HISTORICAL FIRE REGIMES
IN SOUTHEASTERN PINE SAVANNAS

A Dissertation

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by
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ABSTRACT

Southeastern coastal plain pine savannas lack direct evidence of past fire regimes. As a result, uncertainty exists regarding the range of variation in frequency and seasonal timing of past fire regimes and the relative importance of anthropogenic and lightning-ignited fires. Characterization of past fire regimes is needed for effective restoration and management of these high-biodiversity ecosystems. I used dendrochronologically dated fire scars from stumps of old growth longleaf pines in a large coastal, mainland pine savanna and from dead slash pines on a small, coastal barrier island in north Florida to explore past fire regimes.

In the mainland savanna, 71 different fires occurred from 1592-1883, based on a composite record of 109 fire scars from six fire-scarred trees. Almost all (95%) scars occurred during the middle growing season. Only three fires, all in the 1800s after European settlement of the local area, occurred during the dormant season. There was a 2-3 year fire return interval between 1679 and 1868. Variability in fire return intervals was low, with 92% of all fires occurring at < 5 yr intervals.

On the barrier island 159 fire scars occurred in 21 separate years from 1864-2000, based on a record of 52 pines scarred during turpentine operations. Two periods of no fire scars corresponded to times of active pine resin extraction on the island (1911-1918, 1948-1958). Mean fire return intervals averaged four years from 1864-1910 and 1919-1947. A longer nine-year fire return interval occurred from 1959-2000. Most (86%) fires recorded in scars occurred during the growing season.

The very high frequencies of growing season fires recorded in annual rings of these trees indicate that fire regimes were primarily driven by synoptic climatic conditions rather than by cultural burning practices. Both sites recorded frequent, growing season fires, suggesting that lightning fires were occurring frequently both before and after settlement despite differences in size and landscape context. This direct evidence of fire history in southeastern pine savannas can resolve some outstanding questions regarding ecological fire management. Fire managers now have direct evidence that supports frequent, growing season fires in pine savanna.

Chapter 1

INTRODUCTION

Understanding past fire regimes in savanna ecosystems

Fire is important in many ecosystems around the world (Bond and VanWilgin 1996, Whelan 1995, Pyne 1996). Characteristics of past fire regimes, such as return intervals and seasonal timing of fires, have been studied using both direct and indirect evidence. Direct evidence includes fire effects that are preserved over time. Indirect evidence is that which suggests differences in conditions that produce fires or in the responses of organisms. Although most often studies involve either direct or indirect evidence, combinations of data might provide conclusive evidence regarding historical fire regimes.

The best sources of direct evidence include charcoal in sediments and fire scars in trees that produce annual rings. Charcoal sediment records can reveal characteristics of fire regimes over long time periods of thousands of years; however, they usually cannot be used to determine annual or seasonal resolution of fires (Whitlock and Larsen 2001, Watts 1992). Fire scar records contained within annual tree rings generally cover much shorter periods of time than sediment core charcoal records; however, they can be used to obtain fire regime data with fine temporal resolution where there are old trees with fire scars that can be sampled, and with fine spatial resolution where there is an abundance of trees recording fire scars over a wide area (Kipfmueller and Swetnam 2001).

Attempts to infer past fire regimes using indirect evidence have been used mostly where there is a lack of direct evidence. Indirect approaches include those based on the potential importance of Native American burning practices, climate/fuel based models and experimental studies of the response of individual species and communities to different fire regimes. Climate and fuel models are based on decadal, yearly and seasonal patterns of synoptic weather and fuel accumulation. By first determining when lightning and dry conditions coincide it is possible to infer when fires most likely would have occurred. Synoptic climate information is combined with information on the accumulation of fuels in the form of herbaceous and woody plants to calibrate models to infer past fire regimes (Johnson 1992, Beckage and Platt 2003, Beckage et al. 2003, Beckage et al. 2005a,b). Studies of the responses of plant and animal species to different fire regimes have also been used as an indirect method to understand regional historic fire regimes. This approach assumes that most species of plants and animals have adapted to fire regimes that they have experienced over evolutionary time spans. Measurements are made of the responses of species to a range of possible variations of frequency and season of fire. Positive responses of dominant or characteristic species suggest matched prior fire regimes whereas negative responses, which sometimes would lead to the eventual extirpation of a species, are assumed to indicate mismatched prevailing past fire regimes (Beckage et al. 2005b).

Savannas, ecosystems in which there is an incomplete cover of canopy trees and a ground cover dominated by grasses, are present on about one-third of the terrestrial land area in temperate and tropical regions of the world (Bond and VanWilgen 1996). Fires are recognized as occurring in savannas, but direct scientific data exist on characteristics of historical and prehistorical fire regimes for only a few, temperate savannas (Guyette and Cutter 1991, Brown and Sieg 1999, Veblen et al. 2000). An absence of direct evidence generates questions about past fire regimes. For example, one contentious question in many savanna systems is what was the relative importance of anthropogenic and lightning-ignited fires? Fires ignited by lightning and by people may result in divergent characteristics of fire regimes, including the frequency and season of fires (Pyne 1982, Robbins and Meyers 1990, Platt 1999). These differences in seasonal timing or frequencies of fires can produce differences in population dynamics of individual species and even change entire ecosystems (Platt et al. 1988a, Frost 1993, Streng et al. 1993, Drewa et al. 2002b, Platt et al. 2002).

Indirect evidence has problems that allow various interpretations of past fire regimes. Past fire regimes that are based upon climate models cannot take into account the possibility of human caused fires that may have occurred outside of the lightning season. Biotic-response based models are open to a range of interpretations depending on the species being considered and are based on current habitats and distributions of species that often have changed because of recent alterations to fire regimes (see Beckage 2005). In addition, they are time and labor intensive and exist for few locations.

Because of the absence of direct scientific data and proliferation of hypotheses based on indirect evidence it is sometimes difficult to reach a consensus regarding ecological fire management of savannas. Fire-frequented ecosystems often contain high biodiversity and endemic species, both of which decline markedly when fire exclusion occurs or when fire regimes are shifted out of the range of those encountered historically. For ecological management of savannas, it is important to understand the historic range of frequency and seasonal timing of fires and also of the variance that needs to be maintained within the evolutionary context of the community to facilitate survival of all species (Platt 1999, Swetnam et al. 1999).

Southeastern pine savannas

The original terrestrial landscape of the southeastern coastal plain of the United States was dominated by variations of pine savanna (Frost 1993, Platt 1999). As in savannas elsewhere in the world, fires were an intrinsic part of the ecosystem. These savannas lack the high resolution direct evidence of past fire regimes that comes from tree ring fire histories. Climate and biotic-response based models have been used to infer past fire regimes (Olson and Platt 1995, Platt 1999, Glitzenstein et al. 2003, Beckage and Platt 2003, Beckage et al. 2003, 2005b).

Only a few attempts have been made to apply some form of climate fire models in the southeast (Simard et al. 1985, Brenner 1991, Olson and Platt 1995, Harrison and Meindl 2001, Beckage and Platt 2003, Beckage et al. 2003, 2005b). These are mostly focused on yearly and decadal variations in fire frequency caused by El Niño/Southern Oscillation, which results in fires being more frequent and larger in dry La Niña years (Beckage et al. 2003). Inferences about past fire regimes from these climate based models are that fires in southeastern pine savannas were frequent (more than once a decade; Platt et al. 1991, Slocum et al. 2003) and occurred in the lightning season, most commonly in the transition from dry periods of the spring to wet summers (Olson and Platt 1995, Beckage et al. 2003, 2005b, Slocum et al. 2003).

Pine savanna species exhibit traits indicating a long evolutionary association with fire. Frequent fire (at least every 2-5 years) maintains the diverse layer of herbaceous species (DeCoster et al. 1999, Schmitz et al. 2002, Slocum et al. 2003, Glitzenstein et al. 2003, Platt et al. 2006). Nonetheless, longer fire intervals have been recommended (Maehr and Larkin 2004) and annual fires have been proposed to maintain the highest plant diversity (Glitzenstein et al. 2003). There is no unified best interval for all ground cover species; these species require different fire free intervals for maintenance (herbaceous versus woody species) as well as for establishment. The biotic response model is difficult to use to infer mean past fire return intervals, in part because the variance in fire intervals that may have been important to allow the coexistence of so many species is unknown.

