire occurred within the site that year. The period of fire record was 1836-2003.

Short fire intervals, mostly 1-3 years, occurred at all fire history sites over the period of fire record (1784-2005). The mean fire interval (MFI) ranged from 2.5 to 3.7 years (3 year mean for all sites), and the Weibull median interval (WMPI) ranged from 2.0 years to 2.9 years (2.5 year mean for all sites) (Table 9). Fire intervals of 1 to 3 years were the most frequent at all five fire history sites (Figure 22). Over 80% of all fire intervals were 4 years or less at each site (Table 10). In 4 of the 5 sites, 80 percent or more of intervals were 1-3 year (Table 10). Only Echo Range had less than 80 percent 1-3 year interval fires (68%) and that was probably because Echo Range site had the fewest number of trees recording scars over the longest time period of any site, and therefore has a less complete a fire record (Table 10).

Table 9. Summary statistics for fire chronologies, including fire intervals, for the entire Range, and for each of the five major fire study areas.

	Range-wide (all sites)	Echo Springs	Tomlin Gulley	North Fence	Echo Range	Eight-Mile	Mean of major fire sites
Beginning year	1756	1794	1813	1760	1756	1836	
Last year	2005	2003	2004	2004	2005	2003	
Length of fire chronology (years)	250	210	192	245	250	168	213
Total number of samples	151	31	26	26	14	15	
Total number of recorder years	14374	3216	2404	2980	1023	1740	2272
Total number of fire scars	740	117	131	149	84	86	113.4
Total Intervals	184	65	74	58	69	50	63.20
Mean Fire Interval	1.19	2.82	2.5	3.67	3.17	3.1	3.05
Median Fire Interval	1	2	2	2	2	3	2.20
Fire Frequency	0.84	0.36	0.4	0.27	0.32	0.32	0.33
Weibull Modal Interval	1.01	1.1	0.93	0.76	1.16	1.46	1.08
Weibull Median Interval	1.13	2.36	2.08	2.86	2.63	2.66	2.52

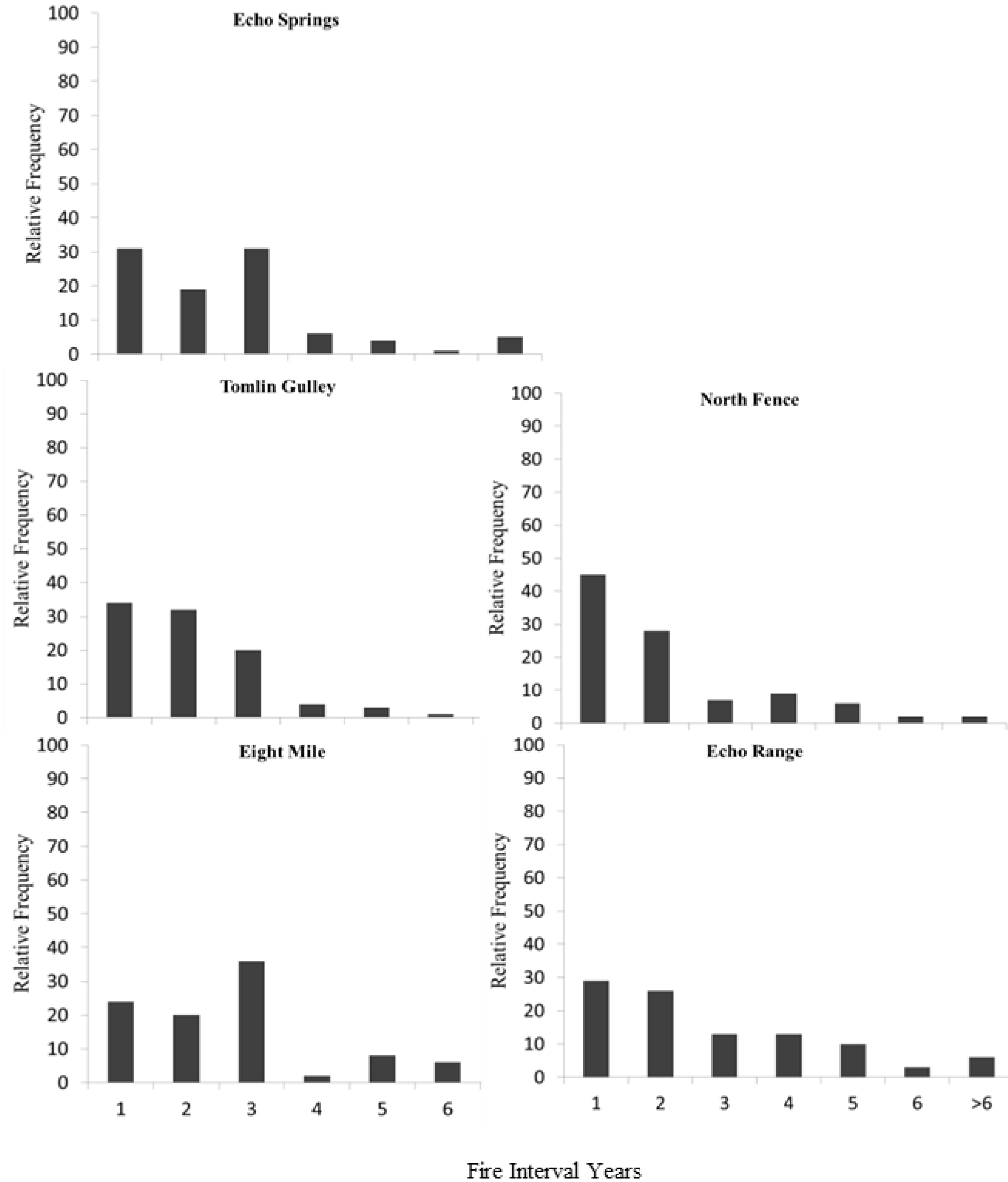


Figure 22. The distribution of different length fire intervals for each fire history site at APAFR over the period of fire record at each site.

Table 10. The proportion of all fire intervals that were 1- 3 years or 1- 4 years, for each fire history site and range-wide. This was during the period of fire scar record for each site.

Area	1-3 year intervals	1-4 year intervals
Echo Springs	81	87
Tomlin Gulley	86	90
North Fence	80	89
Echo Range	68	81
Eight Mile	80	82
Range-wide	98	99

Two methods can potentially be used to examine changes in fire interval at fire history sites over time. The composite fire scar record is often used for this purpose. Because of the fading fire record before the 1880s (insufficient numbers of samples to capture the fires that occurred in the early part of our fire record), it is very unlikely that the composite fire-scar record reflects the true fire interval for the early part of the fire record. Therefore, we used our examination of short-interval fire scars within individual trees to describe change in fire interval over time.

Changes in fire interval over time for most of the individual fire history sites were similar to the range-wide results: 3-year interval fires increased over time and 1- year interval fires decreased. This pattern was strong for the Eight Mile, Echo Springs, Tomlin Gulley, and North Fence Sites (Figure 23). Unlike other sites the Echo Range site had many 1-year interval fires in recent decades. Echo Range had mostly shorter 1 and 2 year intervals both before and after 1900 until the end of the fire record. Echo Range had the greatest numbers of short interval fires which dominated every decade except the 1900s and the 1960s. The 1960s had no 1- or 2-year intervals recorded for any site, and 3 sites did not have any short interval fires recorded (Figure 23). The Eight Mile was also different from other sites because it had by far the most 3 year interval fires, with almost exclusively 3 year intervals from the 1930s to the 1990s. The relatively low sample size when examining each site by each decade (sometimes there were few or no short-interval fires for a decade at a site) makes the site-level examination of change in fire interval over time weaker than range wide. But a consistent pattern included fewer 3-year intervals before the 1900s and 3-year fires being most frequent after the 1920s.

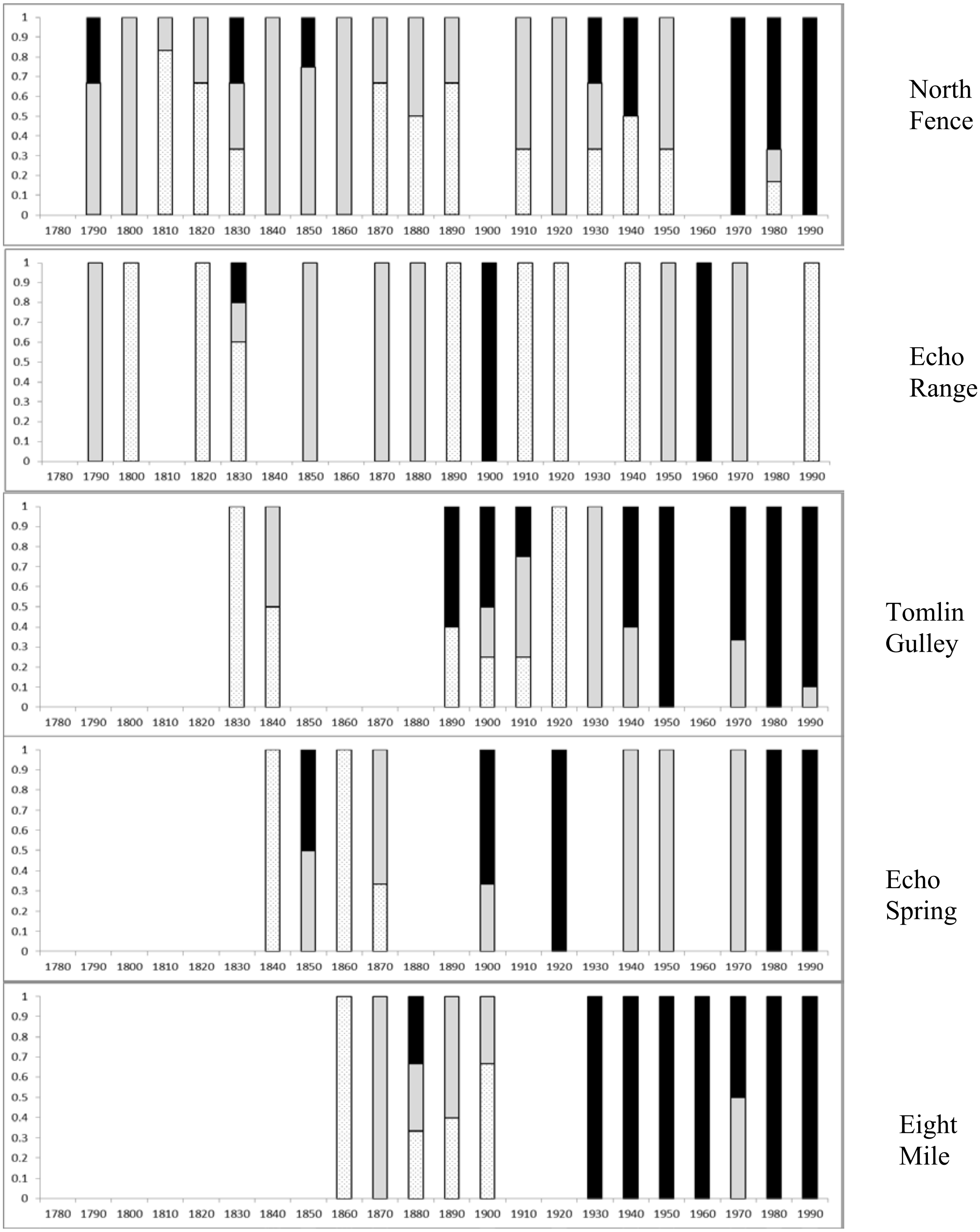


Figure 23. Proportion of 1-, 2-, and 3-year fire intervals for each decade of period of record in each major fire study site in APAFR. Black indicates 3-year interval, grey 2-year interval and white bars are 1-year interval.

Fire time of year

Range-wide. We were able to determine the time of year for almost all fire scars based on their inter-annual ring position (93% or 669 of 719). Over the entire period of record most fires recorded in the tree rings occurred either during the winter “dormant” (46%) or spring/summer “transition” (42%) periods (Table 11). Fires occurred infrequently during the early spring “early” (5%) or fall and early winter “late” (7%) periods.

Table 11. Summary of scar position relative to given times of the year for 669 known-position fire scars.

Scar Position	**Number of Scars**	**Percentage of All Scars**	**Percentage of Known-season Scars**	**Time of Year or Time Periods**
Dormant (between latewood of previous year and current year’s earlywood)	310	43	46	January-February
Early (1st 1/2 of earlywood)	35	05	05	March- and early April
Transition (last 1/2 of earlywood through first 1/2 of latewood)	278	39	42	Late April-May-June-July-August
Late (final 1/2 of latewood)	46	06	07	Sept-Oct-Nov-Dec
Undetermined	50	07	--	unknown

Our fire scar record enables us to examine changes in the intra-annual timing of fires across the Range over the 222-year period of record. The pattern of many dormant and transition and few early or late category fires occurred during each decade of the period of record (Figure 24). Because “early” and “late” scars were a small proportion of all scars (5% or 7%), and because they occurred during times of year that are not as clear regarding ignition source as are “dormant” (almost no lightning ignitions) and “transition” (peak of lightning ignitions), we focused on changes over time in “dormant” and “transition” fire scars.

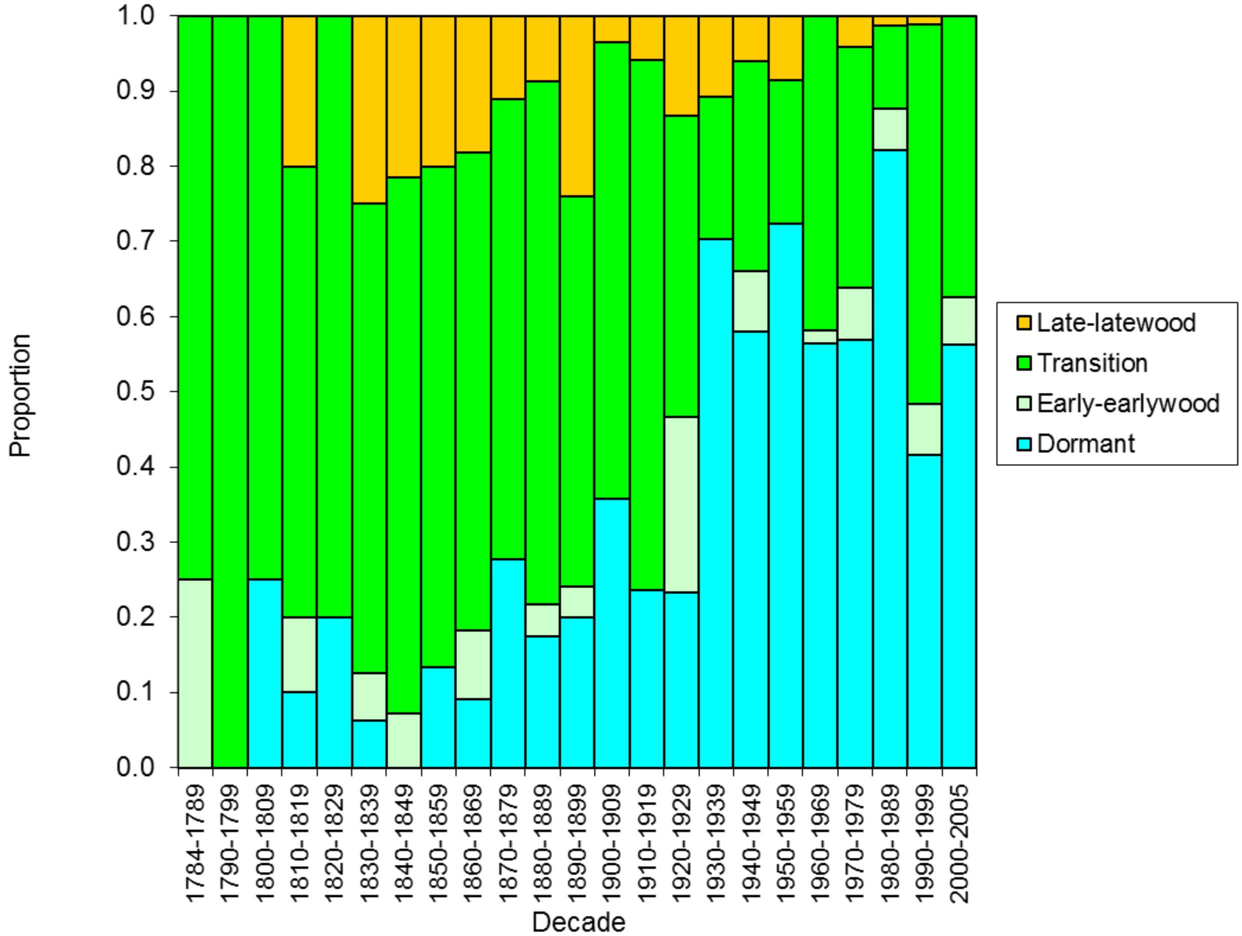


Figure 24. Proportion of late, transition, early and dormant position scars for each decade of the period of fire record (1784-2005). Orange indicates late, green transition, light blue early, and turquoise are dormant position.

The proportion of dormant and transition fire scars changed over time. Transition fire scars dominated the early portion of the fire record (1784-1919), constituting >50% of all scar positions prior to 1920 (Figure 25A). From 1920–2005, transition season fire scars were fewer (31% mean, range 11-51% per decade). The proportion of transition fires was the lowest from the 1920s and through 1989 (27% mean, range 11-40% per decade). Dormant fire scars dominated the later part of the fire record (Figure 25B). Before the 1930s there were relatively few dormant season scars (14% mean per decade, range 0-36%). There is a marked increase in dormant scars beginning in the 1930s. The proportion of dormant scars was high (mean 66%) from 1930s-1980s. Dormant scar frequency peaked in the 1980s with 82% of fire scars occurring in the dormant time of year and only 11% in the transition time of year. A decline in dormant scars occurred during the 1990s (42%). The switch in preponderance of scars from transition to dormant times of the year occurred between the 1920s and 1930s (Figure 25).

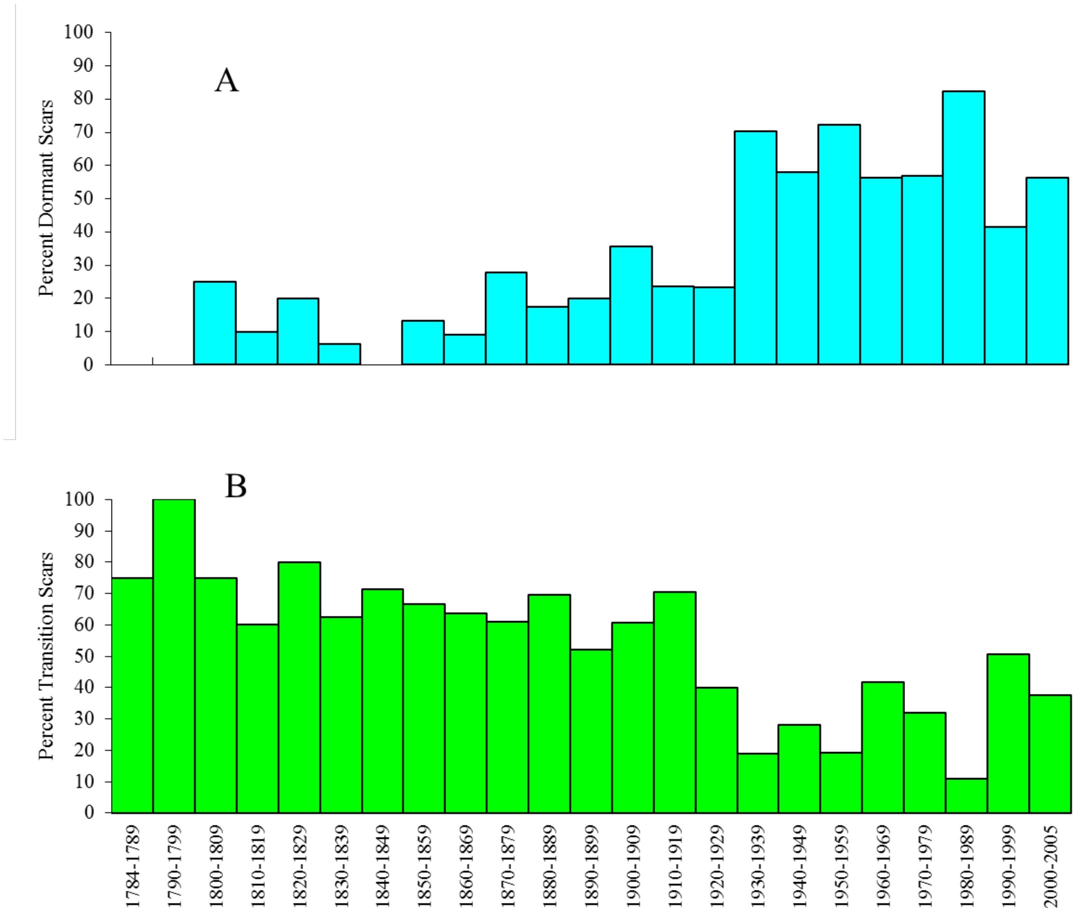


Figure 25. The proportion of transition (A) and dormant (B) fire scars for each decade of the period of fire record (1784- 2005).

Fire history sites. Fire history sites show a shift from predominance of transition fires to predominance of dormant season fires. Four of the five fire history sites (Echo Range, Tomlin Gulley, Echo Spring and North Fence) clearly show a pattern of more transition fires early in the record and more dormant fires late in the record (Figure 26). Only the Eight Mile site had few transition scars and a large proportion of dormant scars.

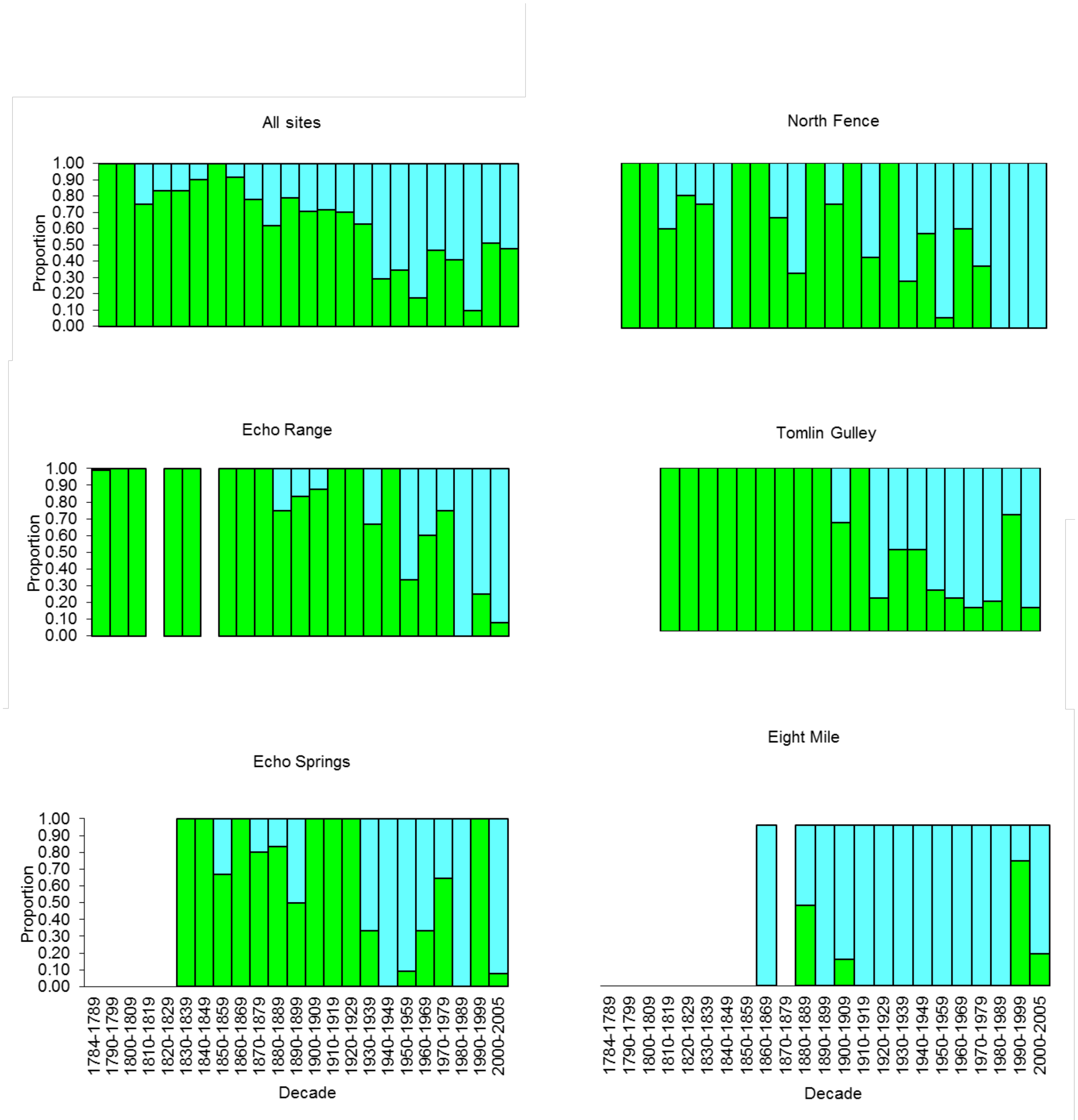


Figure 26. The proportion of dormant and transition fire scars per decade for all trees range-wide and for each fire history site. Dormant scars are represented by blue bars and transition by green bars.

There was a marked difference in the proportion of transition or dormant fire scars before and after the 1930s. Both range-wide and in 4 of the 5 fire history sites there were mostly transition fires before 1930 and mostly dormant fires after 1930 (Figure 27). Echo Range had the greatest proportion of transition fires of all the sites for the entire time period, both before and after 1930, followed by Tomlin Gulley and Echo Springs, then North Fence (Figure 27). Unlike these sites, Eight Mile had more dormant fires than transition fires both before (Figure 27A) and after (Figure 27B) 1930.

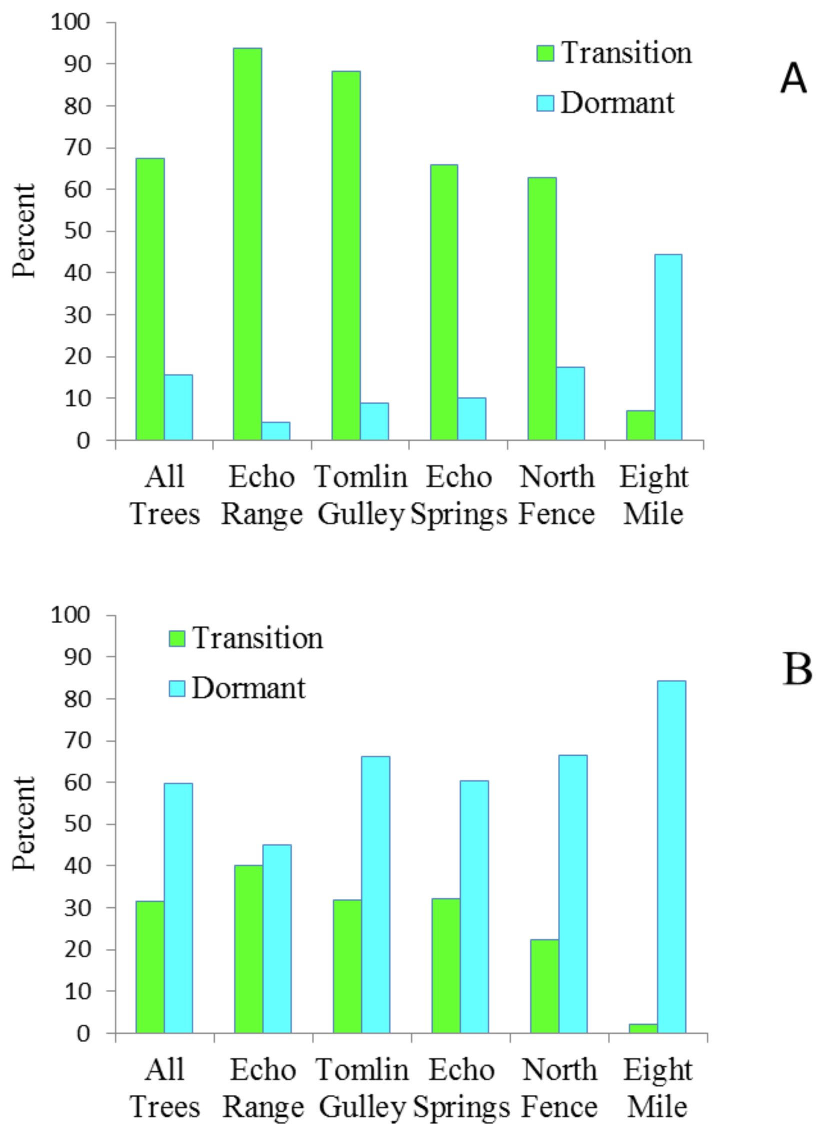


Figure 27. The percentage of transition and dormant fire scars during the time before 1930 (A), and after 1930 (B) for all sites, and for each fire history site. Blue bars indicate dormant and green bars indicate transition fire scars (mean percent per decade) for the period of fire record (1784-2005).

Discussion

Synthesis of fire patterns with land-use history

Many plant and animal species in pine savannas are widely recognized as having a long evolutionary association with fire (Platt 1999). Characteristics of pre-settlement fire regimes in pine savannas, and how humans have altered characteristics of those fire regimes, are much less clear. Our current study of fire scars in the annual rings of dead trees and stumps addressed two characteristics of historical and more recent fire regimes at APAFR (intervals between successive fires and the time of year that fires typically occur) at both local and larger regional scales. We further addressed the nature of changes in these characteristics from the late 1700s to the present, during which humans greatly altered land use patterns, as well as fire regimes.

Human history periods and eras. We explore changes in the influence of humans on fire regimes by placing fire scar records in different time periods marked by major historical events and changes in human land use practices. We divide the period of record for fire scars into decades based on historical information from Devane (1983), Myers and White (1987), and Jones et al. (2007).

We first divide the entire time period into two longer "Eras": the "Pre-extractive Era" (1787-1919) and the "Extractive Era" (1920-2005). In the Pre-extractive Era the few people present in the region were not changing the landscape greatly. Both land use and fire regimes were markedly different during the Extractive Era. Beginning in the 1920s, widespread cutting of old growth trees and changes in grazing practices concurrently altered landscapes and fire regimes (Devane 1983, Jones et al. 2007).

We separate the Pre-extractive and Extractive Eras into different time periods. The Pre-extractive Era contains three periods: the Seminole Period (1780-1839), the Seminole War Period (1840-1859), and the Open Range/Homestead Period (1860-1919). The Extractive Era contains two periods: the Extractive Period (1920-1939), and the Bombing Range Period (1940-2005). We subdivide the final Bombing Range Period into the Early Bombing Range Period (1940-1989) and the Late Bombing Range Period (1990-2005). Details about the different periods are included in Appendix 2.1.

Fire frequency and changes in fire frequency. Fires were frequent throughout the entire pre-extractive era, both during the time when Seminoles were present and later when the open-range/ homesteaders were present. As indicated by analyses of fire scars recorded by individual trees/point in the landscape, fuels were sufficient for fires to occur every 1-2 years; these short interval fires were dominant during all three periods of the Pre-extractive Era (Figure 28). During this era of more than a century, cattle-grazing was the main human use of the land. Sparse populations of Seminoles and subsequently open range cattlemen and settlers took advantage of the large, open, grassy prairies and flatwoods of the Kissimmee River region to raise cattle (Myers and White 1987, Jones et al. 2007). Both Seminoles and the early cattlemen of the region were postulated to have burned annually, primarily to improve grazing for their cattle (Stoddard 1962, Mealor and Prunty 1976, Myers and White 1987). Eldredge (1911) states that "It is only by chance that any area of unenclosed land escapes burning at least once in two years." The fire regime of mostly 1- to 2-year interval fires that we found documented in the fire scar record during this era was what would be predicted based on these reported patterns of frequent ignition by lightning or humans.

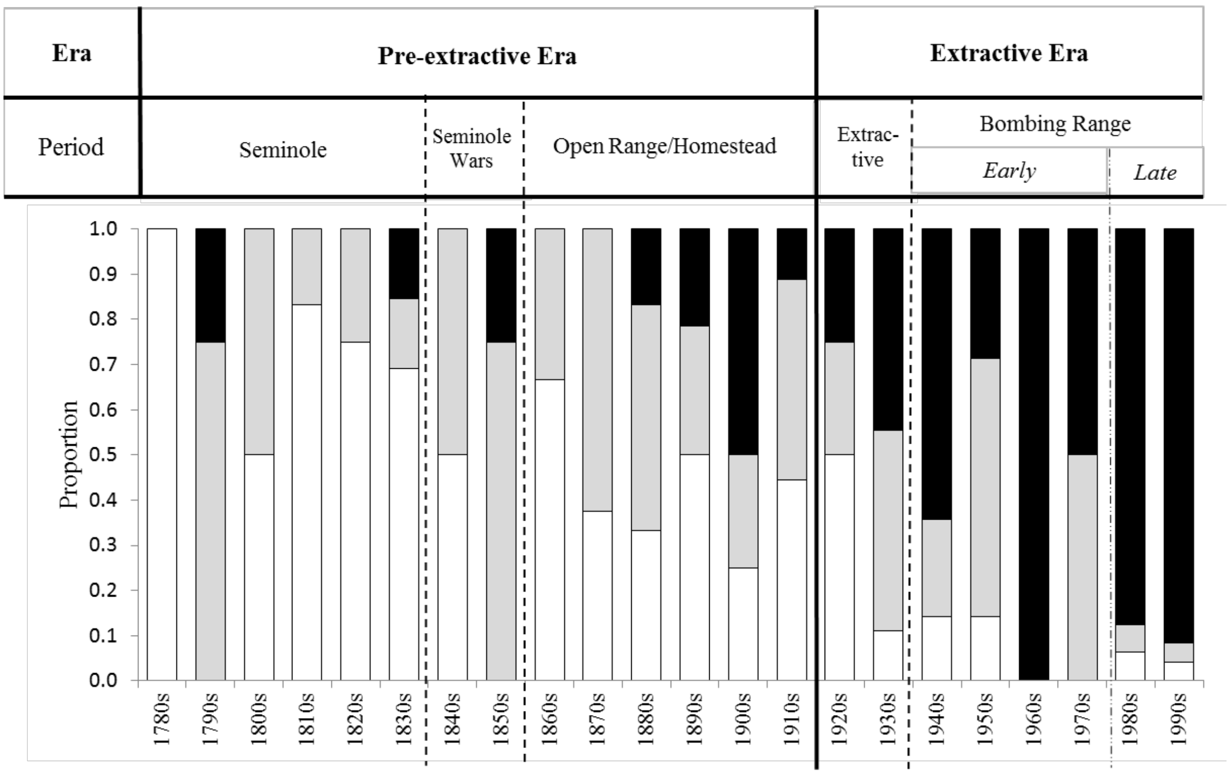


Figure 28. The proportion of 1-, 2- and 3-year interval scars for each decade over the period of fire record with the periods of different human activities indicated. The solid vertical line indicates the division between the Pre-extractive Era and the Extractive Era. The dashed lines indicate the divisions between the five periods and one sub-period (the early and late division of the Bombing Range period).

Fires were extremely frequent even during periods when people were likely absent from the landscape. There were likely no or extremely few people in the area for two periods of time during the pre-extractive era. Before 1823 the region did not have the original inhabitants, who were wiped out by European diseases after Spanish contact (Lewis 1978) and the Seminoles came into the area only after 1823 when they were driven south from North Florida (Devane 1983, Myers and White 1987, Covington 1993). Also in the Seminole war period there were times when no Seminoles, soldiers, or settlers were present (Devane 1983, Covington 1993). The high frequency of fires throughout these two periods suggests that the vast expanses of contiguous fuel and abundant lightning strikes were sufficient to maintain a regime of annual and biennial fires with or without human ignitions. Fires likely occurred as frequently as sufficient fuel was available to burn across grass-dominated prairie and pine savanna landscapes.

After the Pre-extractive Era there was a shift from mostly 1-2 year interval to mostly longer 3-year intervals fires. During the Pre-Extractive Era, the occurrence of 3-year intervals between successive fires increased slightly with successive periods. Large increases in 3-year intervals occurred during the Bombing Range period, and 3-year intervals were more frequent than 1-and 2-year intervals (Figure 29). In the Late Bombing Range era almost all fires were 3 year intervals (Figure 29).

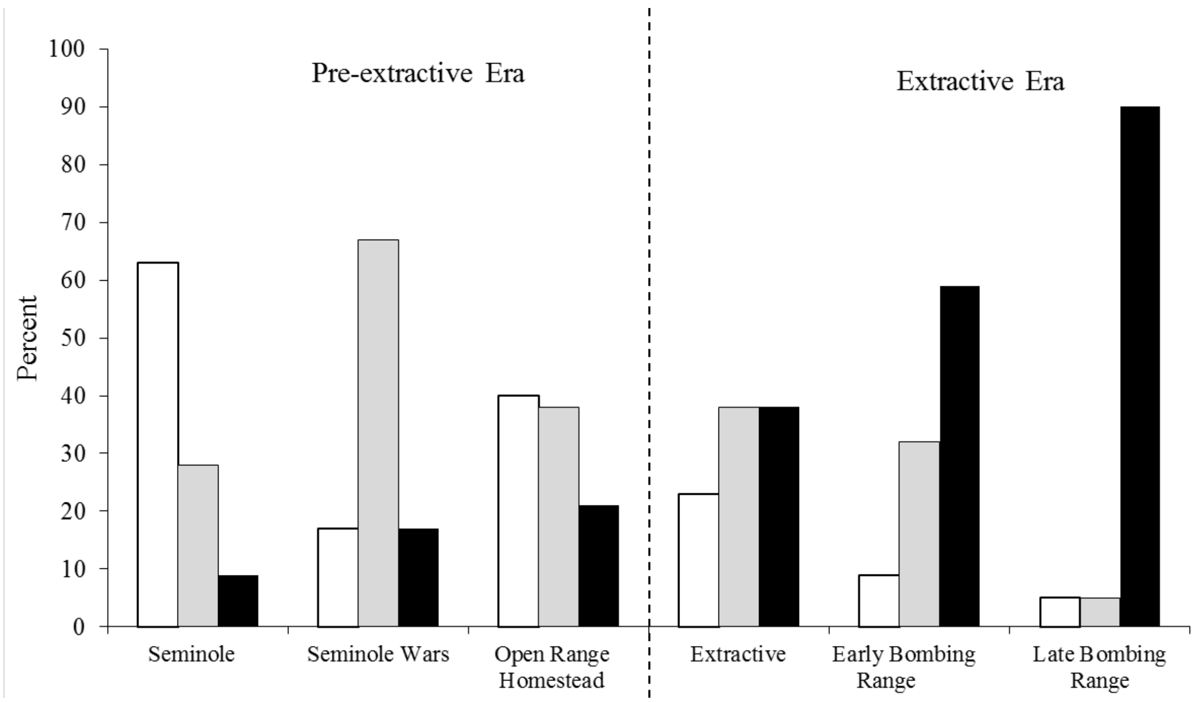


Figure 29. The percentage of 1- year interval fire scars (white bars), 2-year interval (grey bars) and 3-year interval (black bars) for six time periods: the Seminole period (1784-1839), the Seminole Wars period (1840s), Open Range/Homestead period (1750-1919), Extractive period (1920-1929), and two divisions of the Bombing Range Period (Early, 1930-1989, and Late,1990 to 2005). . The Pre-extractive and Extractive Eras are divided by dashed vertical line.

Changes in the human use of the land contributed to this shift to slightly longer interval fires. During the Extractive Period and just after (1920s-1940s) the original larger pine trees over most of the Range were logged. There also was a change from open range, where seasonal grazing was likely short and intense, to fenced pastures with more intensive grazing throughout the year. Such changes in patterns of grazing and stocking densities of cattle could have resulted in the reduction in fine fuels necessary to carry 1-

and 2-year interval fires. At the same time, the highly flammable fine fuel of pine needles would have decreased after widespread logging, also resulting in less fine flammable fuel, and thus in less frequent fires. Less frequent fire also may likely have resulted in increases of woody species, especially palmetto, dense stands of which will not carry annual or even biennial fires. Clearly, establishment of a prescribed fire regime with a 3-year interval between fires in the late Bombing Range period (1970s) (Wildfire Management Plan Draft 2013) also directly contributed to the reduced numbers of 1- and 2-year interval fires.

Differences in land use in different locations across the range also may have contributed to differences in the fire return intervals in the different fire history sites. Echo Range, which had the most 1- and 2-year interval fires during the 1930-2005 time period, has been used as an active bombing range with intensive live-fire military operations and has had less fire suppression, likely resulting in higher fire frequency than the other sites that had mostly prescribed fire (Wildfire Management Plan draft 2013). Thus, when fire frequency was not tightly controlled with prescribed fire, fire intervals appeared to remain predominately 1-2 years, even through the 1990s. In contrast, the Eight Mile site, which had by far the greatest number of 3-year fire intervals of any site from 1930–2005, may have been a site of more intensive cattle grazing and human use. Human settlement was not distributed evenly across the range (Jones et al. 2007) and this may have resulted in some spatial differences in fire regimes across the landscape in the open-range homestead period.

*Fire time-of-year and changes in fire time-of-year***.** During the Pre-extractive Era fires left scars within annual rings indicating that fires occurred primarily during the transition season. These transition time-of-year fires were dominant, occurring in >50% of all scars throughout each period of the Pre-extractive Era (Figure 30). Small percentages (0-20%) of dormant time-of-year fires and large percentages (>60%) of transition time-of year fires occurred through the Seminole period, the Seminole Wars period and the Open Range Period (Figure 31). The presence of some dormant time-of-year fires in the Pre-Extractive Era indicates that people were influencing fire regimes. Nonetheless, most fires occurred during the time when lightning-ignited fires would have spread across APAFR landscapes. Transition time-of-year fire occur at the time of onset of thunderstorms and rain after the long dry season when surface water levels across the landscape are at their driest (Figure 32A), and at a time that lightning strikes begin to increase in frequency (Figure 32B). It is during this dry time that lightning-ignited fires would be most likely to spread across savanna landscapes of central and southern Florida (e.g., Beckage et al. 2003, Slocum et al. 2003, 2010a). The fire scar record thus indicates that even with people present on the landscape and likely setting some dormant season fires, frequent lightning-season fires characterized fire regimes in the Pre-Extractive Era before 1920.

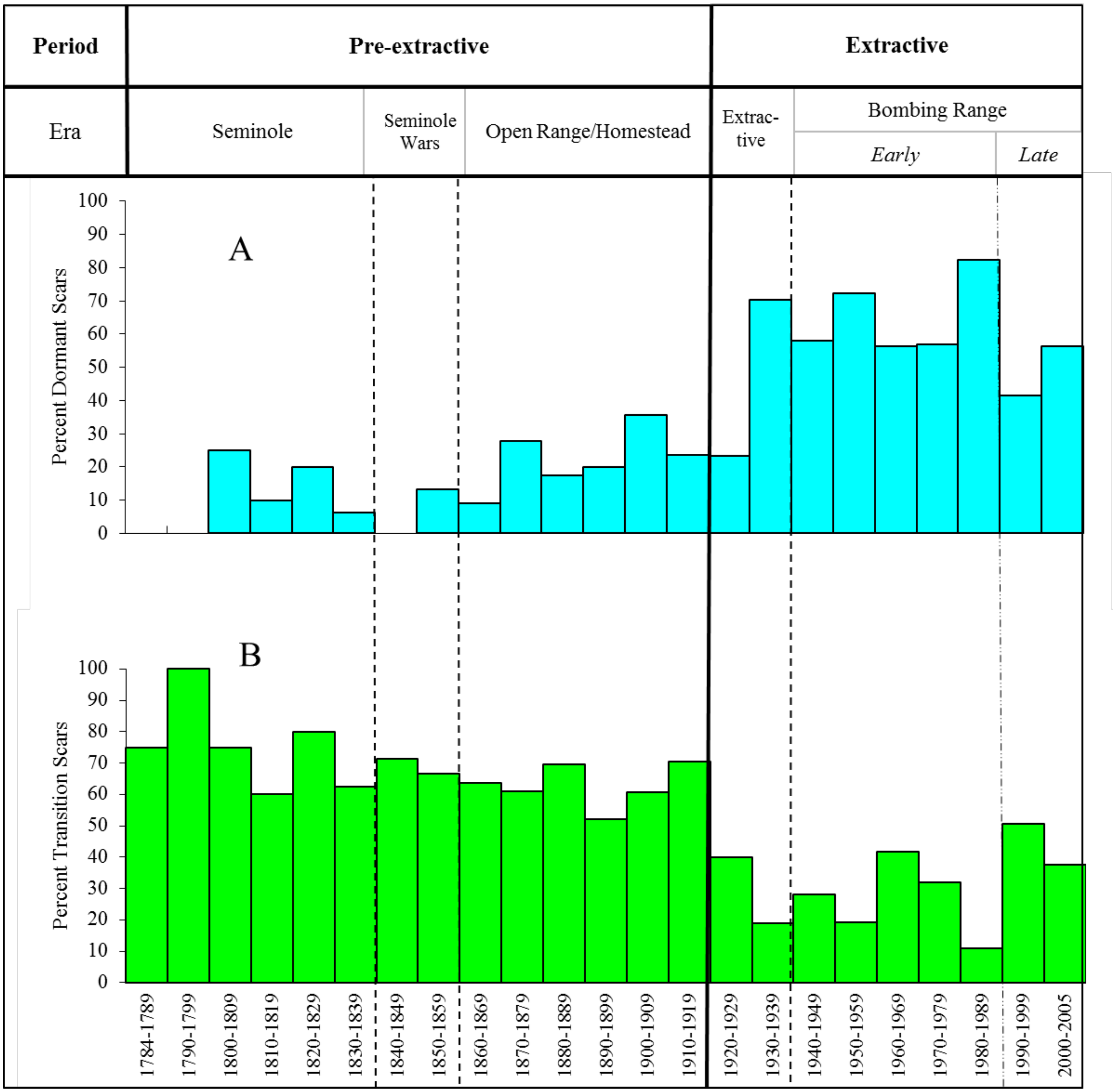


Figure 30. The proportion of dormant scars (A) and transition scars (B) for each decade over the period of fire record with the eras of different human activities indicated. The solid vertical line indicates the division between the Pre-extractive and the Extractive Periods. The dashed lines indicate the divisions between the five Eras and one sub-era (the early and late division of the Bombing Range Era).