Many pine savanna species show strong responses to different seasons of fire. Both increased and synchronized flowering have been shown to occur with growing season fires (Platt et al. 1988a, Streng et al. 1993, Brewer and Platt 1994). Increased mortality and decreased resprouting of woody species has been associated with growing season fires, but not dormant season fires (Glitzenstein et al. 1995, Drewa et al. 2002, 2006). A dominant groundcover grass, *Aristida beyrichiana*, flowers and produces seed after growing season fires but not after dormant season fires (Platt et al. 1988a, Seamon et al. 1989). Biotic response models indicate that characteristic pine savanna species evolved with growing season fires. Both climatic and biotic models give strong evidence for past fire regimes of frequent, growing season fires but it is difficult to refine intervals and variance in fire intervals and season and both climate and biotic models allow room for different interpretations.

Today the pine savannas of the Southeast are hugely reduced by agriculture and forestry, as well as human development. Fire exclusion, both intentional and unintentional has occurred in the remaining fragments. Further, fire management often has involved policy based in silvicultural practices rather than the ecology of savanna ecosystems. Negative effect are known to occur when fire occurs outside of natural frequency and season (Platt et al. 1988a, Seamon et al. 1989, Glitzenstein et al. 1995, Platt et al. 2002).

The continued existence of these remaining fragments of southeastern pine savannas requires ecological fire management. An understanding of the historic range of variation in fire regimes is important for better ecological management of the high diversity and large numbers of endemic species. Existing data on fire regimes of pine savannas lack the precise frequency and seasonal resolution needed to best manage fire.

In this dissertation I use dendrochronologically dated fire scars to produce the first direct evidence of frequency and season of past fire regimes in southeastern coastal plain pine savannas. I focus on the fire history of two different pine savannas in North Florida. I compare these data on past fire regimes to predictions from climate and biotic-response based models of southeastern fire regimes and discuss how my research may help resolve outstanding questions regarding past fire regimes in these savannas.

Dissertation Structure

In this Introduction, I discuss the importance of understanding historical fire regimes in savannas in general and southeastern pine savannas in particular. I also consider how past fire regimes are deduced by using direct and indirect evidence. In Chapter 2, I present results from a dendrochronologically dated fire scar study of fire history in a coastal mainland longleaf pine savanna. In Chapter 3, I present the results of a study of the fire history of a barrier island slash pine savanna. Finally, in Chapter 4, I discuss the importance of these studies for understanding historical fire regimes in southeastern pine savannas, how these results compare to other indirect methods of understanding past fire regimes in savannas and the significance of these results for ecological fire management of pine savannas.

Chapter 2

FIRE HISTORY OF A SOUTHEASTERN PINE SAVANNA

Introduction

Pine savannas in the coastal plain of North America are fire-frequented ecosystems (Platt 1999, Frost 1998). There is, however, at best, anecdotal description of historical fire regimes in these ecosystems. Pre-settlement fire regimes, even entire landscapes, throughout the coastal plain of southeastern North America were altered by humans before scientific data were recorded (Frost 1993, Platt 1999). As a result, both lightning and Native Americans have been proposed as ignition sources, and these sources have been proposed to produce divergent characteristics of fire regimes (contrast Komarek 1964, 1968, 1974, Olson and Platt 1995, Beckage et al. 2003, Slocum et al. 2003 with Wade al. 1980, Pyne 1982, Kalisz et al. 1986, Ware et al. 1989, 1993, Myers 1990, Pyne et al. 1996). Studies of the natural history of pine savanna plants and animals have revealed effects that result from differences in fire regimes and thus, by inference, from differences in ignition sources (Platt et al. 1988a, Rebertus et al. 1993, Streng et al. 1993, Brewer & Platt 1994, Lockwood et al. 2003, Williams 2003, Beckage 2003, Maehr and Larkin 2004, Beckage et al. 2005 a, b).

Over the past century, fire policy has shifted in response to information used to project southeastern pine savanna fire regimes. In the early 1900s, fire suppression was the norm (Platt 1999, and references therein). Once effects of fire suppression were noted (especially the resulting fire hazard from fuel accumulation), fuel reductions became the basis of policy, with fire management policy based on pine silvicultural practices. Recent shifts have been toward ecological management based on indirect evidence that natural fire regimes were entrained by climate-fire relationships (e.g., Brenner 1991, Huffman & Blanchard 1991, Olson and Platt 1995, Beckage et al. 2003) and that ecological communities and characteristic pine savanna plant species respond to experimentally-generated differences in fire regimes (e.g., Platt et al. 1991, Waldrop et al. 1992, Brewer & Platt 1994, Glitzenstein et al. 1995, Drewa et al. 2002 a, b, 2006, Thaxton and Platt 2006). Nonetheless, uncertainty continues regarding the range of variation in frequency and seasonal timing of fire (e.g. Robbins and Myers 1990) and especially the relative importance of anthropogenic and lightning-ignited fires (e.g., Lockwood et al. 2003, Williams 2003, Maehr and Larkin 2004, Beckage 2004, Beckage et al. 2005 a, b). Development of concepts upon which to base effective restoration and management actions is crucial for conservation of these high biodiversity ecosystems (Walker and Peet 1983, Peet and Allard 1993, Harcombe et al. 1993, Sorrie and Weakley 20001, 2006, Platt et al. 2006).

Characteristics of historical fire regimes in many habitats have been deduced from study of scars left by fires in annual growth rings of trees. Extensive, long-term data have been compiled on historical frequency, seasonality, and spatial extent of fire in a number of forests (Swetnam 1990, Brown and Swetnam 1994, Swetnam and Baisan 1996, Niklasson and Granstrom 2000, Veblen et al. 2000, Grissino-Mayer et al. 2004, Wright and Agee 2004). These detailed records of fire frequency and seasonality have been useful in guiding fire management. These data have been used to explore links between climate and fire, establishing baseline information on past fire regimes necessary for gauging the influence of predicted climate change (e.g., Swetnam 1993, Swetnam and Betancourt 1992, Bergeron et al. 1995, Veblen et al. 2003, Grissino-Mayer et al. 2004). They also have sometimes suggested that past human burning practices at a site have resulted in variation in fire regimes over time (e.g., Barrett and Arno 1982, Seklecki et al. 1996).

Dendrochronological fire history studies are lacking for southeastern pine savannas. There are four main reasons. First, old trees were cleared from almost all Southeastern pine savannas between the late 1800s and 1940s. Second, remaining old growth pine stumps were removed from the 1930s to the present. Third, fire scars are rare in the few remaining stumps and trees of old longleaf pine (*Pinus palustris* Mill.) and slash pine (*Pinus elliottii* Engelm.). Fourth, the relatively low intensity fires typical of pine savannas have been assumed not to leave scars on the very fire-resistant pines. The only published fire history was based on fire scars in trees used for resin extraction during the past 150 yrs of a slash pine stand on a small isolated barrier island (Huffman et al. 2004).

We present the first presettlement fire history for a southeastern longleaf pine savanna obtained from tree rings. For this study we used sections taken from stumps of old growth longleaf pines in a coastal pine savanna along the Gulf of Mexico in north Florida. We documented the frequency and variability of fire occurrence, evaluated the seasonality of past fires and determined how and when anthropogenic burning may have influenced fire regimes over time. This first direct evidence of past fire regimes should resolve questions regarding fire regimes in coastal pine savannas.