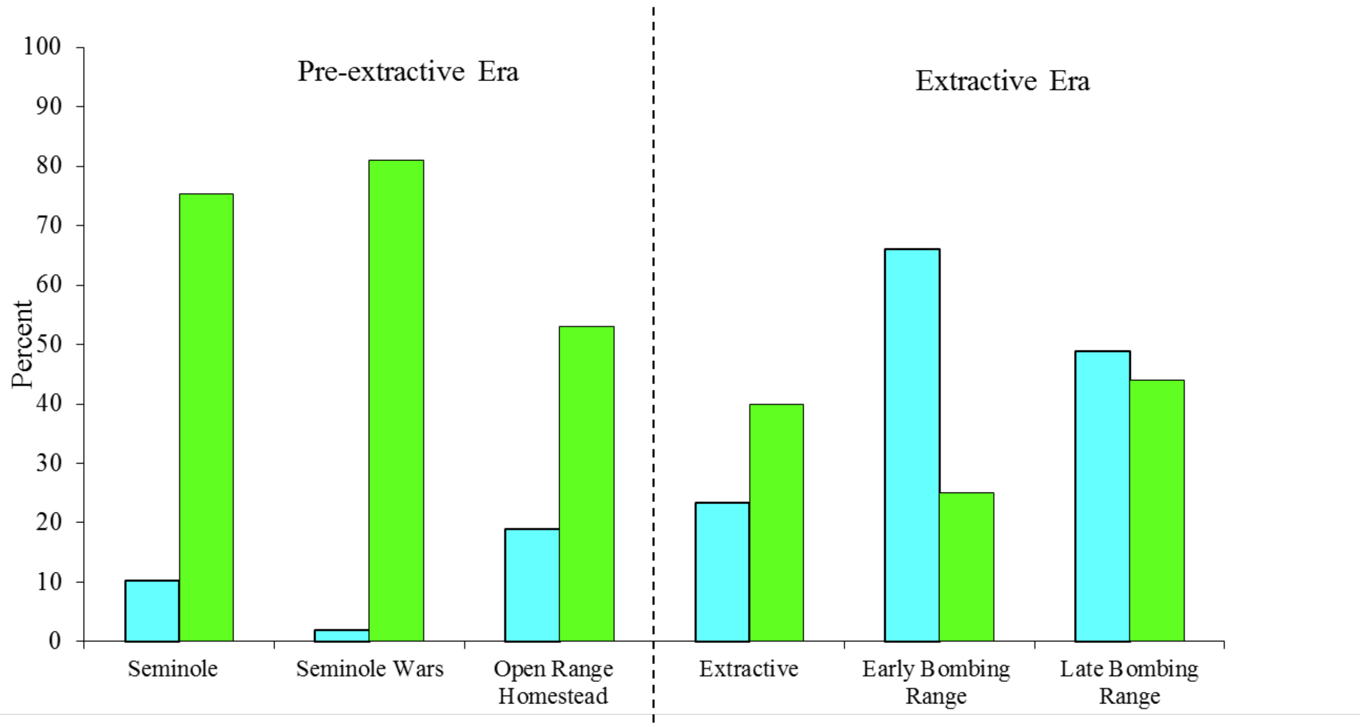


Figure 31. The proportion of transition fire scars (green bars) and dormant fire scars (turquoise bars) for six time periods: the Seminole period (1784-1839), the Seminole Wars (1840s), Open Range/Homestead (1750-1919), Extractive (1920-1929), the Early Bombing Range Era (1930-1989), and the Late Bombing Range Era (1990 to 2005). The Pre-extractive and Extractive Eras are divided by dashed vertical line. Graphs with all four fire scar positions (including "early" and "late" positions) can be seen in Appendix 2.3.

Our results are different than what would be expected from historical descriptions of fires in Florida. People are reported to have burned throughout the year during the pre-extractive era (see references in Myers and White 1987). Romans (1775) stated that "The woods are frequently fired, and at different seasons in order to have a succession of young grass" (Romans 1775, from Myers and White 1987). Some authors report that later cattlemen and homesteaders burned for cattle primarily in March-May (Eldredge 1911), while others indicate they burned mostly in the winter when forage availability was at its lowest (Otto 1984). The fire scar record, a much more objective record than human observations, clearly indicates that fires on the APAFR during the Pre-Extractive Era occurred mostly during the transition period (late-April through August).

A pivotal change in intra-annual timing of fires came during the Extractive Era. Decreases in occurrences of fires during the transition season to <40% and increases in fires during the dormant season to >20% occurred during the Extractive Period. In the Bombing Range Period fires were primarily dormant position and human-ignited (Figure 31). Dormant designation fires occur when there is almost no lightning (Figure 32B) and wetland water levels are moderately high (Figure 32A). These human-ignited fires peaked in the Early Bombing Range Period.

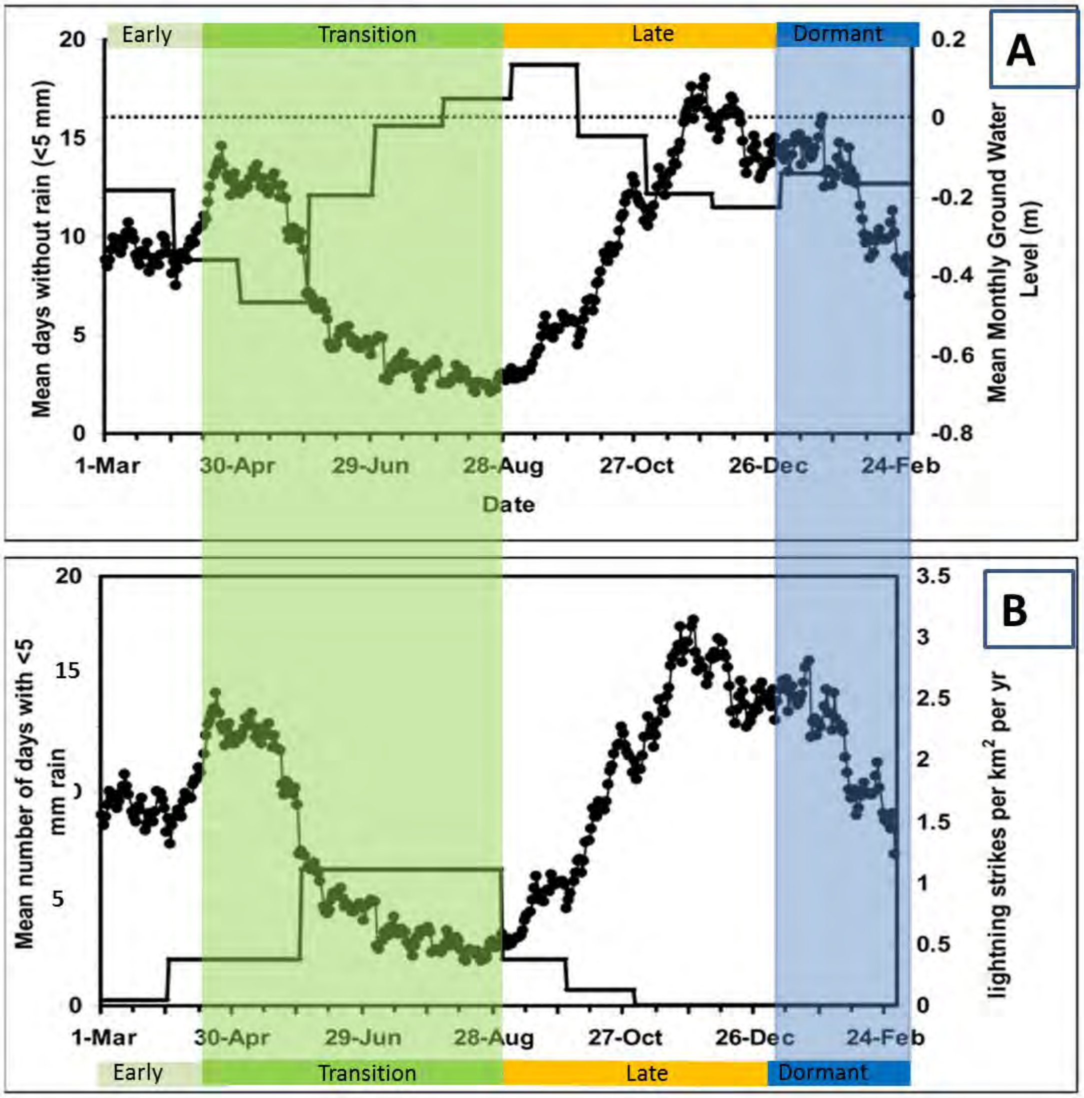


Figure 32. Fire time of year designations (Early, Transition, Late and Dormant) overlaid on graph of Climatic conditions of the Avon Park Air Force Range, Florida from Figure 1. Black circles in both graphs: mean number of successive days with <5mm rainfall recorded at Avon Park, FL for each day of the year during the period from 1944-1997. A: The histogram is the mean monthly ground water level at Tick Island (1974-2004), located in the pine flatwoods/dry prairie matrix of the eastern section of the Avon Park Air Force Range (Polk County, FL). Dotted line indicates ground surface. B: The histogram is the mean number of cloud-ground lightning strikes per km^2 from 1944-1997. Figure modified from Platt et al. (2006).

During the late Bombing Range Period (1990-2005) transition fires increased and dormant fires decreased with the reintroduction of prescribed transition/lightning season fires after a long tradition of dormant season prescribed fires during the Early Bombing Range period (Wildland Fire Plan Draft 2014). For the entire Late Bombing Range Period the percentage of transition scars (44%) was nearly the same as dormant scars (49%, Table 12). During the Late Bombing Range Period the percentage of transition scars (44%) increased over the Early Bombing Range Period (25%) but did still was not near the Pre-extractive Era levels (mean of 70% transition scars during the 3 pre-extraction era periods) (Figure 31).

Table 12. Percentage of Dormant and Transition fire scars during each time period of the fire record at APAFR.

Time Period	Dormant	Transition
Seminole	10	75
Seminole Wars	0	71
Open Range Homestead	21	63
Extractive	23	40
Early Bombing Range	66	25
Late Bombing Range	49	44

Ecological effects of recent changes in fire regimes

The plant communities now at APAFR probably reflect effects of almost 100 years of altered fire frequency and season. Prescribed fire in the recent bombing range period consists of slightly longer intervals and more dormant season fire. This change to slightly less frequent fires and more dormant time-of-year burning likely has affected the plants and animals that evolved with a fire regime of more frequent, lightning-season fires. Based on scientific literature about the effects of different frequency and intra-annual timing of fires there are aspects of the APAFR landscapes that likely have changed in response to the recent changes in fire regimes.

Continuity of fire across wetlands. The wet/dry season seasonal cycles exert strong influences on the likelihood of fire spread across savanna landscapes of central and southern Florida (e.g., Beckage et al. 2003, Slocum et al. 2003, 2007, 2010a). Lightning fires most often occurred at the end of the dry season (transition), when wetland water levels are low were likely to burn well into wetlands (Slocum et al. 2010a). In contrast, dormant time-of-year fires often occurred when wetlands were full of water and thus less area would have burned (Huffman and Blanchard 1990). The shift from fires burning when wetlands were dry to fires burning when wetlands were full of water would have resulted in many ecological changes to wetland ecosystems. Prominent among these would be accumulations of organic soils and a shift in wetlands toward more woody species with less fire resistance (Platt et al. 2006).

Increases in the abundance of woody plant species and decreases in fire return intervals. Increases in woody species caused by the shift from transition time-of-year to dormant season fires would likely have resulted also in depression of flammable fuels such as grasses. Such increases probably occurred first in wetlands as a result of fires occurring when fuels were not dry enough to carry fires. As wetlands become dominated by woody plants, increases in fire return intervals likely shifted upslope, especially if overgrazing was concomitantly removing flammable fuels. As a result, increases in unburned areas spread upslope as hardwoods spread from wetlands into uplands. An increase in woody species (shrubs and trees) also occurs in when fires are less frequent (Glitzenstein et al. 2003). Dormant season fires also favor the increase of woody species (Glitzenstein et al. 1995, Drewa et al. 2002, Drewa et al. 2006, Platt et al. 2006). The recent history of less frequent and more dormant season fires likely has resulted in increased woody cover in upland habitats such as dry prairie, pine flatwoods and sandhill.

Plants and animals. Plants and animals show signs of an evolutionary history with fire regimes similar to our results for the pre-extraction era. Wiregrass (*Aristida stricta*) the most common grass species of APAFR is well known to be finely tuned to flower and set seed only in response to transition time-of-year fires (Fill et al. 2012). Rare species of plants and animals have likely been most affected by the changes in fire regimes over the past century. A striking example of this is the Florida Grasshopper Sparrow which is finely-tuned to very frequent (1-2 year), early transition time-of-year fire regimes (exactly what we found for pre-extraction era). Populations began to decline when the fire regime moves outside of this past range of variation (Wildfire Management Plan Draft 2013, Shriver et al. 1996, Shriver et al, 1999, Shriver and Vickery 2001). Species that are very finely tuned to evolutionary fire regimes are more likely to be rare and declining when fire regimes change.

Relevance of findings to fire management

This fire history study provides scientific data (on frequency and time of year of fires) that can be used to help guide ecologically-based fire management of APAFR and other fire-frequented habitats. To manage for the benefit of natural plant and animal communities at APAFR requires fine-tuning two aspects of prescribed fire regimes: 1) prescribed fires with shorter return intervals of 1-2 years, and 2) prescribed fires during the lightning-season, and especially during the transition time-of-year (from dry to wet, from no lightning to lightning, from early wood to late wood). The move of APAFR managers to reintroduce lightning-season fires in the 1980s was an important shift in direction after 6 decades of mostly dormant season fires. Our findings suggest that a move to more frequent prescribed fires of 1 and 2 year intervals, and more prescribed fire in the early lightning season would be most similar to natural fire regimes and most likely to benefit the native plant and animals of APAFR.

Proposed future studies

Data gained from this study could be used and expanded upon to address several additional questions.

1. **Early fire regimes**. The fire history for APAFR before 1820 is based on few samples and scars because APAFR, like most of Florida, has very little old wood in any form (living trees or stumps). However, nearby on a small portion of the Lake Wales Ridge State Forest there are living old growth longleaf pines and many old stumps. We have conducted preliminary collecting in this area and have found stumps that date back as far as 1583 (Figure 33). In contrast, the oldest APAFR tree in this study dated to 1756. We have also found an abundance of fire scars from the 1600s and 1700s (the APAFR earliest fire scar is from 1784). Adding the trees from this Lake Wales Ridge site into the APAFR fire history study could extend our knowledge of the history of fire in the region back much further back in time. This would also yield a growth chronology that would be the longest and most important for climatic reconstructions in peninsular Florida, and would be essential for climate/spatial analyses of fire.

Figure 33. This cross-section from a stump at Lake Wales Ridge State Forest dates back to 1583. This tree grew very slowly for hundreds of years and has over 300 growth rings.

2. **Analysis of fire/climate relationships.** Using the spatial component of the fire scar records from the APAFR fire history study we could examine the spatial extent of fires for each fire year and compare that to climate (e.g., rainfall/El Nino/La Nina cycles) to determine if/how climate is influencing fire regimes over the period of fire record.

3. **Comparison of tree ring fire scar record of APAFR to known date fires**. The known dates of fires (wildfires, prescribed fires) from 1980-2004 could be compared to the fire scars on our collected tree sections. This would enable us to discern whether different types of fires (e.g., dormant/transition or fires under drought/normal conditions) produced more or less fire scars. This information would allow us to determine the intensity of fire needed to make scars present in the older sections.

4. **Analysis of growth of longleaf pine at Southern range limit.** We could use our growth chronology to further explore climatic variables that influence growth at Southern-most extent of range of longleaf pine.

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Acknowledgements

We would like to thank Steve Orzell for coordinating all aspects of this study and assisting with site selection and logistics for sampling and for seeing it through to the end. His help and persistence were essential to the completion of this study. DOD provided funding to complete this study for which we are very grateful. Portions of this study were supported through NSF Award 0950302 (WJP, PI).

We also gratefully acknowledge the essential work contributed by the following people: Neil Jones who read all of the dendrometer bands for over two years, cut cross sections and produced maps and graphs for this report; Raelene Crandall, who coordinated the installation of the dendrometer bands, contributed to the seasonal growth analysis, and did extensive work central to developing the chronology and dating the fire scars; Darin Ellair who prepared sections and also contributed much to the chronology and dating of fire scars; Grant Harley who contributed to chronology development and fire scar dating, and carried out the FHX2 analysis, Wayne Taylor and Catherine Airey who collected so many cross-sections of downed trees; and Henri-Grissino Mayer who lent lab assistance. We thank each of you greatly for all that you contributed to the completion of this work.

Photo by Raelene Crandall

List of Appendices

Part 1

Part 2

Appendix 1.1. Map of fires that occurred during dendrometer band study period

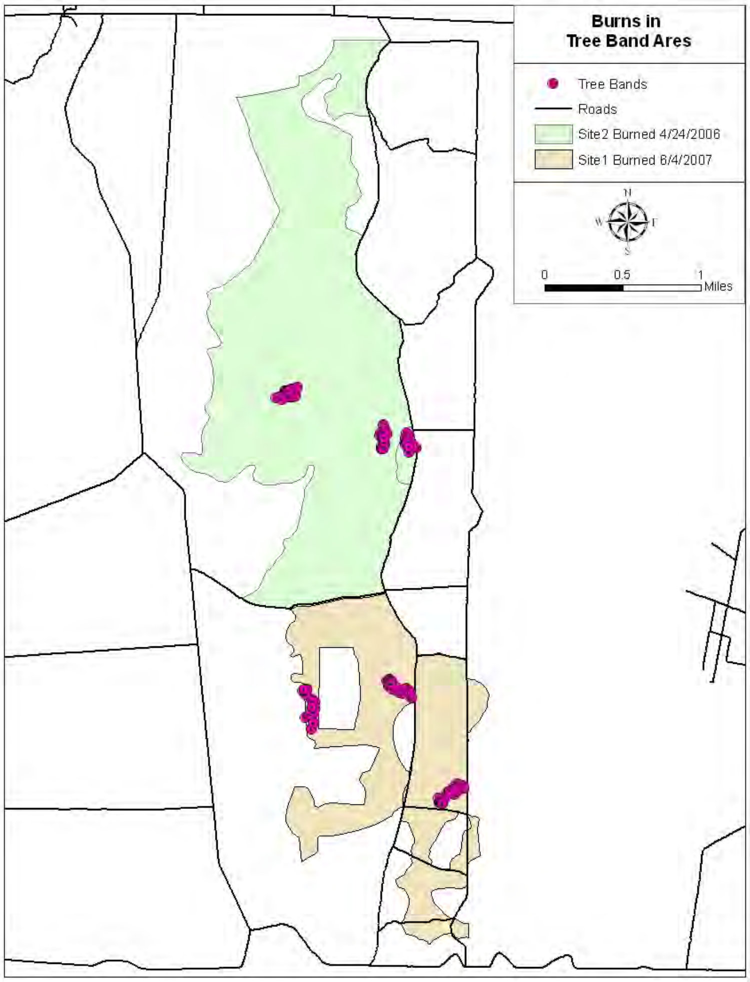

Figure 1-1. Prescribed fires during the period of study. Northern replicates of all three habitats were burned on April 24, 2006; southern replicates of all three habitats were burned on June 4, 2007.

Appendix 1.2. Maps of distribution of longleaf and slash pines in study sites.

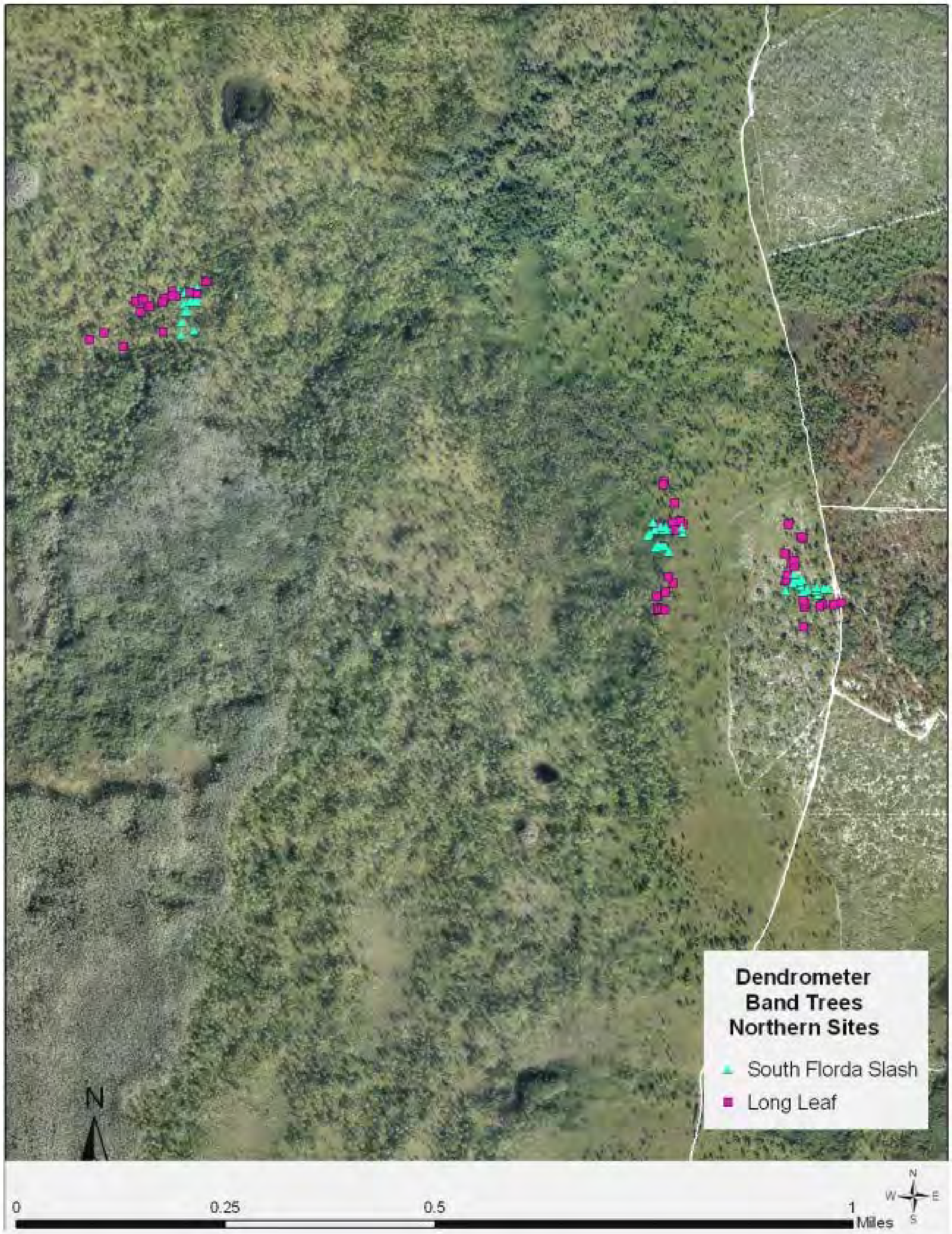

Figure 1-2a. Distribution of longleaf pine (pink squares) and south Florida slash pine (turquoise triangles) in the 3 northern study sites.