Methods

Study Area

We conducted our study within the St. Joseph Bay State Buffer Preserve (SJBSBP) in Gulf County, Florida. We used a 3 ha area of pine savanna (85^{o}16’19” long., 29^{o}42’99” lat.) located 3.4 km west of St. Joseph Bay and 4 km north of the Gulf of Mexico (Figure 1). The SJBSBP is managed by The Florida Department of Environmental Regulation, Office of Coastal and Aquatic Managed Areas, through the Apalachicola National Estuarine Research Reserve. Topography is formed by ancient shoreline dune-ridges and swales that occur parallel to the Gulf, running east to west, and parallel to the bay, running north to south. Pine savannas occur on old dune ridges. Our site, 3-4 m above msl, occurs just north and east of where these two ancient dune ridge systems come together. The old bay shoreline/dune systems can still be seen in the distribution of lower wetlands and upland savannas (darker and lighter areas in Figure 2, respectively).

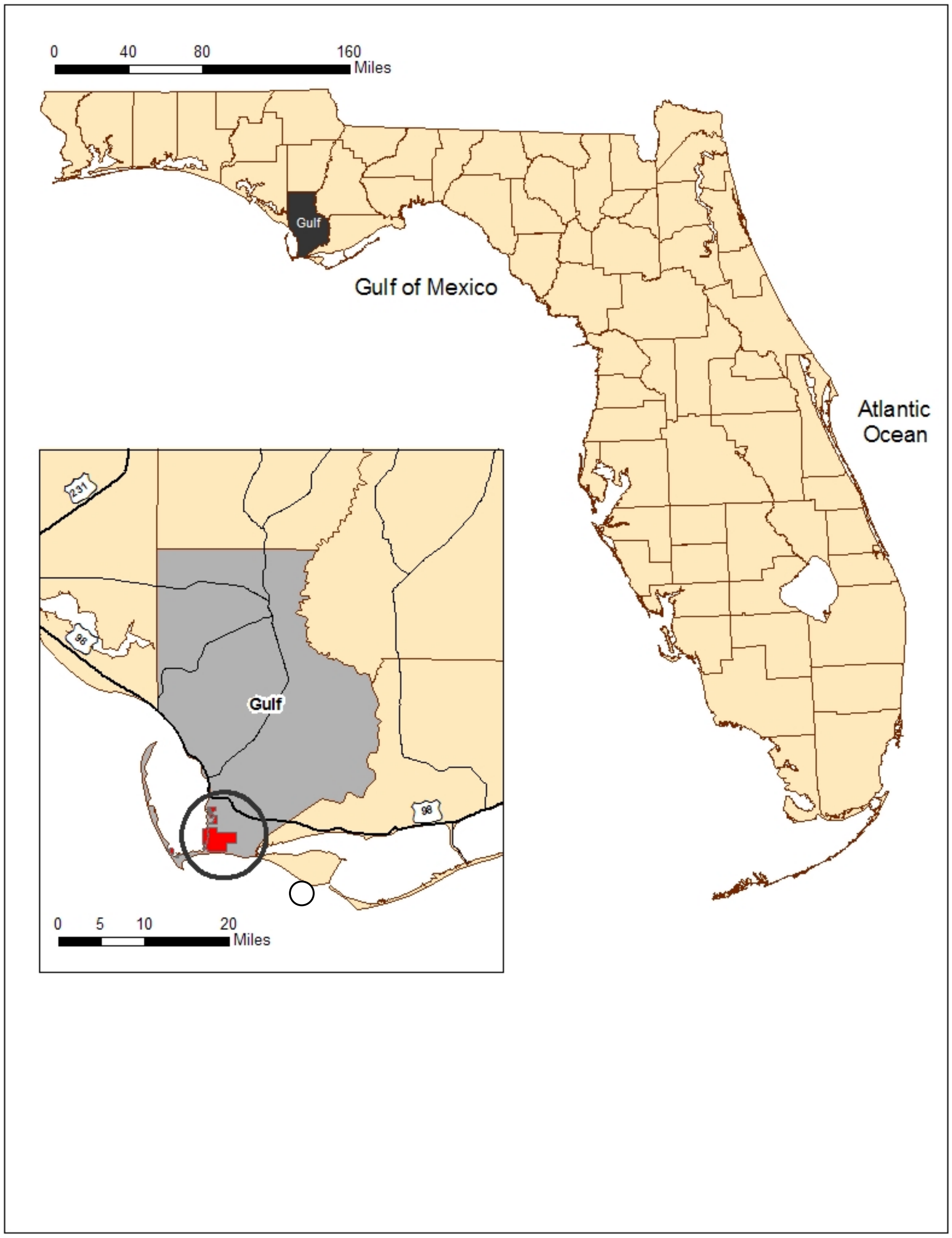

Figure 1. Location of St. Joseph Bay State Buffer Preserve, in Gulf County, Florida.

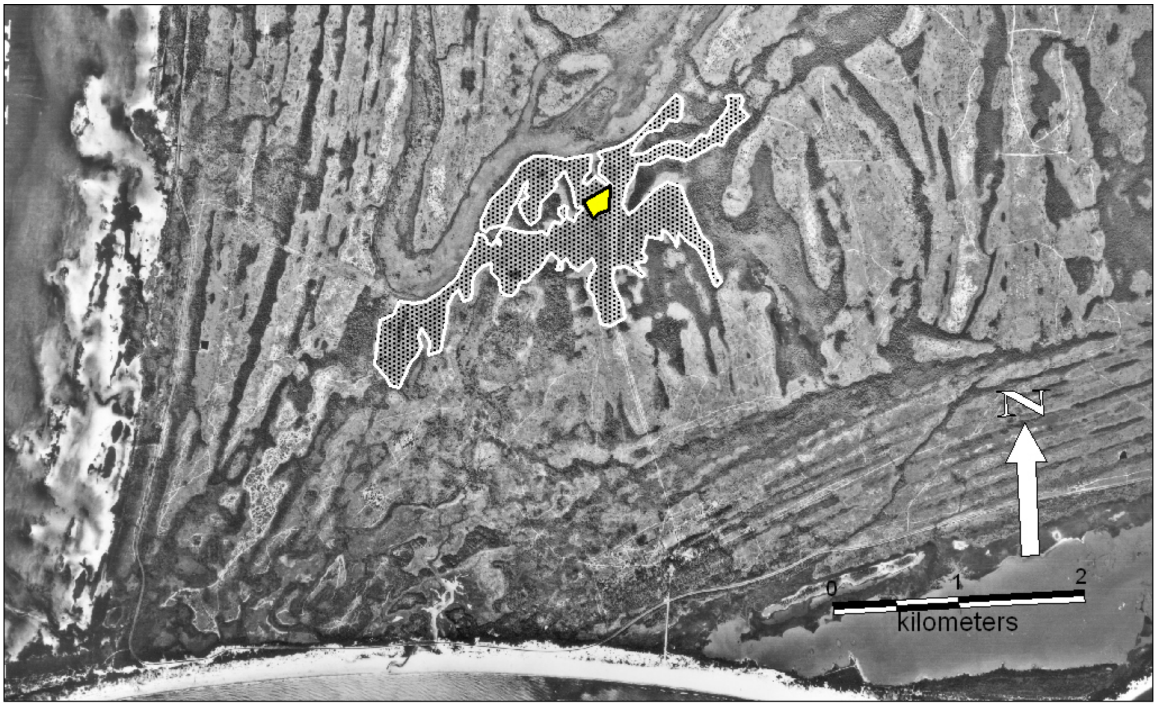

Figure 2. Landscape matrix of study site. Study site, indicated in yellow, occurs within a larger area of mesic pine savanna (165 ha) indicated by the patterned area outlined in white. This pine savanna area is bound by wetlands to the south and southeast, and the wetlands of Depot Creek to the north and northwest. Gulf of Mexico is located to the south, and St. Joseph's Bay is located to the west. Aerial photograph was taken in 1942.

Climate. Seasonal timing of rainfall and lightning determine the times lightning-ignited fires would be most likely (Olson and Platt 1995). Rainfall data from Apalachicola (30 km east) illustrates local climate patterns (Figure 3). Rain-free intervals are typically shortest from late June-September, when there are thunderstorms, and from December-March, when rainfall is associated with frontal systems moving across the region. Long rain-free intervals occur from April-June, and from October-November. Lightning flash densities are lowest from November-February, increase from March-May, peak during June-September, and decrease again in October (Hodanish et al. 1997). The time that long rain-free intervals and an abundance of lightning strikes coincide is during May and June. Lightning-ignited fires during this interval would most likely burn large areas because of reduced fuel moisture in low connecting areas (Slocum et al. 2003). Although rain-free intervals are long enough for fires to burn during July-September, fires at this time are less likely to burn large areas because lower areas are likely to contain standing water and moist vegetation.

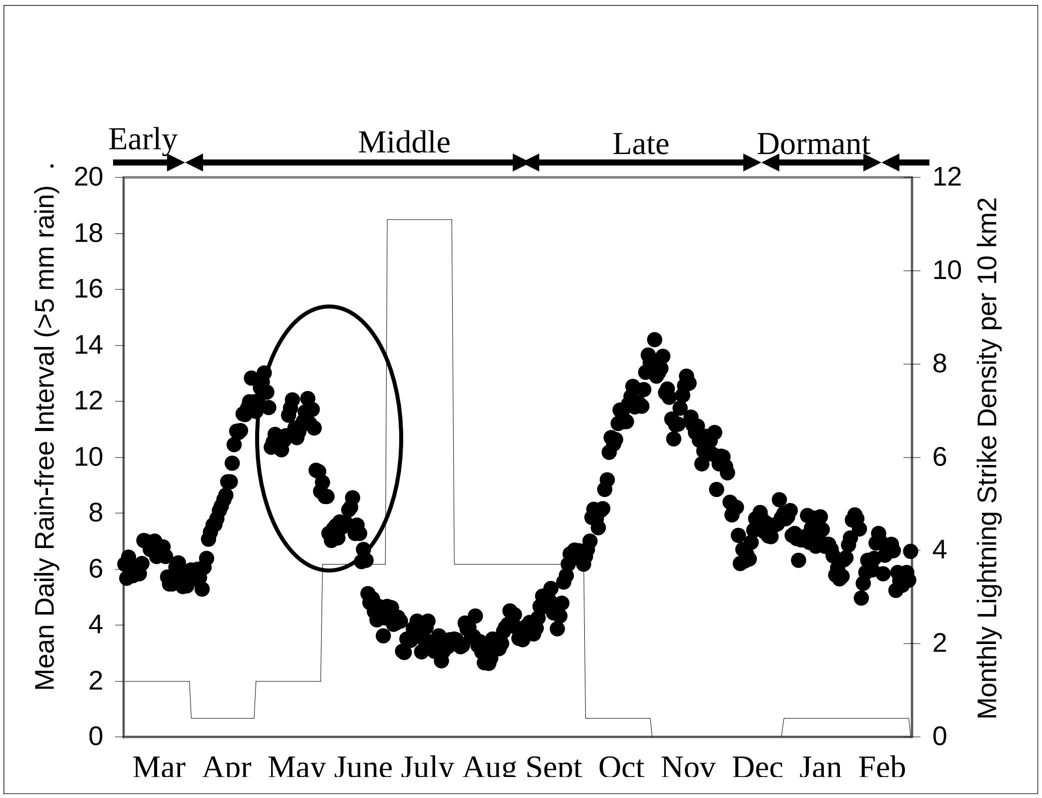

Figure 3. Monthly lightning strike density per 10 km^2 (vertical bars of histogram, right-hand axis) and mean number of days since last recorded precipitation >5mm (dots, left hand axis) in Apalachicola, Florida. Lightning strike density was taken from the 1986-1995 Florida lightning climatology by Hodanish et al. 1997. Rain-free periods were calculated using U.S. climatological data from Apalachicola, Florida between 1931 and 1993. Circled area indicates when long rain-free intervals and an abundance of lightning strikes coincide and lightning-strike ignited fires are most likely. Horizontal lines at the top of the figure indicate growth periods of trees based on studies of growth patterns in living trees (see Table 1).

Vegetation. The study site consists of mesic pine savanna, with widely spaced pines and a dense groundcover of diverse herbaceous species and low shrubs characteristic of Southeastern pine savannas (Figure 4). The canopy was historically dominated by longleaf pine (*Pinus palustris* Mill.), and today is a mixture of young longleaf pine and slash pine (*Pinus elliottii* Engelm.). The groundcover is undisturbed and has an abundance of grasses and herbaceous species that have been used to suggest frequent fires historically (Platt 1999). The herbaceous groundcover is very diverse with an abundance of wiregrass (*Aristida beyrichiana* Trin.& Rupr.) and dropseed (*Sporobolus floridanus* Chapm.) and many forbs (e.g. *Carphephorous odoratissimus* (J.F. Gmel.) H. Hebert). Characteristic shrub species include saw palmetto (*Serenoa repens* (W. Bartram) Small), gallberry (*Ilex glabra* (L) A. Gray), wax myrtle (*Myrica cerifera* L.), a variety of ericaceous shrubs (*Lyonia lucida* (Lam.) K. Koch, *Lyonia fruticosa* (Michx.)G.S. Torr.), and a dwarf oak (*Quercus minima* (Sarg.) Small).

Our site is part of a much larger contiguous area of mesic pine savanna bounded by a variety of wetlands (Figure 3). To the south and west are forested wetlands with cypress (*Taxodium ascendens* Brongn.) in the overstory and shrubs (e.g., *Cyrilla racemiflora* L., *Clethra alnifolia* L., *Lyonia lucida* (Lam.) K. Koch) in the understory. Large wetlands of sawgrass (*Cladium jamaicense* Crantz) occur to the south, and to the west in the Depot Creek drainageway. Grassy, herbaceous, wet prairies often occur in the transition zone between the higher pine savanna and lower forested wetlands.

Figure 4. The open structure of the vegetation of the St. Joseph Bay pine savanna is characteristic of frequently burned savanna.

Cultural history. Historically, few people have lived in the wet, infertile, hurricane and mosquito-ridden lands of the coastal Florida panhandle. Evidence of early human occupation of the area is concentrated along the immediate coast. Little evidence exists for human use of interior pine savannas which are not suitable for agriculture. Evidence from archeological sites on St. Joseph Bay and the greater Apalachicola River region indicates that indigenous populations declined in the St. Joseph Bay area after the late 1400s; by the late 1700s the original human inhabitants of the area, about whom very little is known, were completely gone (White 2004, 2005). There is only one known site with some archeological evidence of human presence around St. Joseph bay during the 1700s (White 2005). The Spanish population is also thought to have been minimal in the St. Joseph Bay area throughout most of this period. EuroAmerican settlement of the St. Joseph Bay region began in the 1820s, but settlement was sparse and concentrated along the coast.

Humans removed the old-growth longleaf pines from the St. Joseph Bay region in the 20th century. Resin extraction for naval stores (turpentining) was begun at the Buffer Preserve site in the very early 1900s and the old growth pine of the region was reportedly clear-cut from the mid 1930s through the mid 1940s (Jimmy McNeill interview in White 2005). No stands of very old living trees remain at the SJBSBP. Not all of the old growth stumps were removed from the SJBSBP, unlike most other sites in the Southeast, where old growth, highly resinous, "lightered" stumps were systematically removed from the 1930s to the present to extract valuable resins. This oversight provided the old growth wood for this study.

Fire History

Sample collection, preparation and dating. Cross-sections were taken from twelve stumps using a chainsaw. Each stump was mapped (Figure 5). Sections were allowed to dry, and then finely sanded for examination using 7-10x magnification. Six of the twelve sections contained fire scars and were used in this study. All tree rings on the scarred sections were crossdated using a longleaf pine reference chronology developed by Joe Henderson and Henri Grissino Mayer (Henderson 2006) for the Eglin Air Force Base, located approximately 161 km west of the St. Joseph Bay Buffer Preserve. The computer program COFECHA (Holmes 1983) was used to assist in dating and to detect and correct any errors in measurement and cross-dating.