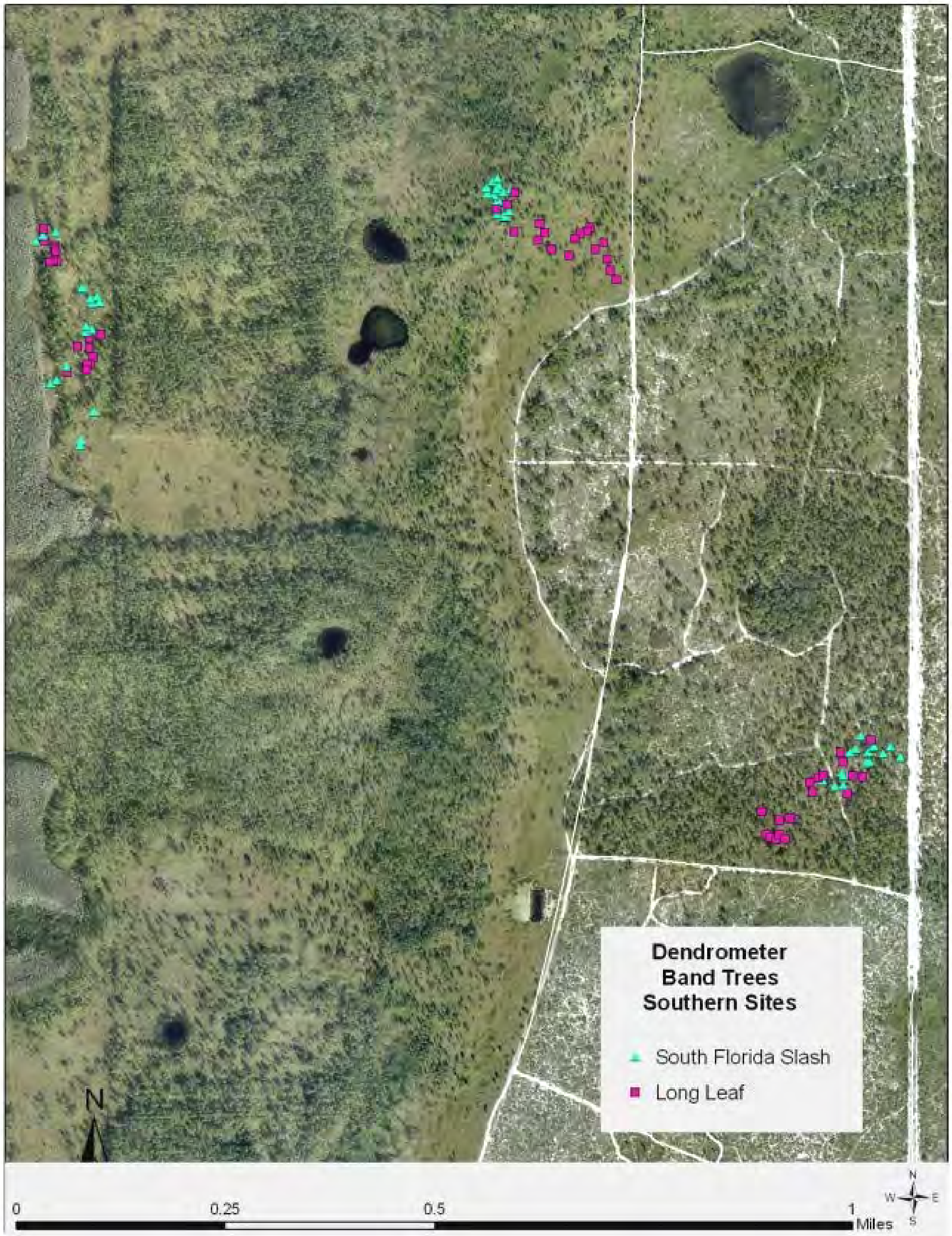

Figure 1-2b. Distribution of longleaf pine (pink squares) and south Florida slash pine (turquoise triangles) in the 3 southern study sites.

Appendix 1.3. Table of experimental design of pine cambial growth study

Table 1-3. Experimental design of pine growth study including numbers of trees that were fitted with dendrometer bands and growth measured from 2/2006-7/2008.

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Site	Tree Species	Habitat	Size trees
Site 1 108 total trees	54 Longleaf	18 Wet	6 small
			6 med
			6 large
		18 Dry	6 small
			6 med
			6 large
		18 Seep	6 small
			6 med
			6 large
	54 S. FL. Slash	18 Wet	6 small
			6 med
			6 large
		18 Dry	6 small
			6 med
			6 large
		18 Seep	6 small
			6 med
			6 large
Site 2 108 total trees	54 Longleaf	18 Wet	6 small
			6 med
			6 large
		18 Dry	6 small
			6 med
			6 large
		18 Seep	6 small
			6 med
			6 large
	54 S. FL. Slash	18 Wet	6 small
			6 med
			6 large
		18 Dry	6 small
			6 med
			6 large
		18 Seep	6 small
			6 med
			6 large

Appendix 1.4. False ring occurrence 2006-2007

Introduction

False rings, known as intra-annual density fluctuations, occur when a tree produces fluctuations in density of cells within an annual ring, either producing thin line of earlywood cells within latewood growth, or lines of latewood cells within earlywood growth. Dendrochronological work with longleaf and slash pines, which relies on the exact interpretation of annual rings, is often difficult because of the abundance of false rings. The abundance of false rings appears to increase moving southward in the range of these species, and false rings appear to be particularly abundant in south Florida (Harley et al. 2011). Knowing the cause of false ring formation could result in these ring anomalies providing useful information about past climate.

We present a preliminary examination of the distribution of false rings between years, habitats and size classes of longleaf and south Florida slash pines at APAFR during 2006 and 2007.

Methods

General field and laboratory methods are presented in the main body of this report. We examined corelet wood samples that were originally collected to determine the timing of latewood production, for the formation of false rings. We recorded any false rings that occurred in 2006 or 2007. We then explored any differences in false ring formation by species, tree size, and environmental variables (habitat and rainfall) by graphing occurrence data.

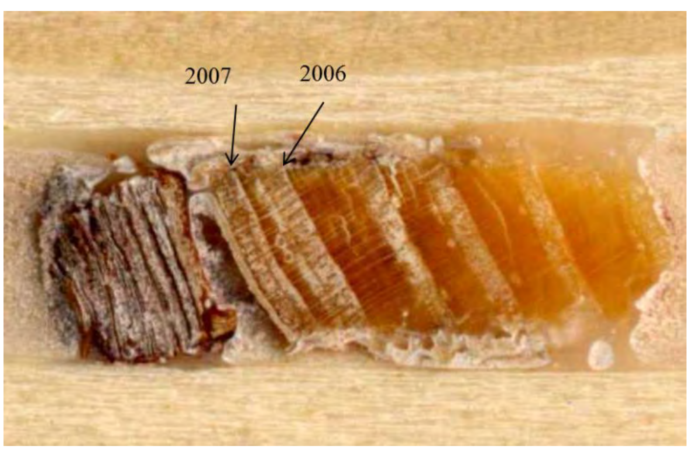


Figure 1.4. A “corelet” sample that was taken on June 26, 2007 from a small, overtopped longleaf pine growing in seep habitat. Arrows indicate the beginning of the 2006 and 2007 annual growth rings; in both of these growth rings intra-annual density fluctuations (thin lines of latewood cells within the earlywood) are visible.

Results

False rings were abundant during the two years of the study. Of the 72 trees sampled, 46 (64%) had false rings in at least one of the two years, that we examined. Many trees had false rings in both years that were sampled. The distribution of false rings was not random with respect to years. In 2006 nearly half (46%, n=33) of all trees sampled had false rings, and in 2007 33% (n=24) had false rings. All of the 57 false rings noted in the corelets occurred as production of earlywood after latewood production had begun.

The distribution of false rings varied among species, size classes and habitat types of trees.

Species. False ring formation was common in both longleaf and south Florida slash pines. Longleaf pines had slightly more false rings (53% of all false rings) than south Florida slash pines (47% of all false rings). During both full sample years the proportion of false rings that occurred in longleaf and south Florida slash was similar (55% versus 45% in 2006 and 50% versus 50% in 2007) (Table 4-1).

Size class. There were differences in frequency of false rings in different size classes of trees. Smaller trees had the most false rings. Trees of the small size class (from 6-20 cm dbh) had 56% of all false rings, medium size class trees (20.1-30 cm. dbh) had 14% of false rings and trees over 30 cm. dbh had 30% of false rings (Table 4-1).

Habitats. There were differences in the distribution of false rings among habitat types and the distribution varied between years. Overall, seep site trees had more false rings than either wet or dry site trees (42% versus 30% and 28% respectively, Table 8). The distribution of false rings was fairly even among habitats in 2006, while the seep sites had the largest proportion of false rings (54%) in 2007 (Table 4-1).

Species x habitat. There were differences in the distribution of false rings between longleaf and south Florida slash pine in different habitats. Overall, for both longleaf and south Florida slash pine a higher proportion of false rings occurred in trees in the seep sites, and the proportion is similar between species (.43 longleaf versus .41 slash). In contrast, in dry habitat a higher proportion of south Florida slash pines than longleaf pines had false rings (33% slash versus 23% longleaf), and in wet habitat a higher proportion of longleaf than south Florida slash pine had false rings (33 versus 26 wet) (Table 4-2).

Habitat x species x year. The differences in the distribution of false rings between the two species varied between years. In 2007 a much higher proportion of false rings occurred in longleaf in the wet sites and south Florida slash in the dry sites (Table 4-3). In contrast, during the dry year of 2006 a higher proportion of false rings occurred in longleaf versus slash in seep sites (.64 versus .36 respectively), while the distribution of false rings was even between species in the wet and dry habitats.

Fire may have an influence on the formation of false rings. One half of the trees (Site 2) burned in 2006 and the other half (Site 1) burned in 2007. Rates of false rings on seep and wet sites were lower in the burned sites versus unburned sites (Table 4-1).

Table 1.4a. Proportion of false rings by species, habitat type, site and size class for 2006 and 2007 and both years grouped together. Numbers in red indicate sites that had been burned early in the growing season of that year.

	2006	2007	2006/2007
Longleaf Pine	**0.55**	0.50	0.53
South Florida Slash Pine	0.45	0.50	0.47
Small	**0.52**	**0.63**	0.56
Medium	0.18	0.08	0.14
Large	0.30	0.29	0.30
Wet	0.30	0.29	0.30
Seep	0.33	**0.54**	0.42
Dry	**0.36**	0.17	0.28
Site 1	**0.55**	0.29	0.44
Site 2	0.45	**0.71**	0.56
Total number false rings	33	24	57

Table 1.4b. Species x Habitat. Proportion of all false rings that occurred in dry, wet or seep habitats for longleaf and south Florida slash pine.

	Dry	Wet	Seep
Longleaf pine	0.23	0.33	**0.43**
South Florida slash pine	0.33	0.26	**0.41**

Table 1.4c. Species x Habitat x Year. Proportion of false rings in longleaf and south Florida slash pine, in dry, seep, and wet sites, for each year of study.

		2006	2007
	Dry LL	0.50	0.25
Dry	Dry SFS	0.50	**0.75**
	Seep LL	**0.64**	0.46
Seep	Seep SFS	0.36	0.54
	Wet LL	0.50	**0.71**
Wet	Wet SFS	0.50	0.29

Discussion

False rings are a prominent feature of longleaf and south Florida slash pines of all sizes and habitats from APAFR. Because we studied a large number of trees, we can begin to examine variables that influence the formation of false rings, such as species, sizes of tree and habitat.

We examined the occurrence of false rings in longleaf pine and south Florida slash pine. Slash pine is known to have an abundance of false rings (Harley 2012, Ford and Brooks 2002) and was once thought to be unusable for dendrochronological studies. Longleaf pine is known to also have false rings (Henderson 2006) but false rings are not nearly as common in longleaf pine as they are in slash pine in north Florida (pers. obs.). We expected south Florida slash pine to have more false rings than longleaf pine. Contrary to expectations, longleaf pine at APAFR, which is at the southern extent of the range of the species, had false rings more frequently than south Florida slash pine.

False rings occurred most commonly in smaller trees. Young trees are well known for their propensity to form false rings (Copenheaver et al. 2006, De Luis et al. 2009, Vieira et al. 2008). False rings were most common for both longleaf and slash pine on seep sites.

Causes of false ring formation in longleaf and slash pines at APAFR could likely be determined by conducting an analysis of false rings from a larger sample of trees and years and comparing formation of rings to climate variables (e.g., monthly rainfall, drought index and solar radiation,) that potentially have an influence on the formation of false rings. This could be carried out using samples already collected for the fire history portion of this study. From our preliminary analysis we present three hypotheses regarding the cause of false ring formation that would be worth pursuing:

1) Drought or extreme fluctuations of rainfall and growth within the growing season, causes false rings. Fluctuations of rainfall or extreme dry periods within the growing

season are known to cause false rings in some pine species (Wimmer et al. 2000, De Luis et al. 2011, Campelo et al. 2007, Vieira et al. 2008). Several observations point to the possibility of drought influencing false ring formation in APAFR pines: the greater number of false rings in 2006, which had an exceptionally dry period during the first half of the growing season; the abundance of false ring formation in seep sites where functional drought may be more pronounced because of the shallow root systems in trees in seep sites; and the abundance of false rings in small slash pines on dry sites (the size and species of pine that would presumably be most drought-stressed on a dry site).

2) Periods of rapid growth result in false ring formation. Copenheaver et al. (2006) found that false rings occurred in *Pinus banksiani* during or immediately after periods of rapid growth. At APAFR small trees that grow more rapidly, and are dormant for shorter durations, have a much greater incidence of false rings than mature trees. Also trees on wet and seep sites grew faster and had more false rings than those on dry sites where growth was slower.

2) Variations in solar radiation influence false ring formation. The only other study of false ring formation in south Florida slash pine (Harley et al. 2012) observed a correlation between increased solar radiation and false ring formation in four south Florida slash pines in 2010, but no correlation with rainfall or other climatic variables. Solar radiation influences pine growth and dormancy and may have an influence on the formation of false rings.

Additional note on missing rings. Rings were considered “missing” when no measurable or visible growth occurred during an entire growing season. Corelets and growth data were used to determine the numbers of missing rings.

Three missing rings occurred in the 72 sampled trees during the entire 27 months of sampling. All occurred in the driest year (2006), in south Florida slash pines in seep habitat. Two were from trees that were in an overtopped canopy position (dbh 7.9 and 17.6 cm) and one was a dying tree that was not overtopped (39.4 dbh).

Missing rings were rare. This is reinforced by our chronology, which also had few missing rings across thousands of individual growing years.

Instances of missing rings were likely related to drought stress in seep sites. All of the trees that had missing rings occurred on seep sites. Seep sites have edaphic characteristics that may make drought functionally more severe for pines. In seep sites pines do not grow deep taproots (personal observation). This is likely because the surface water table is usually very near the surface for much of the year confining roots to upper layers of soil. Subsequently, in drought years, when the surface water table is low, the tree roots are shallow with no access to deeper levels of water. These trees may be functionally more drought-stressed than trees even on dryer sites that have deep root systems (Ford and Brooks 2003). Seep site trees were the most difficult trees to date rings from because of the occurrence of false and missing rings.

Appendix 1.5. Variation in quantity of seasonal growth

In the main report we examined the timing of cambial growth; in the following section we present results from an analysis of differences in the *amount* of seasonal cambial growth that occurred among wet, dry and seep habitats; between longleaf and south Florida slash pine; and among different size classes of trees (small, medium, large) (analyses by Raelene Crandall). We examine total growth for six consecutive time periods during 2006 - 2008: 2 early wood growth periods, 2 latewood growth periods and 2 dormant periods. During the dormant period few trees are growing, and there is very little growth, but this small amount of growth was examined to determine potential differences in patterns of dormancy.

Methods

We explored whether environmental variables might explain observed differences in the amount of seasonal growth between species, habitat types and sizes of trees. We divided measurements of growth into time periods corresponding to the dormant season, early wood growth and latewood growth. Trees lacking the final measurement for a time period were not included in analyses. A two-way mixed-model analysis of variance (ANOVA) was used to test for differences in growth by species (*Pinus palustris, P. elliottii* var. *densa*), habitat type (wet, seep, dry), and size class (small, medium, large) ($P \leq 0.05$; Steele and Torrie 1980). We also tested interaction effects for each combination of explanatory variables. Analyses were performed in SAS version 9.2 (SAS Institute, Cary, NC, USA). We also graphed mean monthly growth for the period of the study.

Results

There were significant differences in the amount of growth between trees growing in different habitats, between species of trees, between size classes of trees and between habitat x species and species x size class (Table 2-1).

Table 1-5a. Summary of Results of ANOVA. The effects of environmental variables on total cambial growth divided into three intra-annual seasonal periods: earlywood, latewood, and dormant season growth. ANOVAs results with P-values, * indicates a significant difference <0.05, ** indicates a significant difference <0.001.

Response Variable	Habitat	Species	Size Class	Habitat x Species	Habit at x Size Class	Species x Size Class	Habitat x Species x Size Class
Dormant 2007	0.1663	0.0882	****≤0.0001**	0.4199	0.6009	0.0585	***0.0094**
Dormant 2008	***0.0135**	***0.0065**	***0.0061**	0.6316	0.5669	0.0810	0.0849
Late 2006	***0.0017**	0.9674	***0.0019**	***0.0149**	0.1952	***0.0027**	0.2575
Late 2007	****0.0005**	0.1664	****<0.0001**	0.0836	0.8300	***0.0045**	0.1325
Early 2007	****0.0002**	***0.0412**	****<0.0001**	***0.0379**	0.0552	***0.0062**	0.4229
Early 2008	****<0.0001**	***0.0046**	****<0.0001**	***0.0393**	0.1913	****0.0008**	0.1621

Habitat. Trees in different habitats had different rates of cambial growth during the growing season. Growth was consistently greater in wet sites compared to seep sites, and in seep sites compared to dry sites (Figure 2-1). This pattern of greater growth in wetter sites was similar over both years of study (Figure 2-1). The greater growth in wet sites was evident as greater mean monthly growth over the period of study (Figure 2-2). Habitat type had a highly significant influence on total growth during earlywood and latewood growth periods for both years (Table 6).

Trees growing in different habitats also had different rates of growth in the dormant season and differences in dormancy. Growth rates in the dormant season, although small, tended to be related to the differences in sites (Figure 2-1). Growth was greater in seep and wet sites than dry sites during the dormant seasons of 2007 and 2008 (Figure 2-1). Seep and wet sites had similar, extremely small, rates of growth in 2007, but not 2008 (Figure 2-1). The proportion of trees that were dormant was consistently lower for trees in wet sites than those in seep and dry sites (Figure 2-2).

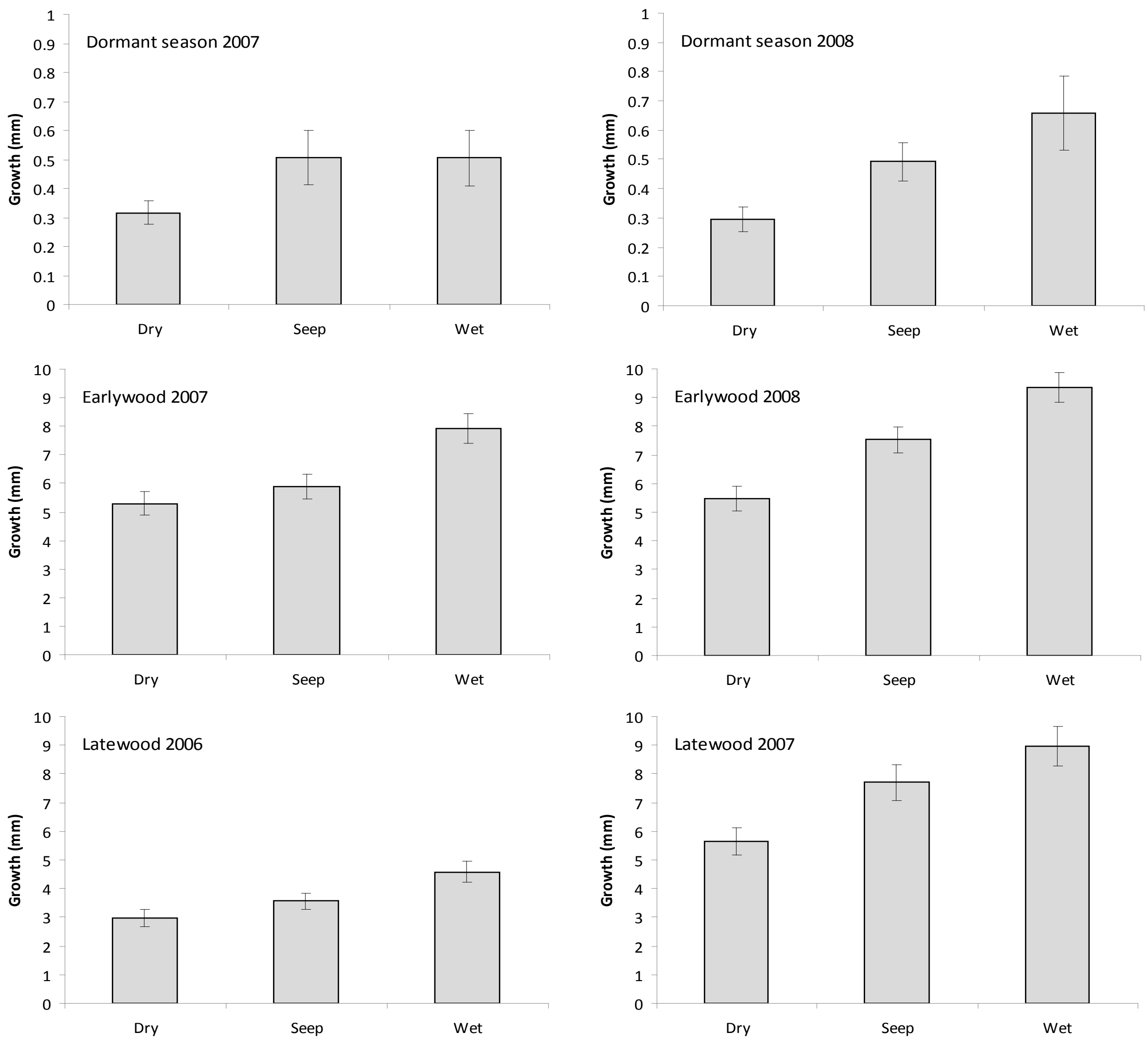


Figure 1.5a. Mean growth in circumference (+ one standard error) in three habitats along a moisture gradient (dry, seeps, wet) at the Avon Park Air Force Range (Highlands County, FL) from 2006 – 2008. Data are for three periods of wood production during the year: dormant (January-February, upper), earlywood (March-May, middle), and latewood (June-December, lower). Different scales were used above for growth in dormant and growing seasons. Data are for all species and all sizes of trees combined.