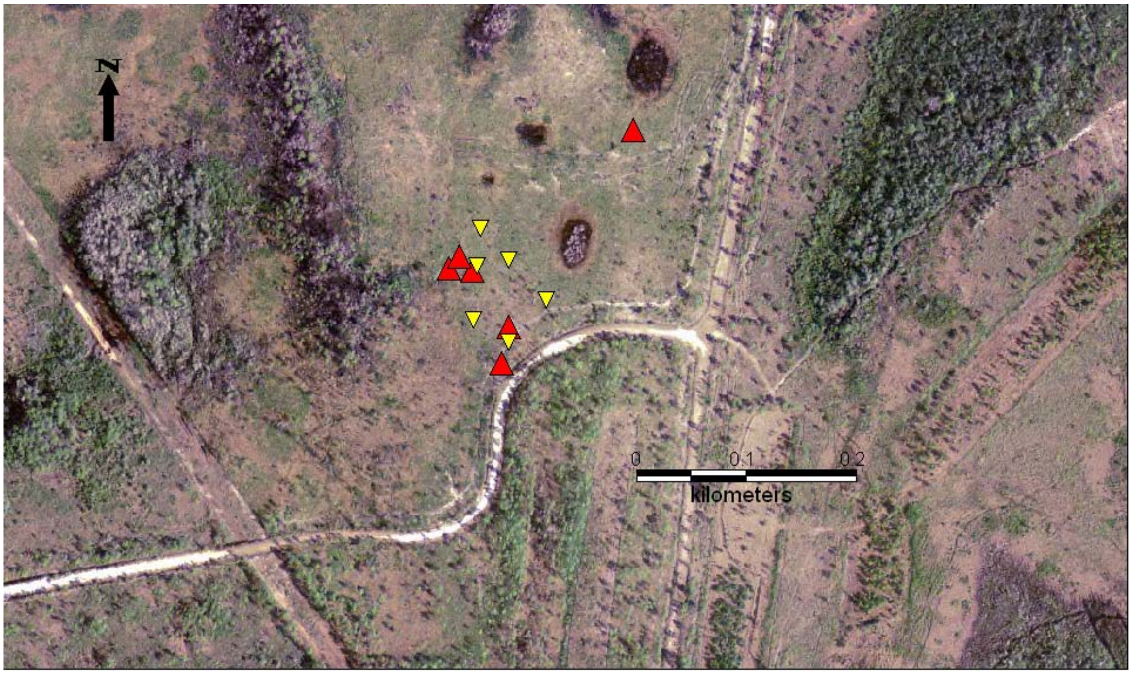

Figure 5. Locations of stumps sampled on an aerial photograph of the study site. Stumps are indicated as with fire scars (upright triangles) or without fire scars (inverted triangles).

Fire Scars. Each scar was examined and categorized. Dates were assigned relative to position in the dated tree-ring series. The two scar categories used, "Curl or Distortion" and "Split", are illustrated and described in Figure 7. We used these ring anomalies to indicate fire injuries. Curl or Distortion scars are anomalous patterns to subsequent wood growth known to be caused by fire damage to the cambium. There was evidence that Split scars were also caused by fire because of the resin canals associated with the injuries, the discoloration around the split, and the association of this type of scar with curls or distortions on other parts of the same ring. Because there is no distortion of the wood that is formed after a split, Split scars were never used as the only evidence to determine a fire date. For each Split scar, at least one other tree had a Curl or Distortion scar in the same year; therefore split scars were used as supplemental evidence of a fire.

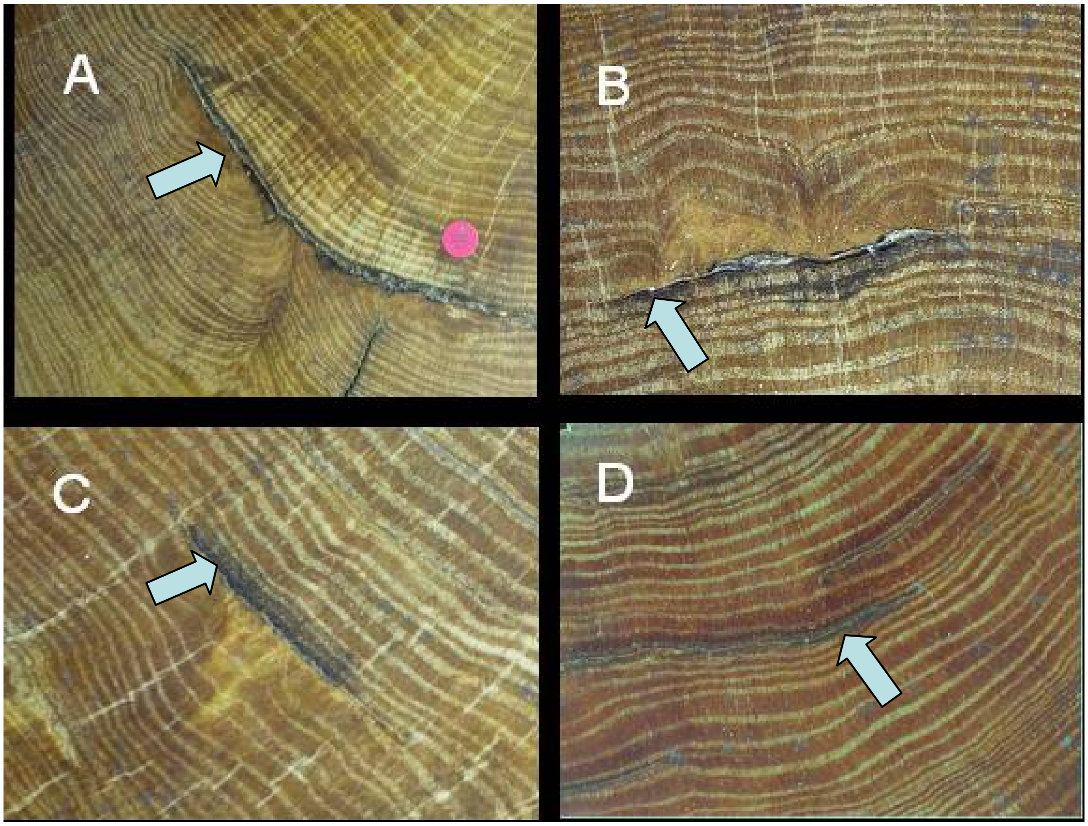

Figure 7. Examples showing three types of basal fire scars. Arrows denote scars. A: “Curl” scars are characterized by areas of vascular cambium that were killed and subsequent tissue grew over the dead area from both sides, forming the curls. B and C: “Distortion” scars are characterized by areas of 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. Also, discoloration, either dark or light colored, is typically associated with the scar and often the subsequent wood. D: “Split” scars are characterized by a split or separation within a ring or between rings where there is also some discoloration and/or increased resin production associated with the crack/injury, but no distortion of subsequent growth.

Season of fire. The season of fire was determined by the location of each fire scar within the growth ring. Similar procedures have been used in other studies (Dieterich and Swetnam 1984, Baisan and Swetnam 1990). Eighty-seven percent of all scars were clear and distinct enough to date to season.

We defined zones in the growth ring that corresponded to ecological time periods for the Southeast (Table 1). We used growth data from a two-year study of growth in longleaf and slash pines at the St. Joseph Bay State Buffer Preserve and increment cores collected throughout the year from slash pines on nearby Little St. George Island (J. Huffman, unpublished data) to determine which months were most likely to correspond to different intra-annual positions of scars. These designations of different periods of annual ring growth should be refined by ongoing studies of growth patterns of longleaf pines in this area.

Table 1. Season of fire for burn scars was determined by the position of the scar within the growth ring.

Scar Designation	**Location in Ring**	**Corresponding Months**	**Lightning frequency**
Early	First ½ of early wood	Late Feb. - March	Low
Middle	Final ½ of early wood or first ½ of latewood	April - Aug	Very High
Late	Final ½ of latewood	Sept. - early Dec.	High in September, then very low
Dormant	Between the end of the latewood and the next year's earlywood	Late Dec. - Feb.	Very low

Patterns of ring growth were used to assign fire season to scars. Annual ring growth begins in late February-March; any scars in the first half of early wood were designated as "Early". These scars occurred when lightning frequency was low (Figure 3). Scars designated as "Middle" occurred in the second half of early wood or the first half of late wood (Table 1). The middle period of ring growth occurs during the dry late spring and long summer wet season when the majority of the year's lightning occurs (Figure 3). Scars designated as "Late" occurred during the second half of latewood (Table 1). These scars occurred during a time in which the frequency of lightning was declining to zero (Figure 3). Scars designated as "Dormant" season occurred between latewood of one year and earlywood of the subsequent year (Table 1). These scars occurred at a time with very low lightning frequencies (Figure 3).

The final determination of scar position within the growth ring was based on the position of the majority of scars from all the individual scars on different trees from any particular fire year. Individual trees were found to vary in the timing of their growth and so the position of fire scars within the ring can vary from tree to tree. For instance, the same fire can produce a late earlywood scar in one tree and an early latewood scar in another tree because not all trees start producing late wood at the same time. When there were equal numbers of middle and late scar designations for different trees with the same year scar, the scar was classified as a middle/late scar. If there was a scar from one tree that could not be determined and another that was known, the known scar determined the season position for that fire year (Appendix 1).

The season in which scars occurred indicated potential sources of ignition for fires. We interpret fires that occurred in the growing season as most likely ignited by lightning, which occurs frequently each year and is known to start fire. Within the growing season, middle position scars that occurred when lightning strike density is high (Figure 3) and could have been started by lightning (Table 1). Middle/late and late scars also may have been started by lightning, which is still relatively likely in September. We can not distinguish between fires ignited by lightning and those ignited by humans burning during the lightning/growing season. Scars that occurred in the dormant season when lightning is very uncommon are most likely of human origin.

Fire frequency**.** Fire frequency for the site was determined by compiling all of the fire scar data. The date of the ring in which each fire scar occurred was determined for each sample. The year of fire for each scar and information on each section, (beginning and ending year, and whether the rings were recorder or non-recorder years) was entered into an FHX2 database (Grissino-Mayer 2001). FHX2 is a software program designed for graphing and conducting statistical analyses on fire history data (Grissino-Mayer 2001). FHX2 was used to create a graph of the temporal pattern of past fires including a composite fire chronology where fire dates from all samples were entered onto a single time series.

Analysis of fire frequency was conducted only for the time period when there were at least three “recorder trees”. A tree was not considered a recorder tree prior to the time of the first scar; from that first scar onward it was considered a recorder tree (Figure 9). After an injury, the tissue of trees is more prone to record subsequent injuries; using only the period of time that a tree is recording fires is standard in dendrochronological fire history analysis (Grissino-Mayer 1999). The years used for statistical analyses included the 189-year period for which there were at least three recorder trees (1679-1868). We calculated mean and median fire frequency for this period.

We examined the adequacy of the sample size in relation to fire frequency by determining the number of unique fire scar years that were added by each cross-section when taken in twenty-five runs of random order of cross-sections. A second order polynomial trend line was fitted to the mean of these runs. This trend line, based on the six scarred samples that we used, was projected forward to determine the number of sections necessary to have a complete sample of fire scar years and to estimate the projected total number of fire scars that would be found in a larger sample.

Results

Fire scars

Scars occurred in the sections taken from stumps at the St. Joseph Bay State Buffer Preserve including numerous small scars and localized disruptions of the morphology of annual rings. These scars were not visible from outside the section, but were contained within the wood. A total of 109 scars were found from the six dated sections that had scars. The scars were not uniform. Some were typical fire scars with relatively large areas of dead cambium and “curls” of wood growing over the scar. At the other extreme, there were small cracks within the growth ring; these had varying degrees of distortion of subsequent growth, discoloration and increased resin canals (Figure 7). Often one fire year was marked within the radius of one ring by two or more types of scars, for instance, both distortion and split scars. A total of 87 percent of all scars used were either curls or distortion scar types. Sometimes scars followed one another in a small area over several decades (Figure 8). Often fire scars were spread out around the circumference of the tree.

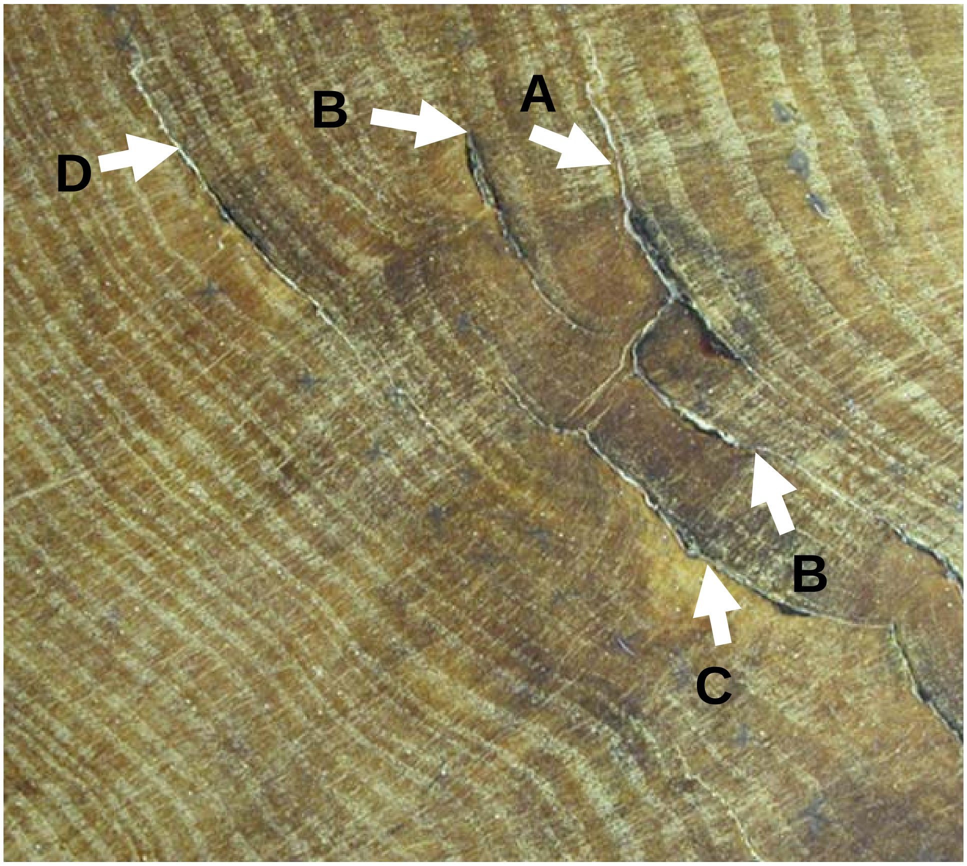

Figure 8. Example of a sequence of fire scars. The first scar in this sequence A: is a curl scar from 1719; followed by B, a well-developed distortion scar from 1722; C, another distortion scar from 1728; and, finally, D, a minor distortion scar from 1732.

Fire seasonality

The seasonal timing of fires was based on ring position of scars. Of the 71 years with fire scars, 62 were clear enough to determine position within the ring (Table 2). Almost all (95%) scars occurred during the growing season (early, middle, middle/late or late positions). Only three fires, all in the 1800s (1831, 1838, and 1848), occurred during the dormant season. Eighty five percent of the growing season scars occurred in the middle-growing season. The remaining 15% of fires all occurred toward the end of the growing season (Table 2).

Table 2. Summary of scar position for all 71 years that had fire scars.

Scar position	Number of years with scars	Percent of all scars	Percent of all known-season scars
Early	0	0	0
Middle	50	70	80
Middle/Late	3	4	5
Late	6	9	10
Dormant	3	4	5
Undetermined	9	13	
Total	71		

Scars indicate an increase in the frequency of non-lightning season fires after 1830. Eighty-eight percent of all scars before 1830 occurred during the middle period (Table 3). During these first 238 years of recorded fires there were no dormant season fires and only 12 percent of fires occurred in the middle/late or late position. In contrast, after 1830 almost half the scars were designated as dormant, middle-late, or late season scars.