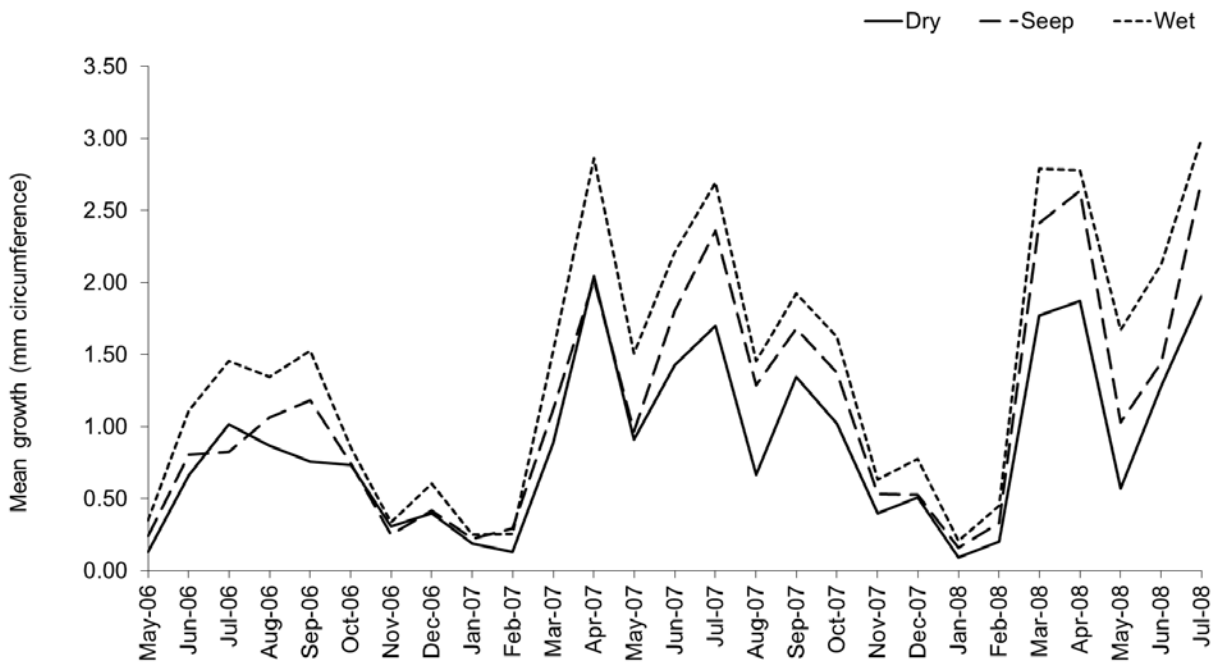


Figure 1.5b. Mean monthly increase in circumference (mm) over the period of study in three habitats (dry, seep and wet sites).

<u>Species</u>. Overall, south Florida slash pine grew at a slightly faster rate than longleaf pine. Slash pine grew a mean of 16% more than longleaf pine over the period of the study. Mean monthly growth (mm.) for longleaf pine was 1.05± 0.20 s.e. and for slash pine it was 1.25 ± 0.24 s.e.. Slash pine also grew more than longleaf pine in every month of the study period, except August, September and October of 2006, when longleaf growth was equal or slightly higher than slash pine growth (0.1, 0, or .14 higher, respectively) (Figure 2-4). Differences in growth were less in the dry 2006-2007 year than in the wetter 2007-2008 year (Figure 2-3). The difference in growth was significant in the earlywood growth period (2007 P=0.0412, 2008 P=0.0046), but not in the latewood period, and in the dormant period of 2008 (P=0.0065) but not in 2007 (Table 2-1).

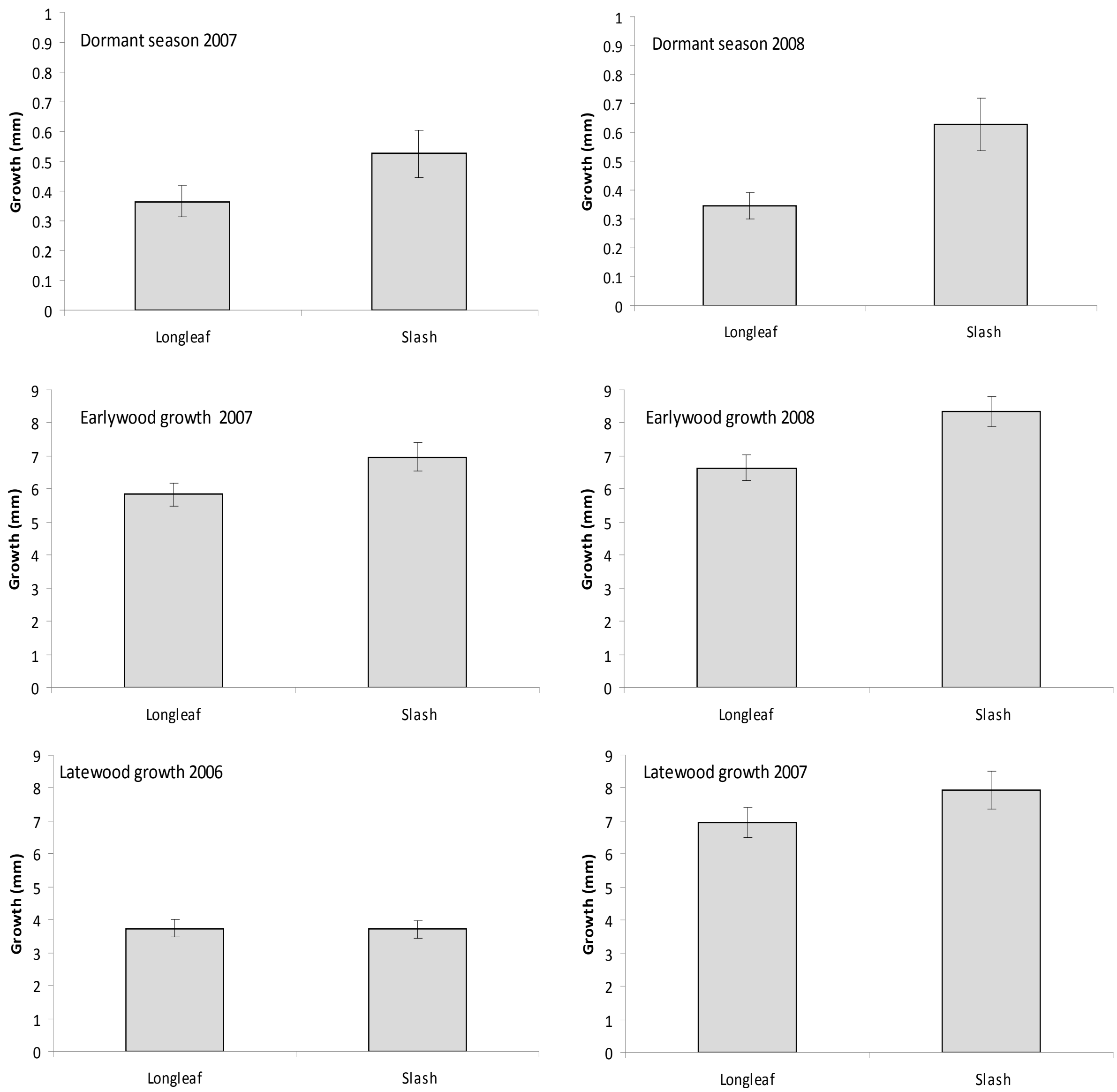


Figure 1.5c. Growth in circumference (± one standard error) of longleaf pine (*Pinus palustris*) and south Florida slash pine (*Pinus elliottii* var. *densa*) at the Avon Park Air Force Range (Highlands County, FL) from 2006 – 2008. Data are for three periods of wood production during the year: dormant (January-February, upper), earlywood (March-May, middle), and latewood (June-December, lower). Different scales were used above for growth in dormant and growing seasons. Data are for all habitats and all sizes of trees combined.

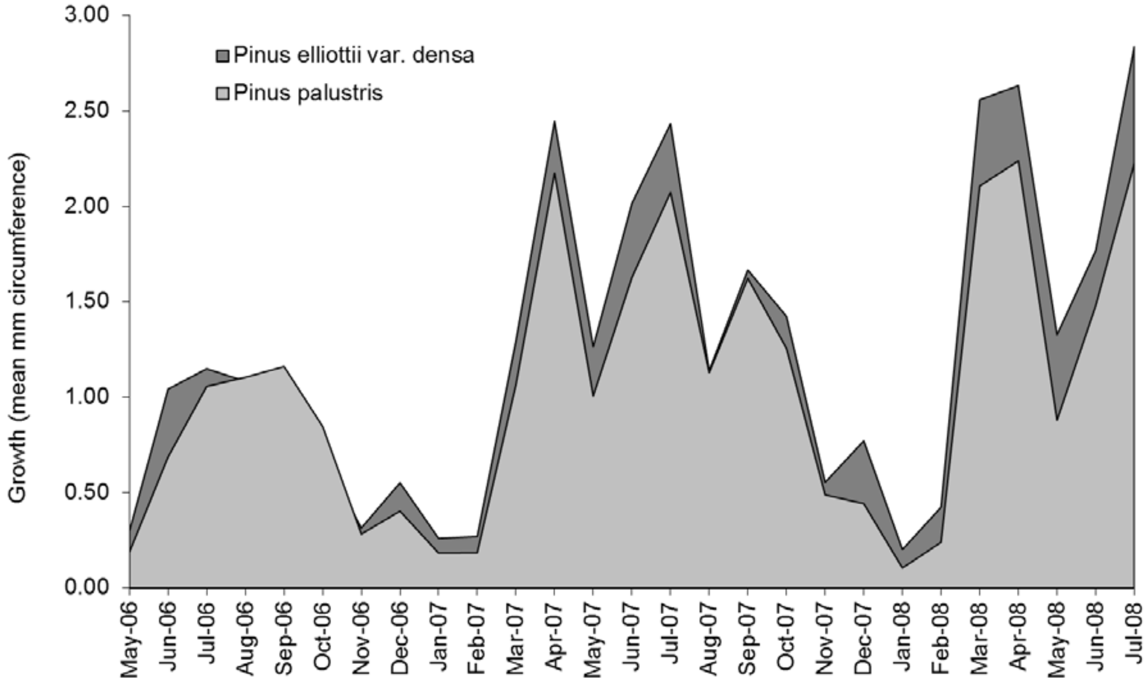


Figure 1.5d. Mean monthly increase in circumference (mm) over the period of study of South Florida slash pine (*Pinus elliottii* var. *densa*) and longleaf pine (*Pinus palustris*).

<u>Species x Habitat.</u> There were differences in monthly growth between longleaf and south Florida slash pines in different habitats. The largest difference in mean monthly growth between the species was greater growth of slash pine growth than longleaf pine in wet sites (Figure 2-5). In addition, mean monthly growth in circumference indicated a consistent slightly greater rate of growth of longleaf pine in the dry and seep sites (Figure 2-6). The greatest difference in longleaf growth over south Florida slash pine growth was from June through October of 2006 when conditions were exceptionally dry. In 2008 growth rates of slash and longleaf were nearly identical in the dry site. There was a significant difference in growth during the earlywood growth period (2007 P=0.0379, 2008 P=0.0393) and the latewood growth period of 2006 (P=0.0149) (Table 2-1). In summary, longleaf grows as much or more than slash on dry and seep sites and slash grows more than longleaf on wet sites.

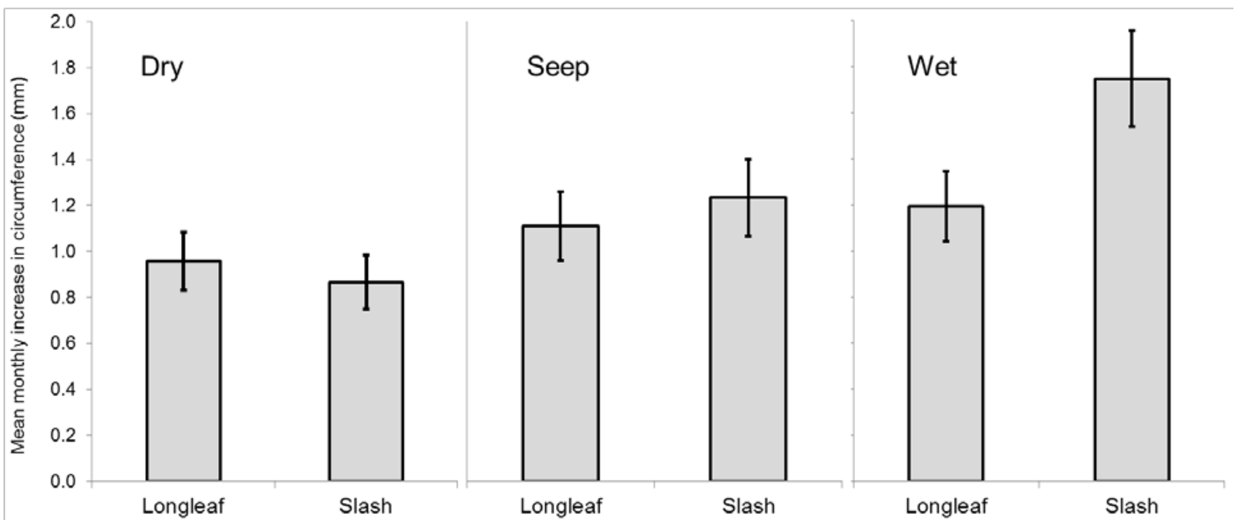


Figure 1.5e. Mean monthly growth in circumference (<u>+</u> one standard error) of longleaf pine (*Pinus palustris*) and south Florida slash pine (*Pinus elliottii* var. *densa*) along a moisture gradient (dry, seep, wet) at the Avon Park Air Force Range (Highlands County, FL) from 2006 – 2008. Data are for all months and all sizes of trees combined.

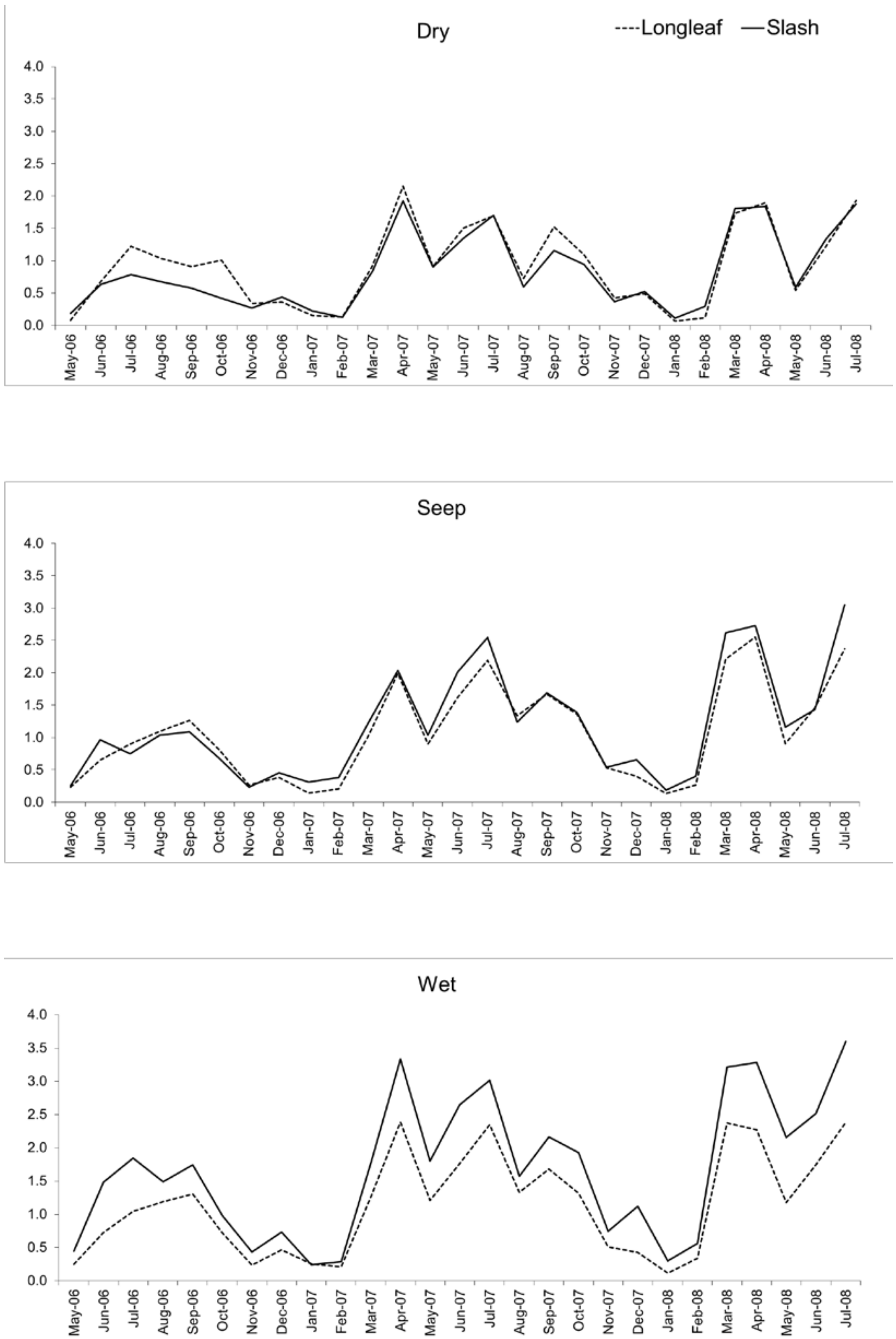


Figure 1.5f. Mean monthly increase in circumference (mm) over the period of study of South Florida slash pine (*Pinus elliottii* var. *densa*) (solid line) and longleaf pine (*Pinus palustris*) (dashed line) in dry, seep and wet habitat types.

Size Class. There were differences between growth of pines in different size classes, as well as the timing of cambial growth initiation, and dormancy. Seasonal cambial growth was greater for trees in small (6-20 cm dbh) than in medium (>20 to 30 cm dbh) or large (>30 cm dbh) size classes (Figure 2-7). Small trees grew a mean of 1.53 mm per month, while medium trees grew 1.06 and large trees grew 0.85 mm per month over the period of study. Figure 3-8 indicates that small trees consistently increased in circumference more than medium or large trees during the growing season throughout the study. Smaller size class trees thus grew faster than medium and large trees during both earlywood and latewood periods of the year (Figure 2-7). There was a significant difference for every growth period (Table 2-1).

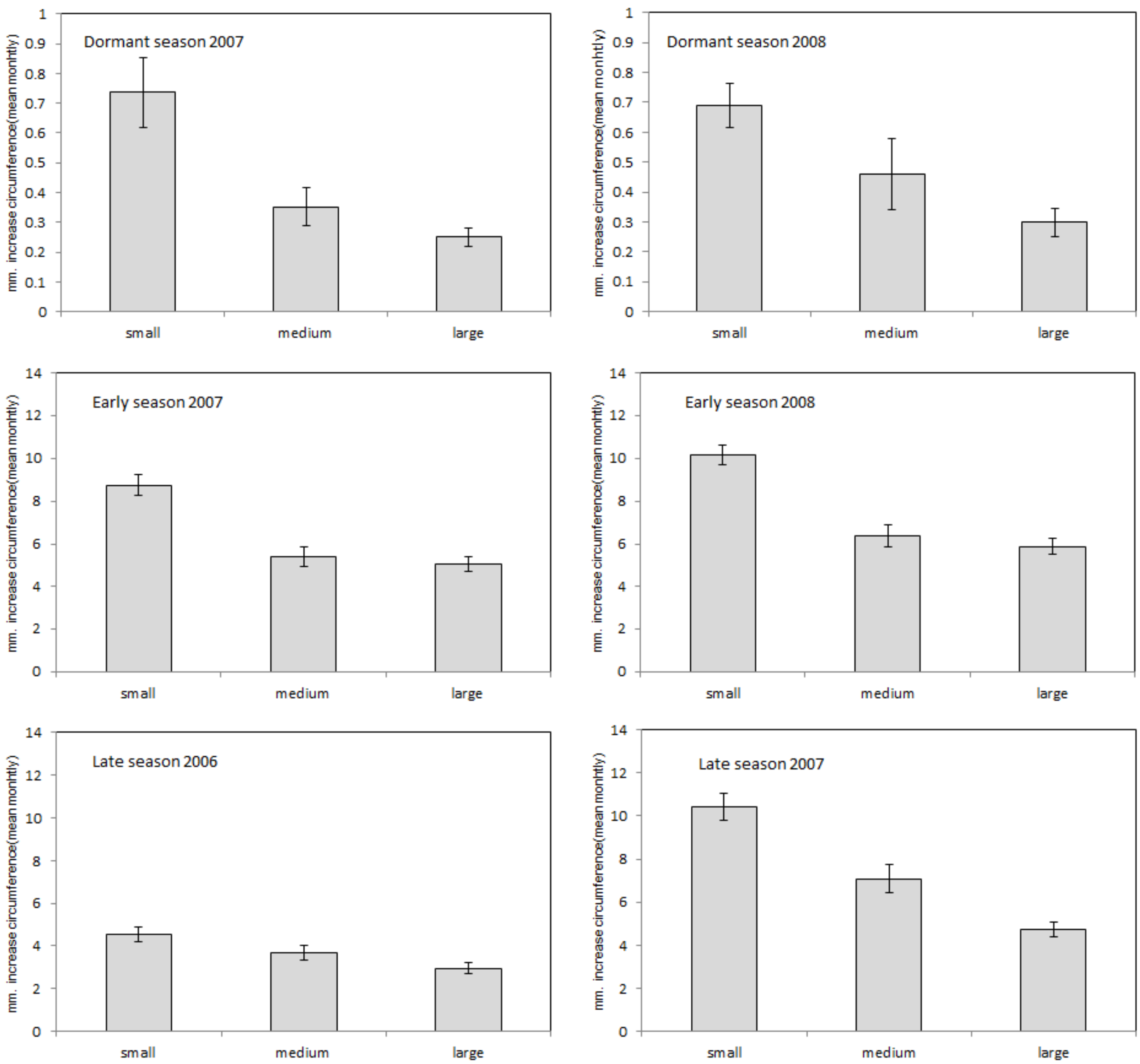


Figure 1.5g. Mean growth in circumference (+ one standard error) of pines in three size classes of pines at the Avon Park Air Force Range (Highlands County, FL) from 2006 – 2008. Data are for three periods of wood production during the year: dormant (January-February, upper), earlywood (March-May, middle), and latewood (June-December, lower). Size classes ranges are small (5 - 20cm dbh), medium (>20 to 30 cm dbh) or large (>30 cm dbh). Different scales were used above for growth in dormant and growing seasons. Data are for all habitats and species combined.

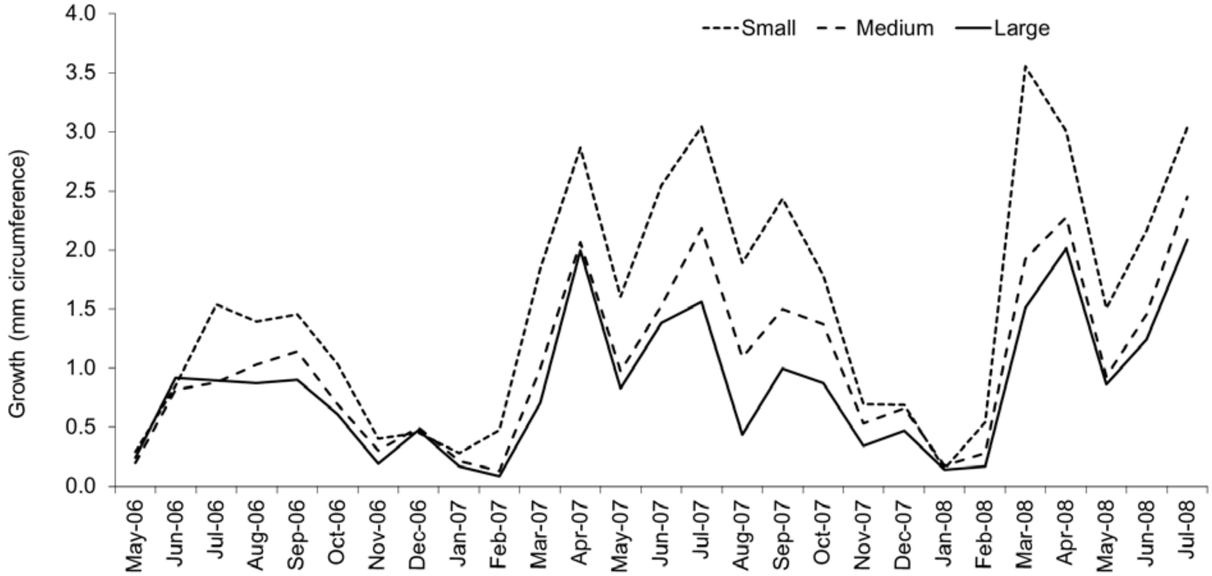


Figure 1.5h. Mean monthly increase in circumference (mm) over the period of study of small, medium and large size class pines. Horizontal line indicates monthly growth ≤0.4mm, one criterion for assigning trees to dormant category.

Species x Size Class. Growth varied between longleaf and slash pines of the three size classes. Monthly increases in circumference were greater for longleaf pine than slash pine in the small size class, but greater for slash pine than longleaf in the medium and large size classes (Figure 2-9). Monthly growth for small trees shows that slash pines grew slightly more during the dormant season, but longleaf grew more in the growing season (Figure 2-10). Medium trees had the largest difference in growth between species with slash pines consistently growing more than longleaf, while large trees differed less in the difference between slash and longleaf growth (Figure 2-9). There were no differences in timing of seasonal growth based on species and size class interaction. The interactive effects of species and size class were significant for all four growing season periods (P=0.0027, 0.0045, 0.0062 and 0.0008) (Table 2-1).

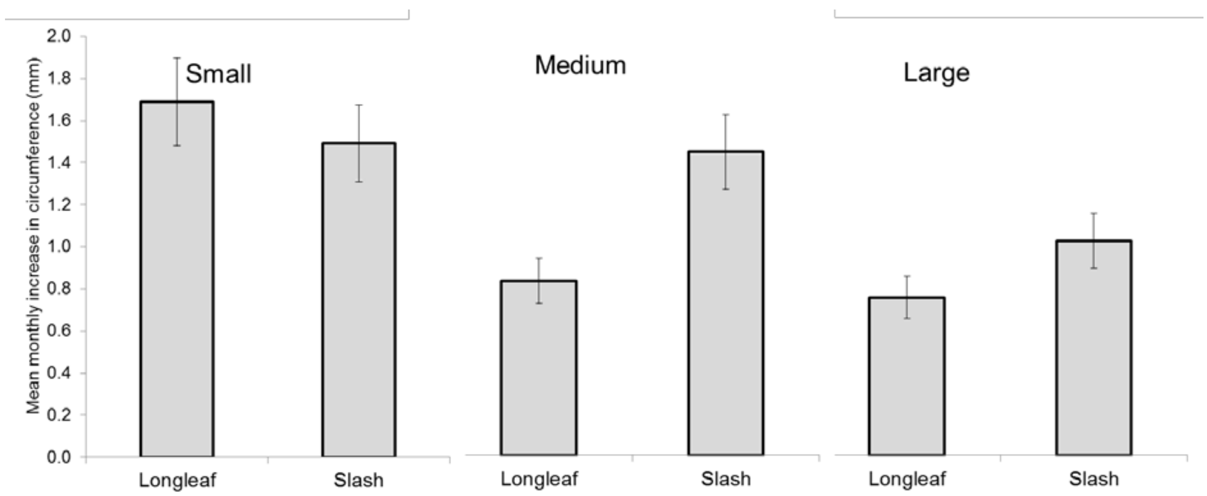


Figure 1.5i. Mean increase in circumference (+ one standard error) over the 27 month period of study for longleaf and slash pines in small, medium and large size classes.

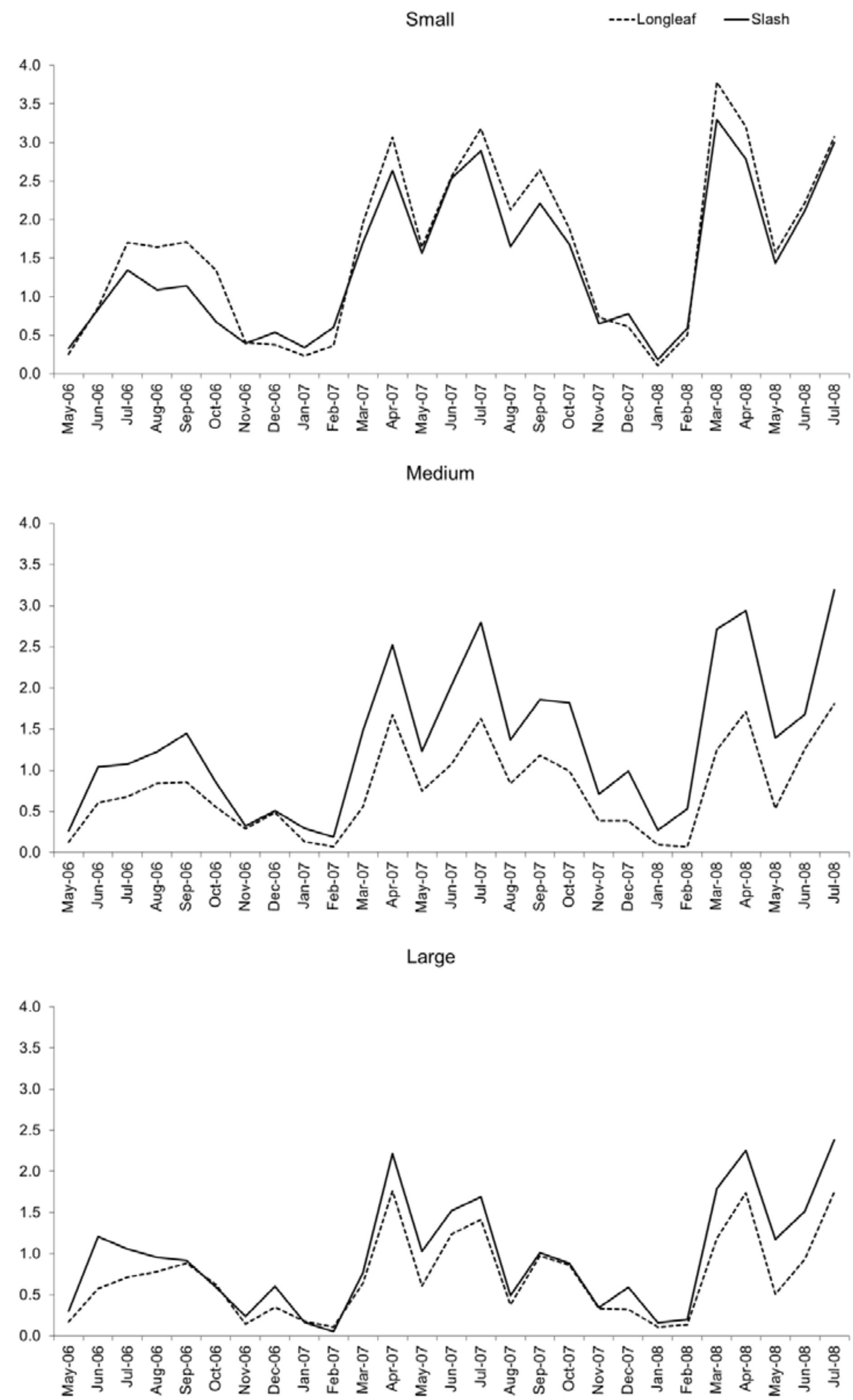


Figure 1.5j. Mean monthly increase in circumference (mm) over the period of study of longleaf pine (*Pinus palustris*) and south Florida slash pine (*Pinus elliottii* var. *densa*) in small, medium and large size classes.

Appendix 1.6. Environmental influences on seasonal timing of cambial growth.

A fire scar position system should encompass inter-annual variation in timing of seasonal cambial growth among trees, something that is strongly influenced by climatic variables. Both inter-annual and intra-annual timing and quantity of growth in longleaf and south Florida slash pine are influenced by precipitation, day length and solar radiation (Langdon 1963, Ford and Brooks 2003, Henderson 2006, Henderson and Grissino-Mayer 2009, Harley et al. 2012). Quantity of cambial growth for longleaf and south Florida slash pine is influenced most strongly by rainfall (Larson et al. 2001, Ford and Brooks 2003, Henderson 2006, Henderson and Grissino-Mayer 2009). Some researchers, however, have suggested that solar radiation, not rainfall, is the variable most important in determining timing of cambial growth in south Florida slash pine (Langdon 1963, Harley et al. 2012).

For a preliminary examination of the influence of day length, solar radiation and rainfall on monthly growth of the longleaf and slash pines at APAFR we graphed and examined potential correlations that might help explain differences in inter-annual and intra-annual timing of growth.

Day length, solar radiation, rainfall and timing of cambial growth

Day length is likely a major influence the timing of growth and dormancy of these pines. The months of dormancy or extremely low growth (November through February) correspond to the months of shortest day lengths and the growing season period of high growth corresponds to longer day lengths (Figure 3-1). A positive correlation exists between monthly mean increase in circumference and day length (.58). Earlywood growth is known to be influenced by the previous year's conditions rather than those of the current year. There was a slightly higher correlation between day length and monthly growth when excluding the initial earlywood months of March and April (.69).

Actual solar radiation did not appear to influence growth any more strongly than day length. Mean monthly solar radiation measured from nearby Sebring was less strongly correlated with monthly growth (.55 for all months and .50 for all months less March and April) (Figure 3-2).

Rainfall also may influence the timing of growth and dormancy of these pines. Greater cambial growth occurred during months of higher rainfall and lower growth occurred during times of little rainfall (Correlation monthly rainfall/increase in circumference .60) (Figure 3-3). The relationship between monthly growth and rainfall was stronger (.85) when the earlywood months of March and April, that are influenced by the previous year's conditions, were excluded. A summary of correlations between monthly growth and these three environmental variables is presented in Table 4.

Both Harley et al. (2012) and Langdon (1964) found no relationship between rainfall and either timing or quantity of seasonal growth for south Florida slash pine and suggested that day length/solar radiation was the variable that controls growth in south Florida slash pine in south Florida.

We suggest that both solar radiation/day length and rainfall strongly influence cambial growth patterns. The high correlation we found with rainfall and growth, especially when the confounding influence of the earlywood growth months were removed, points to an important influence of rainfall on amount of cambial growth. Day length appears to be most important in controlling the period of winter dormancy and the initiation of growth in the spring. Rainfall and day length are inter-correlated (.64) making it difficult to infer which may have more influence, it is likely that both influence growth and timing of growth; rainfall both of current and past year strongly influencing the amount of growth, and day length influencing the timing of growth.

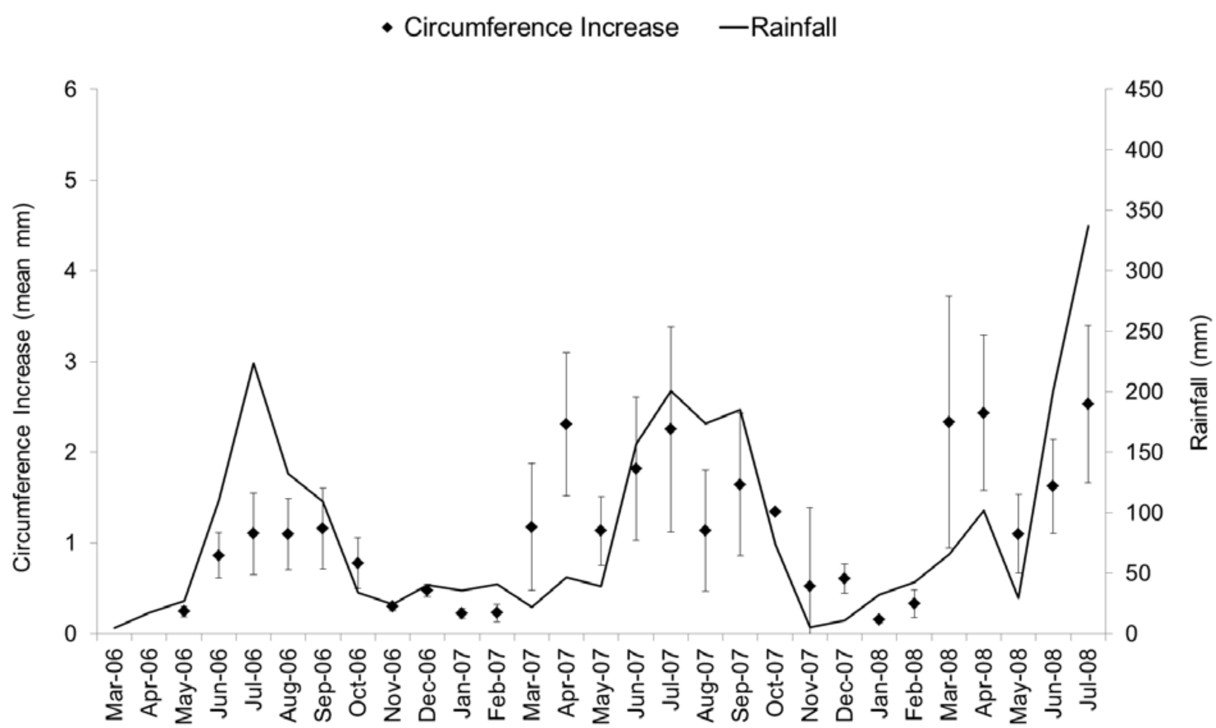


Figure 1.6a. Monthly mean increase in circumference (mm) among all trees for period of study (black dots with bars representing variance) plotted with monthly mean hours of day length (solid black line).

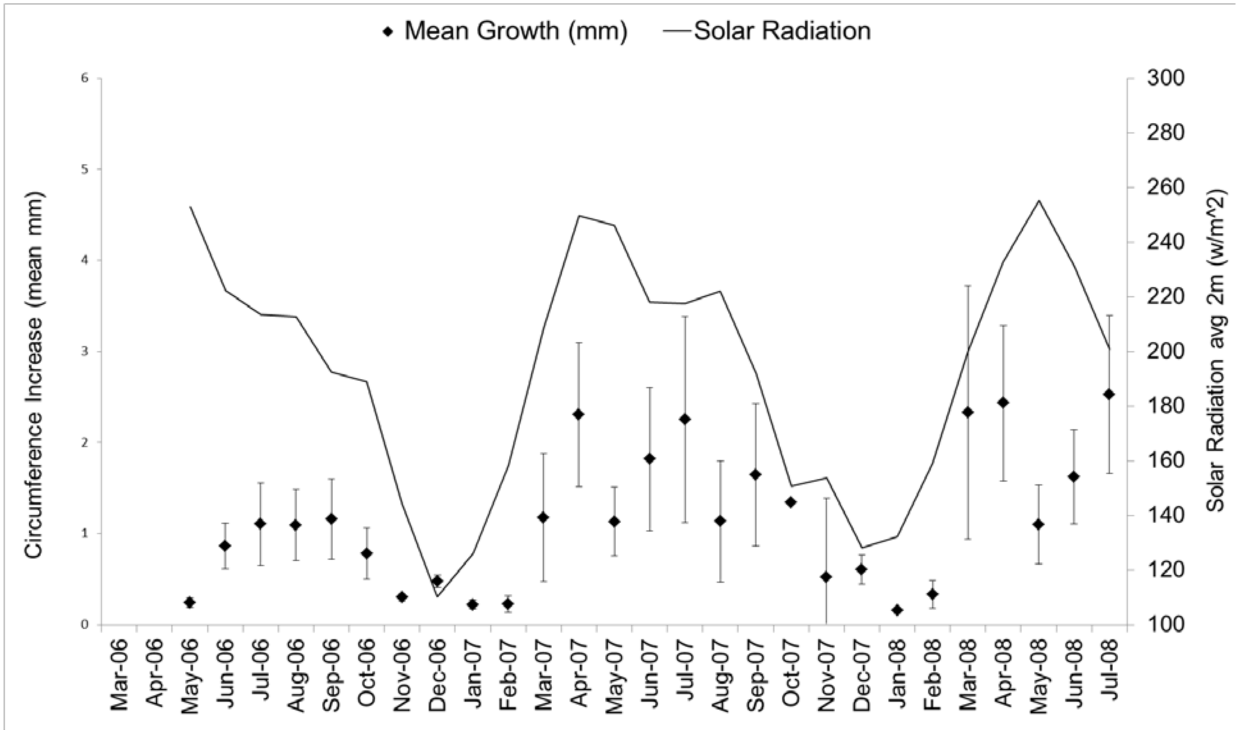


Figure 1.6b. Monthly mean increase in circumference (mm) among all trees for period of study (black dots with bars representing variance) plotted with mean monthly solar radiation (from Sebring FL) .

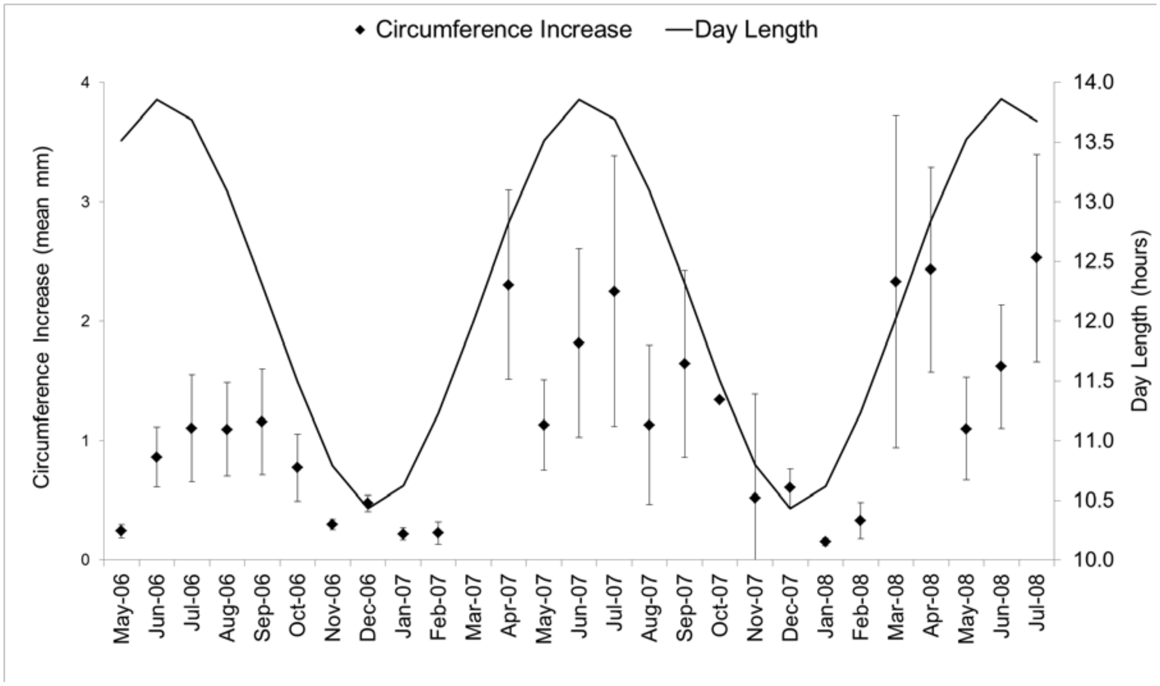


Figure 1.6c. Monthly mean increase in circumference (mm) among all trees for period of study (black dots with bars representing variance) plotted with mean monthly mean rainfall (solid black line).

Table 1.6. Correlations between mean monthly growth of pines and environmental variables (rainfall, day length, solar radiation) for period of study May 2006-July 2008 (27 months), and for period of study less March and April earlywood growth months (25 months).