Table 3. The number fires outside of the lightning season increased after 1830. Number of fire years and percent of all scars and of known-position scars are presented for the period before 1831 (238 years) and the period after 1830 (56 years).

Scar Position	Before 1830 (1592-1830)			After 1830 (1831-1883)		
	Number of years	Percentage of all years for this time period	Percentage of know-position scars	Number of years	Percentage of all years for this time period	Percentage of know-position scars
Middle	42	75	88	8	53	57
Middle/late	2	4	4	1	7	7
Late	4	7	8	2	13	14
Dormant	0	0	0	3	20	21
Unknown	8	14		1	7	
Total	56	100	100	15	100	100

Fire frequency

Fires occurred frequently throughout the entire period of record (1592-1883) in the St. Joseph Bay pine savanna. Figure 9 provides a graphic representation of the 109 fire scars from the six trees that, when compiled as a composite record, indicate 71 different years in which fires occurred. During the 189 years between 1679 and 1868 at least 3 trees recorded fire scars; this is the time period we used for analysis of fire intervals.

Most fire intervals were short (Figure 10). The mean fire interval was 3.2 years and the median interval was 2.5. Almost 3/4 (72%) of the intervals were 1 to 3 years, with biennial fires comprising almost half (42%) of the intervals. Another 23 percent of the fire intervals were 4 to 6 years. Only a few (5%) of all fire intervals were greater than 6 years, and the maximum intervals were 10 years. Variability in fire return intervals was low, with 92% of all fires occurring at < 5 yr intervals (Table 3). We note that this high fire frequency may be a conservative (low) estimate of fire occurrence. Annual or biennial fires occur prior to accumulation of much fuel and therefore are unlikely to be intense enough to scar many trees. Also, because the trees were collected in a very small area (3 ha), each fire was likely to have burned through the area containing all these trees.

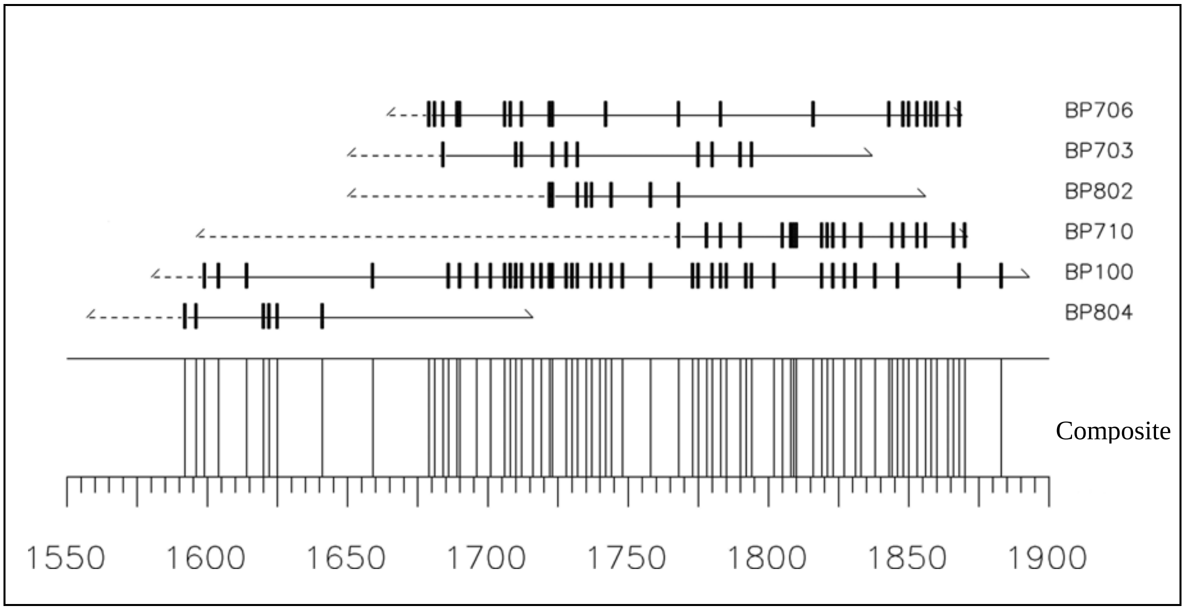

Figure 9. Composite fire history of the St. Joseph Bay pine savanna, north Gulf coast, Florida. Horizontal lines represent individual trees: solid lines indicate recorder years and dashed lines indicate non-recorder years. Vertical bars mark years with fire scars. A composite of all fire years from all samples is presented at the bottom of the figure.

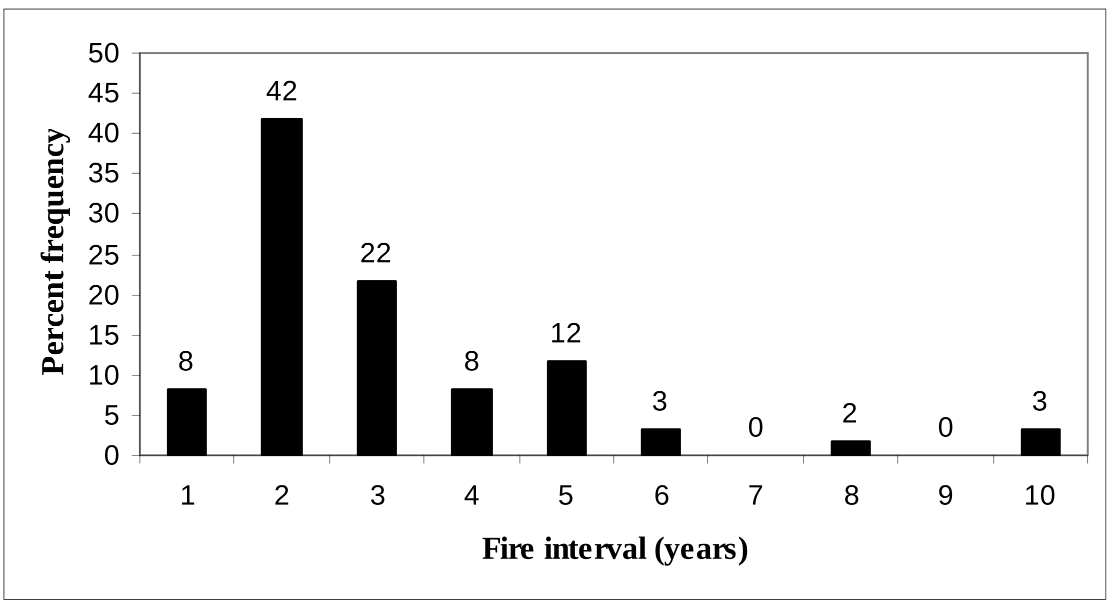

Figure 10. Frequency distribution of intervals between successive fires in the St. Joseph Bay pine savanna.

We expect that our sample size comprises about 2/3 (6 of 9) of that necessary to capture all fire scar years for the time period between 1592 and1883. Our expectations are based on our analysis of sample size in relation to fire frequency (Figure 11). Based on fitting curvilinear regression models to the data, we anticipate that we have identified 71 of 80 expected fire scars, or 89 percent of all expected scars.