	Correlation for full period of study	Correlation for period of study less March & April earlywood growth months
Monthly rainfall/Monthly growth	0.61	0.84
Day length/Monthly growth	0.58	0.68
Solar radiation/Monthly growth	0.55	0.50
Day length /Rainfall	0.64	

Appendix 2.1. Summary land-use history of the APAFR region 1500-present

Early indigenous inhabitants 1500-1700s. The introduction of disease from Europeans in the 1500s marked the beginning of the population decline of the indigenous groups that inhabited Florida before the 1700s. These indigenous inhabitants of Florida were almost wholly eliminated by the early 1700s.

Seminole Era 1780s through 1830s. Seminole Indians were a mix of Southern tribes fleeing the loss of their lands to the North that came to Florida during the 1700s (Covington 1993). Seminoles were a combination of various tribes of people, predominately Creek, that were pushed out of the Southeast into North Florida, and then further and further south into the peninsula of Florida. They inhabited this region of Central Florida in low numbers in the late 1700s or early 1800s.

Seminole Wars 1835-1851. The Seminole war was an attempt by the government of the United States of America to remove all Seminoles from Florida. It began regionally in 1835, just 12 years after a large part of the central Florida region was designated as a Seminole reservation in 1823 (Covington 1993). At the APAFR region there were two significant occupations when the U.S. military constructed and occupied short-term forts in the region and focused on killing or otherwise removing all Seminoles from the region. The first attempt at removing the Seminoles from the APAFR region occurred in 1837 and the next, and last, in 1849-1851 (Devane 1983).

This may have been the period when human population was at its lowest point, there were few soldiers present in 2 forts for limited periods of time, and the Seminole population, which probably was never very high, was declining rapidly. The final removal of the Seminoles from the north-central Florida region in the 1850s opened the way for the next era of homesteaders and open range cattle.

Homestead/Open Range Era. Low numbers of people and unknown numbers of cattle, both resident and transient, characterized the Homestead/Open Range Era. This era began in 1859 when the first homesteader settled in the area that is now APAFR (Devane 1983). It extended until 1919 when extractive uses (naval stores and logging) became dominant. Homesteading and open range land use continued into the Extractive Period and beyond, but during 1859-1919 homesteaders were the only permanent human residents of the area. Numbers of settlers varied: before 1865 there were very few settlers, more arrived after the end of the Civil War. The peak population is estimated by Devane to have been 30 families.

These settlers had cattle and presumably, large numbers of cattle were grazed here throughout this time. Cattle were grazed here and driven through the area on their way to port in Punta Gorda or north toward St. Augustine during the Civil War (Devane 1983). Cattle provided beef for the Confederacy (1860-1865) and cattle drives reported took place in the spring and early summer (Devane 1983).

This land was purchased by Consolidate Naval Stores Co. and mapped 1918 in preparation for the extensive naval stores and logging operations that would occur in the following decade

Extractive Era. The years of 1919-1930 marked a major change in the landscape of the APAFR lands. Consolidated Naval Stores Company purchased the land in 1918, beginning a series of intensive, extractive uses of the land for the first time. First, the extensive old growth pines of the site were tapped for resin (turpentining) beginning in 1919 and continuing until 1928 (Devane 1983). Also beginning in 1919, Consolidated Cattle Company brought in 25,000 cattle and sheep. Although the sheep operation was not successful, cattle were a constant over the homestead and extractive eras. After the pines were tapped for resin the old growth trees of the site were cut. The old growth timber of the site was cut between 1925 and 1930 (Devane 1983). The Extractive Era of the 1920s marked a radical change in the use of the land.

Bombing Range Era. The Bombing Range Era, from 1931- the present has been characterized by several major events – the purchase of the land by the War Department in 1939 and the closing of the open range by fencing in the late 1940s (Devane 1983). By approximately 1930 everything that could be extracted and sold off of the land was gone. The land continued to be used by an extremely small number of homesteaders and for cattle grazing. After the land was purchased by the War Department cattle grazing continued and the fencing of the open range led to more intensive cattle grazing and management. During WWII from 1942 through 1945 the base was developed and used Air Corps training (Beasley et al. 2009). The base was deactivated and government leases for cattle grazing began in 1950 (Beasley et al. 2009). During the 1960s forestry, in the form of slash pine plantations was also added to the land use. Military operations, cattle grazing and forestry have been the dominant land uses until the present.

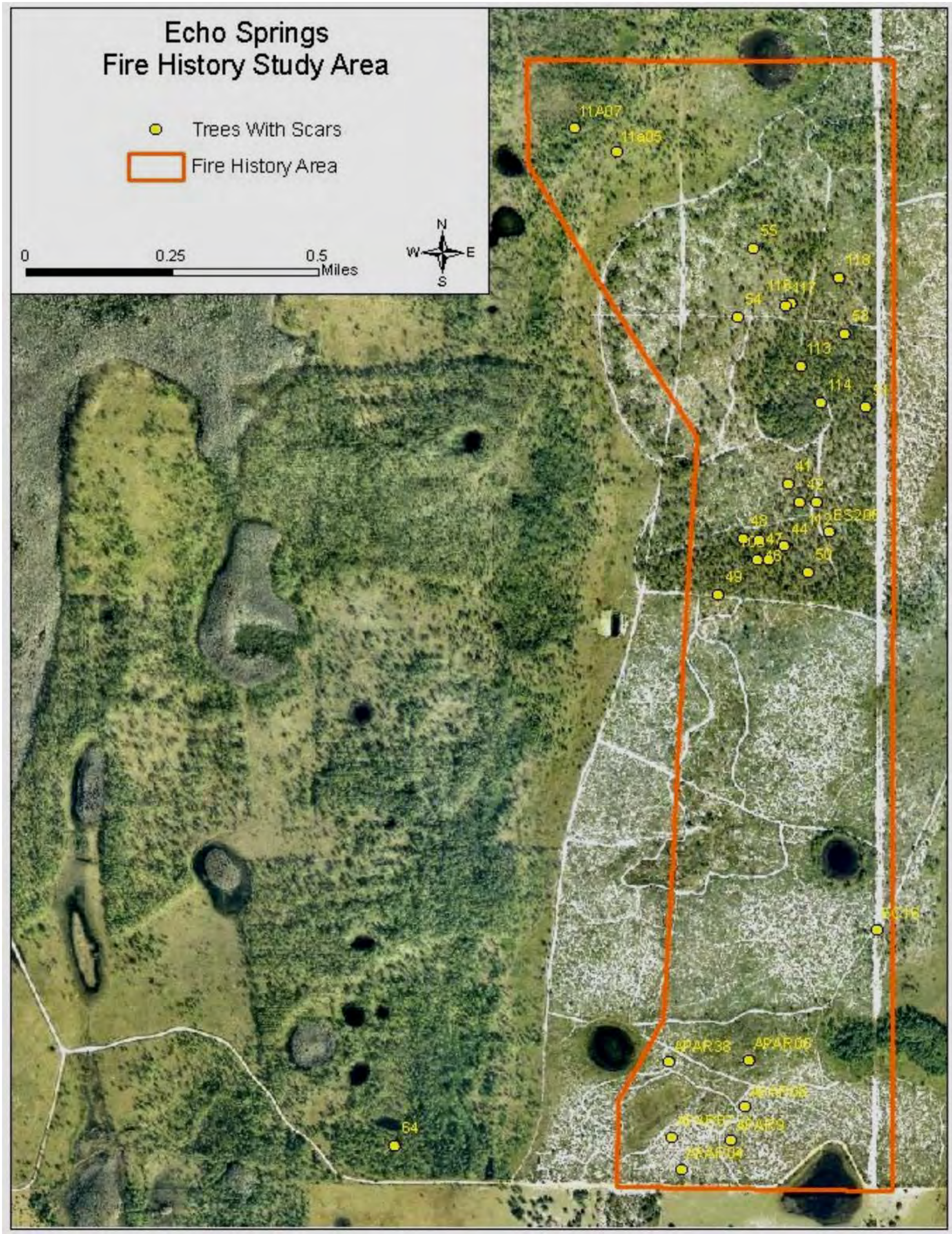
Appendix 2.2. Fire history study site maps and minor fire history study sites

Five major and five minor fire history sites were delineated based on the distribution of fire scarred trees. Fire scarred trees and stumps were located across the Range but tended to be clustered. We delineated 10 separate areas based on where fire scarred samples were clustered, current roads, and habitat types, in an attempt to delineate areas where one fire might have been likely to burn all of the trees in the past. We defined five major fire history sites that were discussed in the report and five minor sites that were not used in the report and are only presented here. Major fire history sites had: 1) more than 10 trees or stumps with fire scars (range 14-33 per site) and 2) a site chronology that went back in time more than 150 years (range 155-221 years). Minor fire history sites have 8 or fewer recorder trees and only record time periods after 1900. Major fire history sites were larger than minor sites, ranging from 474 to 1836 hectares in size. Of the 151 trees used in this study all but 9 fall within one of the 10 study areas. The minor study areas are very incomplete in terms of fire history but they were included because they may be of interest regarding the potential spatial variation of fire characteristics in different sites across the range in the 20^{th} Century.

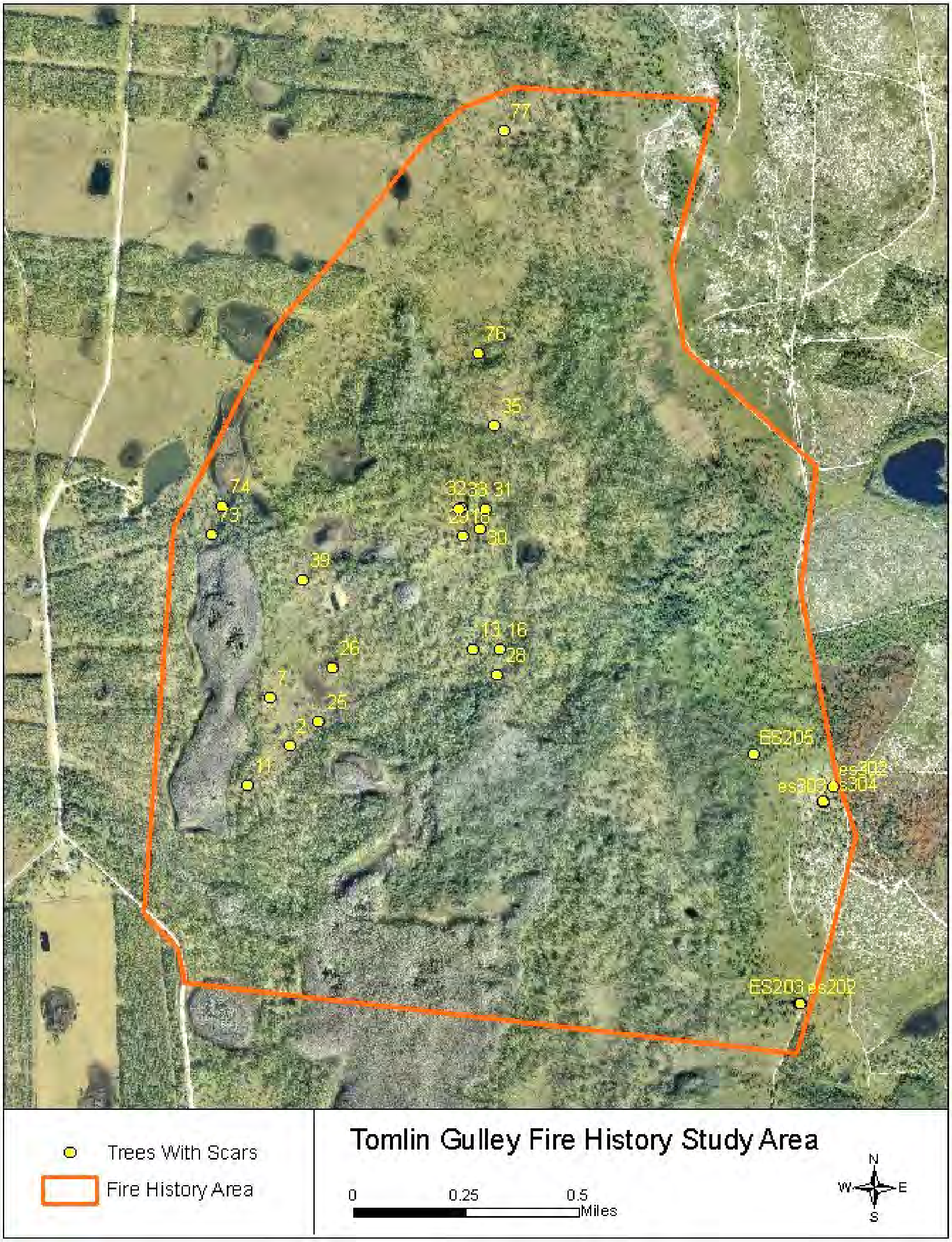
Major Fire History Sites

Following are aerial photos of the five major fire history sites with outlines of the study site boundary and trees used in fire history reconstruction represented by yellow dots

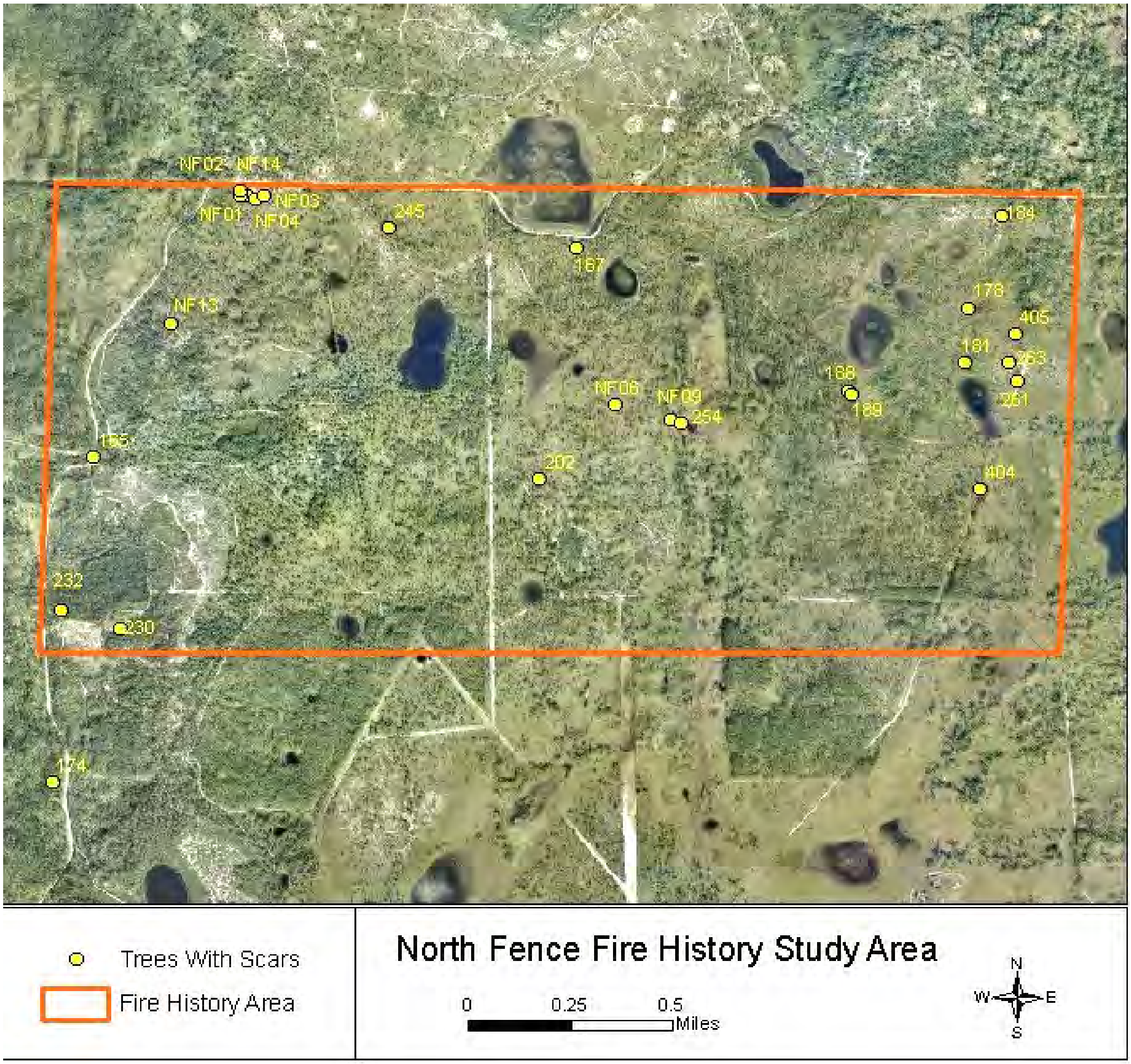
Site 1) Echo Springs



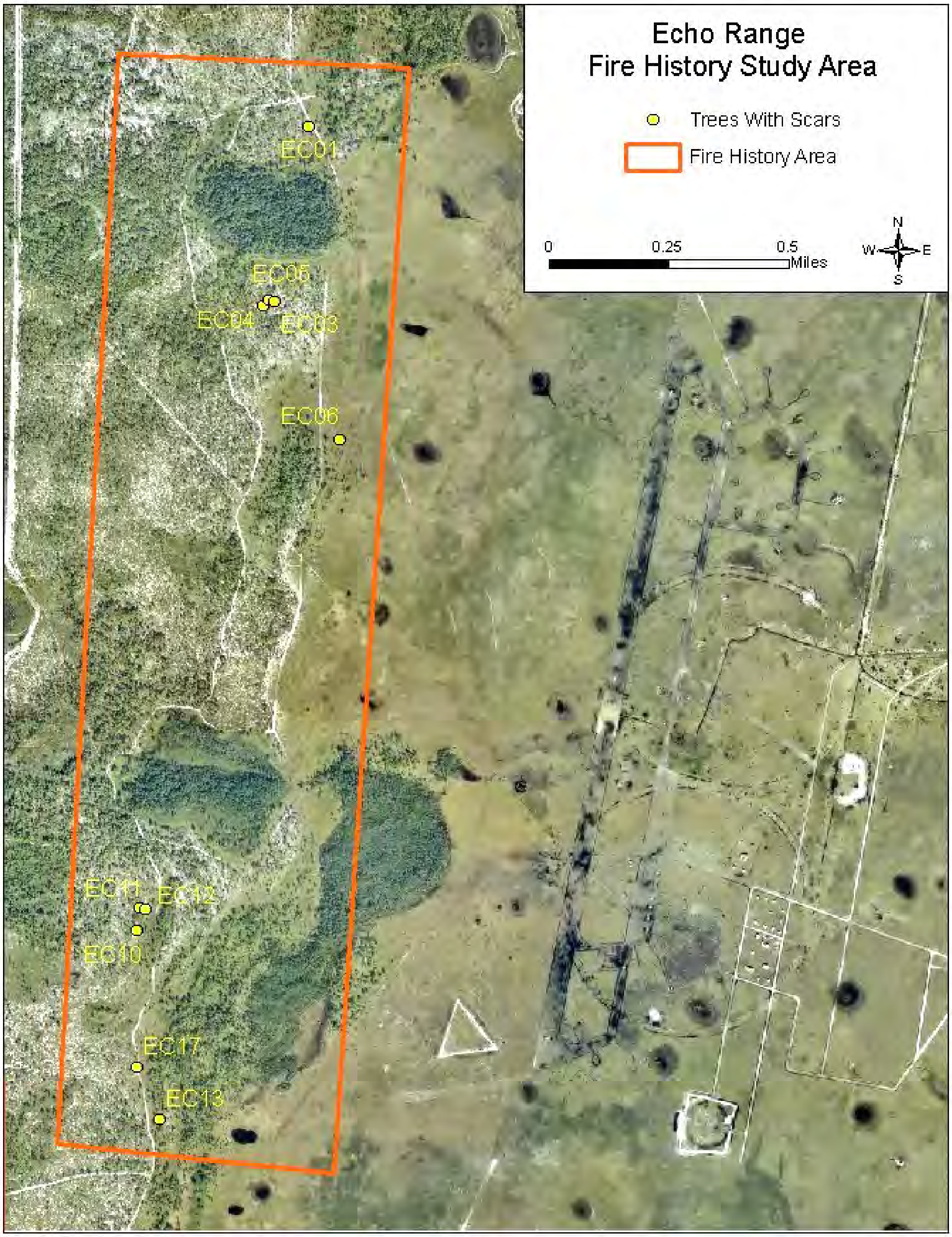
Site 2) Tomlin Gulley



Site 3) North Fence



Site 4) Echo Range



<u>Site 5) Eight Mile</u>

Minor Fire History Sites

The following five sites are less complete fire history reconstructions than the previous five sites. They record fires only from 1900 onward and have 9 or fewer recorder trees. However, they may be of interest regarding the potential spatial variation of fire characteristics in different sites across the range in the 20th Century. For each site aerial photos of the study site and the fire history composite graph are presented.

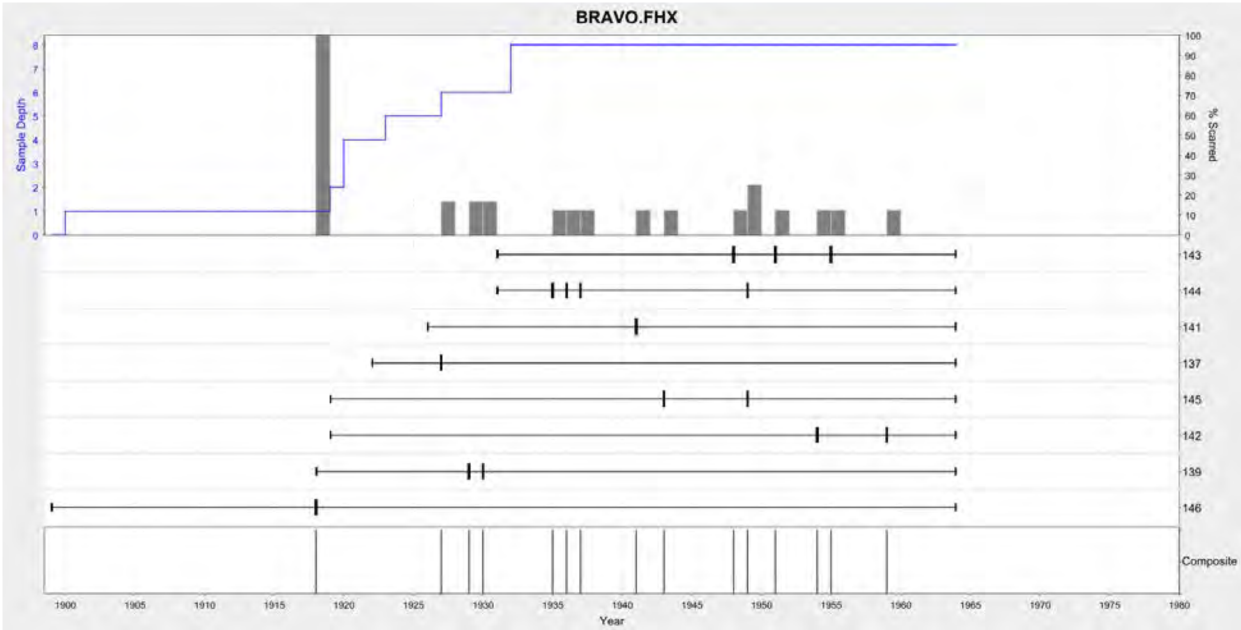
Table 2-2. The five minor fire history sites, their location, size, number of trees and time period of fire history.

	Fire History Site	Size Hectares	Size Acres	Total Number Trees	Range of Scar records	Length of Fire History Period (Years)
6	Bravo	183	452	8	1957-1998	41
7	Hard Luck	8	20	9	1900-2002	102
8	Arnold Hammock	173	426	4	1915-2003	88
9	County Line	7	17	4	1930-2001	71
10	Orange Hammock	86	214	4	1934-2003	69
	Other/Not in a fire history site			9	1943-2003	60
	TOTAL			151		

Site 6) Bravo

The Bravo site is a wet to mesic area of cutthroat seep within a bombing range. No old trees occur in this area.

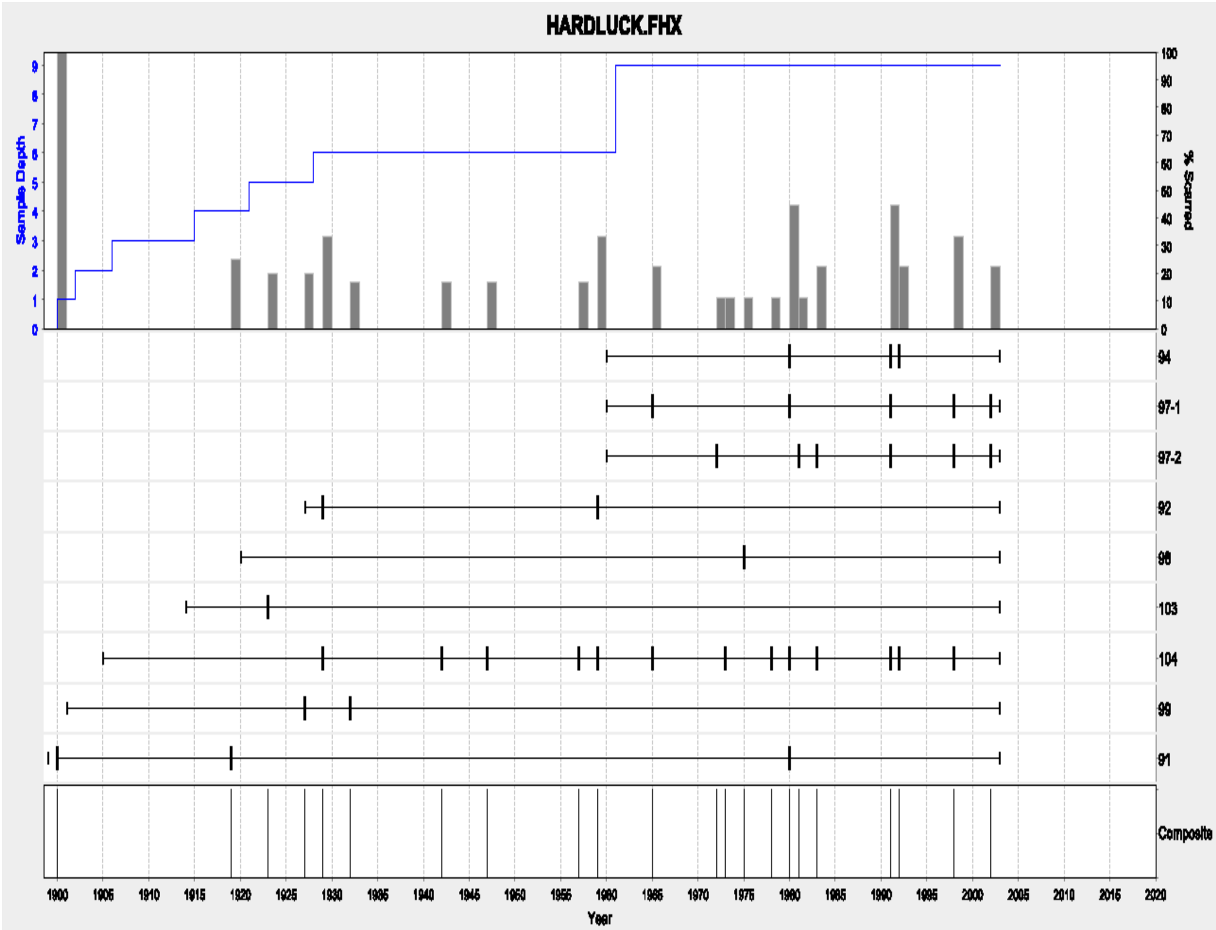
Fire History Site	Size Hectares	Size Acres	Number Trees	Range of Scar records
Bravo	183	135	8	1957-1998


BRAVO.FHX
Sample Depth
% Scarred
143
144
141
137
145
142
139
146
Composite
Year

Site 7) Hard Luck

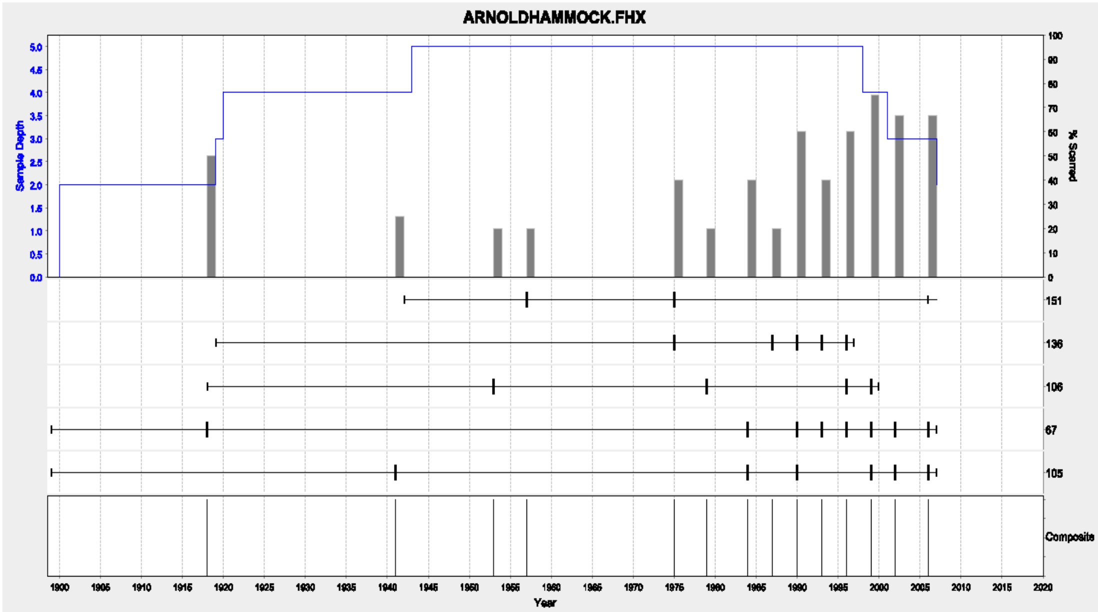
Hard Luck is a small site (8 ha) of mesic flatwoods surrounded by wetlands.

Fire History Site	Size Hectares	Size Acres	Number Trees	Range of Scar records
Hard Luck	8	20	9	1900-2002


HARDLUCK.FHX
Sample Depth
% Scarred
94
97-1
97-2
92
98
103
104
99
91
Composite
Year

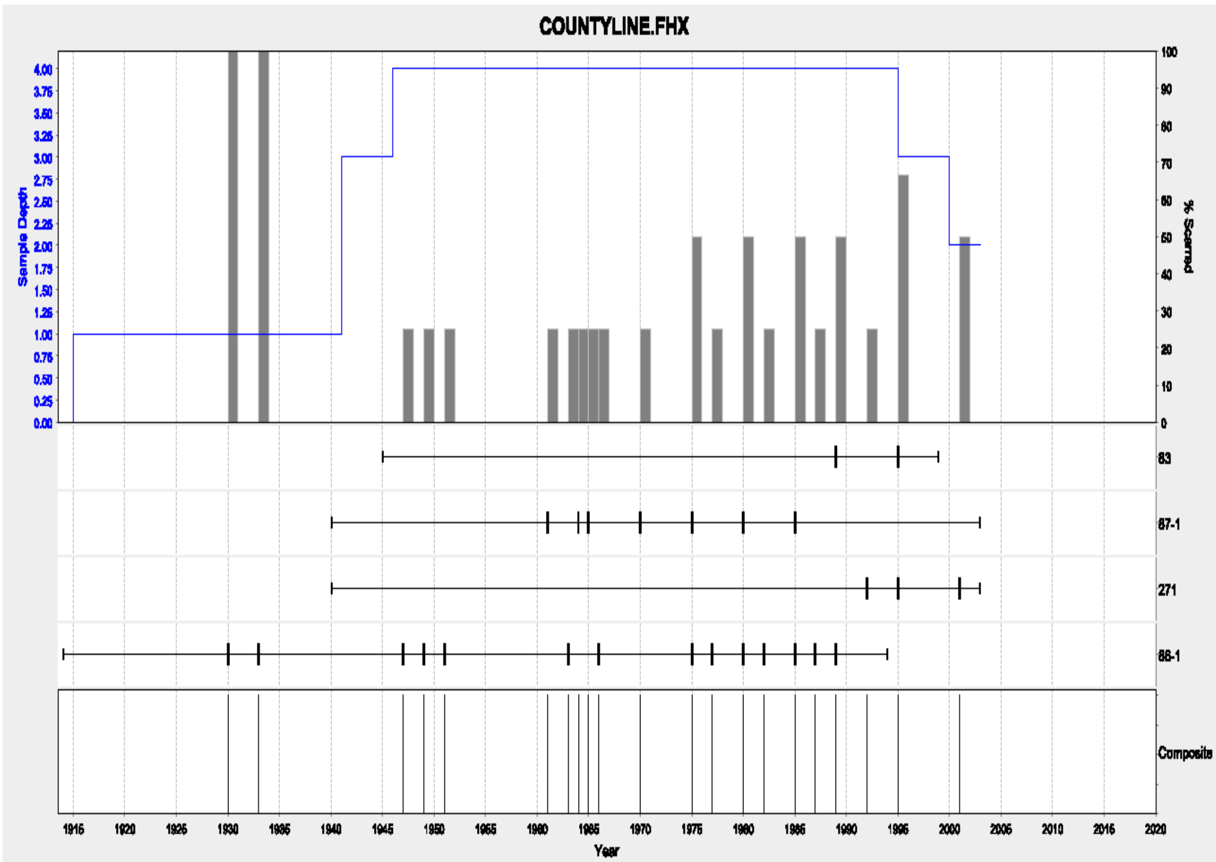
Site 8) Arnold Hammock

Fire History Site	Size Hectares	Size Acres	Range of Scar records
Arnold Hammock	173	426	1915-2003


ARNOLDHAMMOCK.FHX
Sample Depth
% Scarred
151
136
106
67
105
Composite
Year

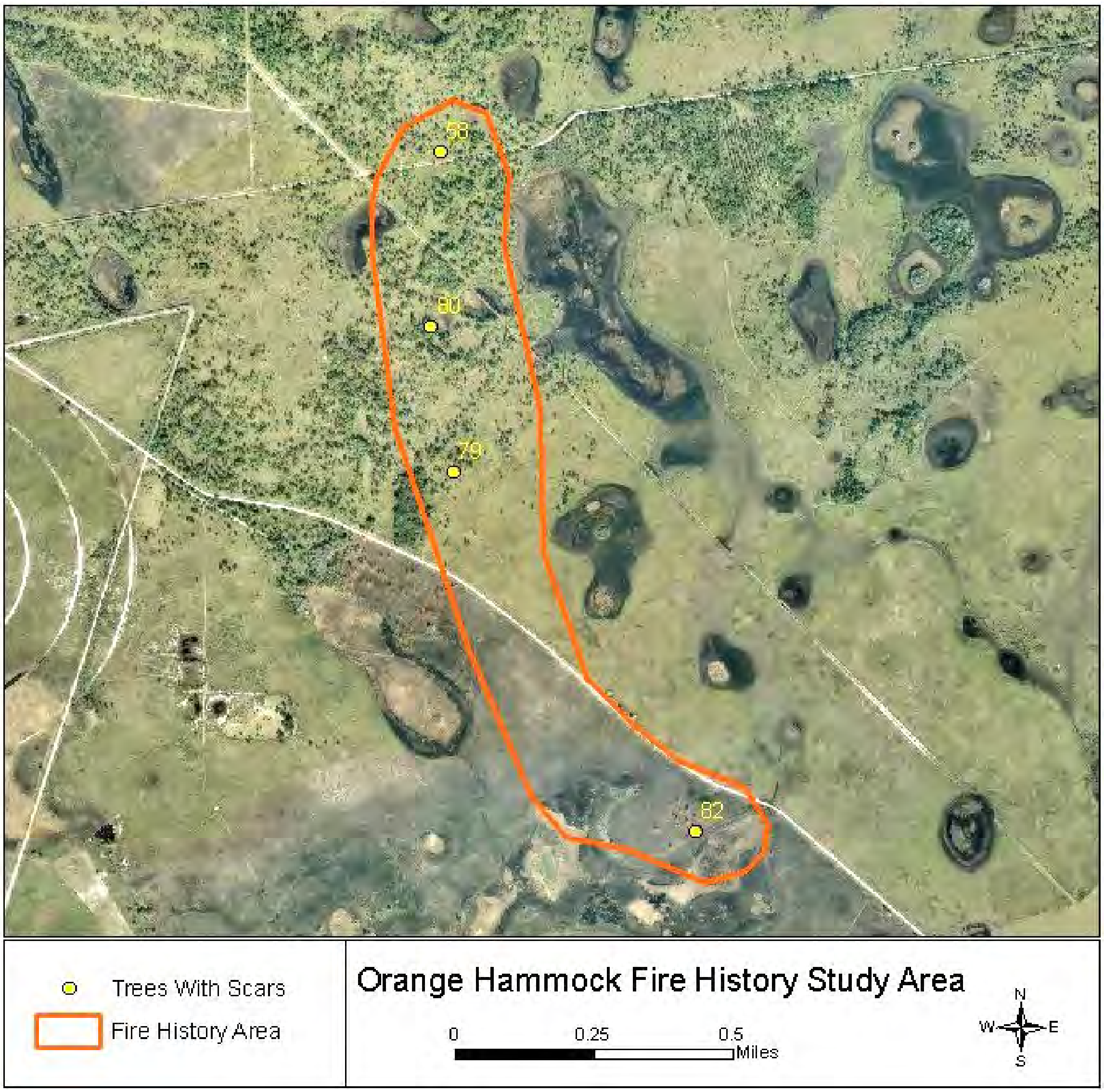
Site 9) County Line

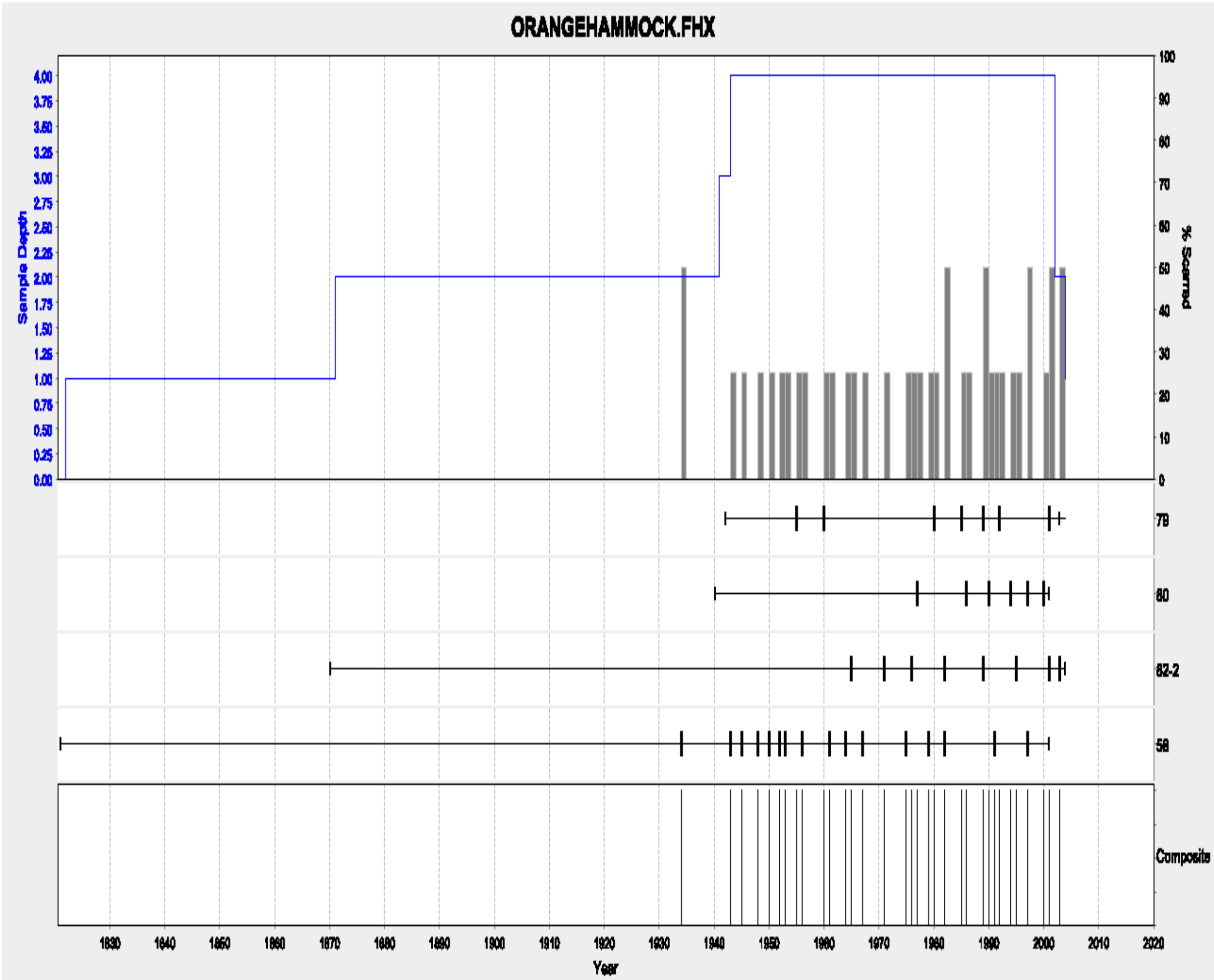
Fire History Site	Size Hectares	Size Acres	Number Trees	Range of Scar records
County Line	7	17	4	1930-2001


COUNTYLINE.FHX
Sample Depth
% Scarred
83
87-1
271
88-1
Composite
Year

Site 10) Orange Hammock

Fire History Site	Size Hectares	Size Acres	Number Trees	Range of Scar records
Orange Hammock	86	214	4	1934-2003




ORANGEHAMMOCK.FHX
Sample Depth
% Scarred
Year
79
80
82-2
58
Composite

Appendix 2.3. Fire time of year (all positions of fire scars) in relation to each human land use era.

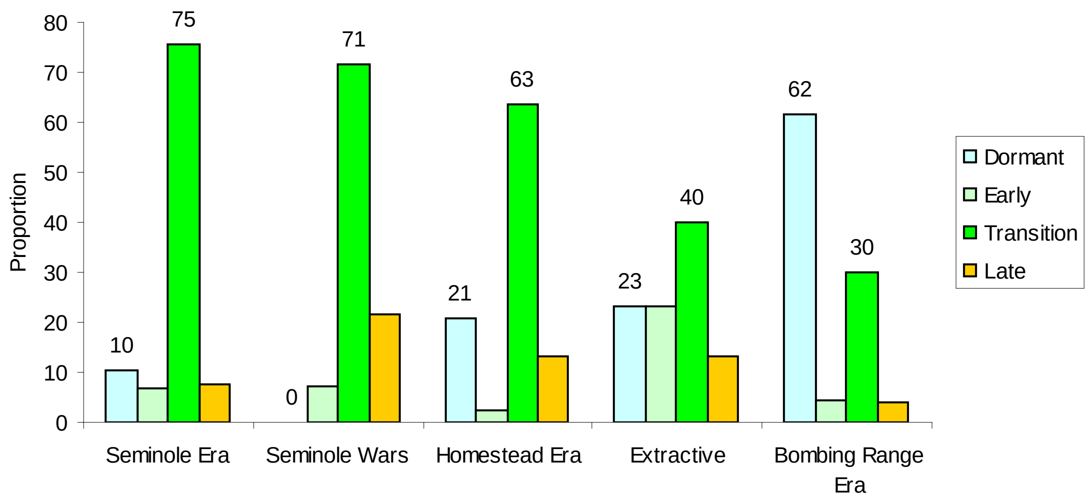


Figure 2.3a. Season of fires, based on fire scar positions, for different eras of human history on APAFR. This includes all four scar positions ("dormant", "transition", "early" and "late").

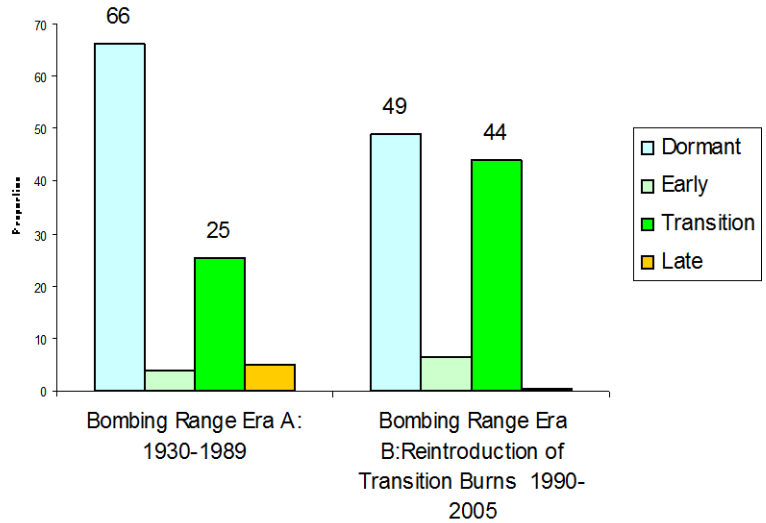


Figure 2.3b. Transition fires increased and dormant fires decreased in the 1990s with the reintroduction of prescribed transition/lightning season fires after a long tradition of dormant season prescribed fires during the Bombing Range Era.