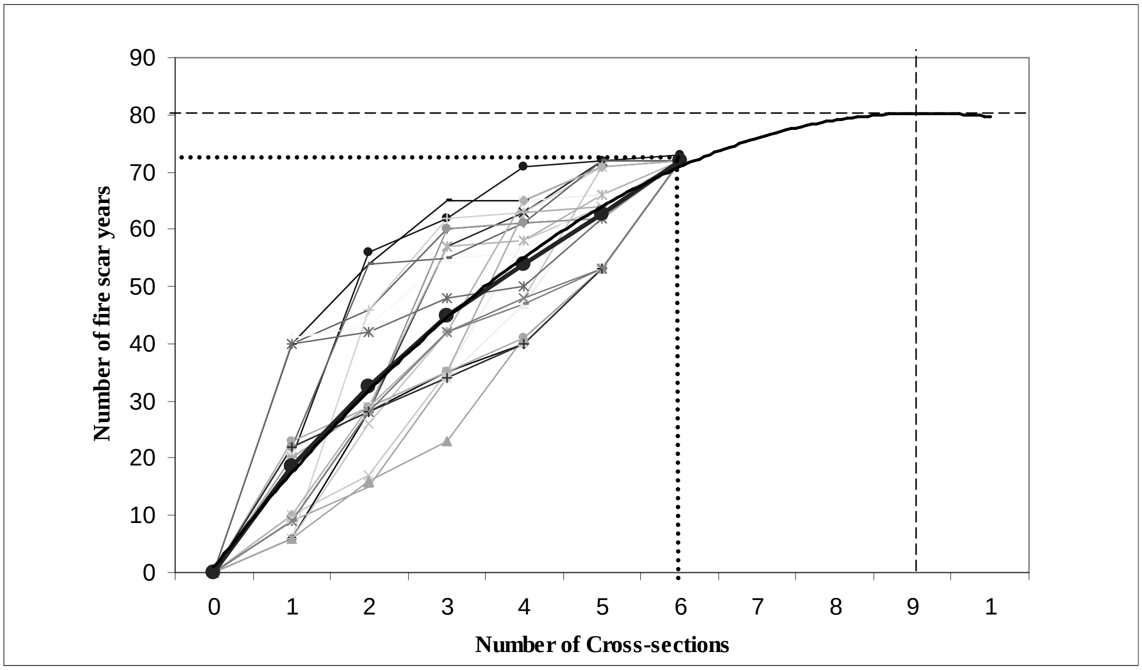

Figure 11. Number of samples necessary to capture total number of fire scar years based on projections made from the six cross-sections used in this study. Heavy black line is second order polynomial trend line fitted to the mean of the 25 random order runs of cross sections showing unique fire scar years. Dotted lines indicate the current number of cross-sections (6), and the current number of fire scar years (71); dashed lines indicate the projected number of sections (9) needed to capture the projected total number of fire scar years (80).

Discussion

Fires were very frequent in the coastal savanna we studied. There was a 2-3 year fire return interval during almost the entire two centuries prior to European settlement of the area. This direct evidence supports predictions based on climate-based models (Komarek 1964, Beckage et al. 2003) and on plant species and community responses from experimental studies (Platt et al. 1988a, b, 1991, Waldrop et al. 1992, Brewer & Platt 1994, Glitzenstein et al. 1995, 2003, Drewa et al. 2002a, 2002b, 2006, Thaxton and

Platt 2006). Our results also are aligned with observations of early ecologists, who noted frequent fires in longleaf pine savannas (Chapman 1926, 1932a,b). Arguments for longer fire intervals (e.g., Maehr and Larkin 2004, Schurbon and Fauth 2003) are not supported.

Small ranges of variation in fire intervals are expected when fires occur frequently. Very frequent fires (1-2 years), in particular may not allow the establishment of some plant species that require longer time intervals to become established after fire. Although 50% of all intervals between fires were two years or less, 50% of the fires occurred at longer intervals. Still, few intervals were > 5 yrs. Thus, longer periods of time, during which hardwood tree sprouts could grow into the canopy, did not occur during the almost two century period of record. High frequency of fires, even in habitats like mesic savannas, thus would have resulted in patches of overstory hardwoods being rare in the landscape except where moisture conditions prevented frequent fires (cf. Harcombe et al. 1993).

There has been continuing debate regarding the importance of lightning and humans as ignition sources in the Southeast. Our data provide conclusive support for the hypothesis that has emerged from ecological, climate-fire relationships and studies of responses of plant communities and species to experimental treatments: pre-European settlement fires in Southeastern pine savannas occurred at very high frequencies and during the growing season. Lightning season fires were the only fires recorded in the annual rings of pines at the St. Joseph Bay savanna between 1592 and 1830. Annual frequencies of cloud-ground lightning strikes in the coastal plain of the Southeastern United States rank among the highest in the world (Goodman and Christian 1993). Lightning frequencies over much of the Gulf of Mexico coast, for example, range from 4-

6 cloud-ground lightning strikes per km^2 annually (Orville and Huffines 2001). There thus are abundant opportunities for ignition sources throughout much of the growing season. When lightning occurs in the early growing season, fuels in low-lying areas are often dry (Olson and Platt 1995, this study). As a result fires are likely to burn large areas, especially in La Niña drought years (Brenner 1991, Beckage et al. 2005a, b).

We found no evidence of fires outside the lightning/growing season between 1592 and 1830 and therefore no definitive evidence of human ignitions before 1830. Indigenous people may have concentrated on coastal resources and not have burned mainland pine savannas, or they may have burned within the lightning season. In addition, indigenous populations of the St. Joseph Bay area decreased and disappeared during this time period. In some other areas of North America, indigenous populations also have had little apparent influence on fire regimes, even in areas where they were known to be present (Kaye and Swetnam 1999, Mooney et al. 2001, Allen 2002, Grissino-Mayer 2004). If indigenous people were adding some fires, their influence would have been overwhelmed by background climatic conditions producing very frequent growing season lightning fires.

The first humans to show evidence of altering season of fire are the early EuroAmerican settlers. From 1831 through 1848 dormant season fires occur in the tree ring record and late growing season fires increase in frequency. The first settlers moved into the area in the late 1820s, and they began open-range grazing of cattle and burning of the nearby savannas for winter forage production. The town of St. Joseph (approximately 10 km northwest of the St. Joseph Bay savanna site) was settled in 1836 on the shores of St. Joseph Bay. A yellow fever epidemic in 1841, in conjunction with repeated hurricanes, caused abandonment of settlement, which was not reestablished until 1909. Nonetheless, scattered settlers and open-range grazing persisted during the 19th century.

Ecological fire management in the southeastern United States has been uncertain because of the absence of hard data on historical variation in frequency and season of fire. Our results show that nearly 3 of 4 presettlement fires occurred within a 1-3 year interval (72%) but there was variation that included occasional longer intervals of 4, 5 or 6 years (23%), and some, infrequent 8-10 year interval fires (5 percent). These data suggest that, at least in pine savannas along the Gulf coast, the large majority (i.e., roughly 75%) of fires should occur at short return intervals (1-3 yrs), but there also should be some longer intervals (i.e., 3-6 yrs), and perhaps rarely (i.e., once-twice a century) some longer periods of up to a decade without fire. Our results also show that all presettlement fires occurred during the growing season.

Chapter 3

FIRE HISTORY OF A BARRIER ISLAND SLASH PINE (*Pinus elliottii*) SAVANNA

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Introduction

Barrier island savannas dominated by slash pine (*Pinus elliottii* Engelm.) are one variation of the pine savannas that historically were widespread across the coastal plain of southeastern North America (Platt 1999). Such habitats contained a non-contiguous overstory of pines and a groundcover dominated by herbaceous species, especially warm season C4 grasses. The widespread, mainland savannas dominated by longleaf pine (*Pinus palustris* Mill.) have been hypothesized to have evolved with frequent, low-intensity fires (Platt 1999). Natural fire regimes on barrier island pine savannas, however, are uncertain. Did fires occur less frequently in the small, narrow, and isolated barrier island pine stands than in the larger, much more extensive, and less isolated pine stands of the mainland? Were most fires over the past decades primarily of lightning origin, in the growing season as hypothesized for longleaf pine savannas (Platt 1999)? Or were the fires primarily anthropogenic dormant season fires? Knowledge of the characteristics of fire regimes on barrier islands would be useful in developing a scientific basis for fire management of remaining barrier island pine savannas.

Dendroecological examination of trees in barrier island pine savannas might produce information on historical fire regimes. Long fire histories have been reconstructed from ponderosa pine and mixed-conifer forests in the western United States (Swetnam 1990, 1993; Swetnam and Baisan 1996). Reconstruction of fire history using southeastern pines has not been attempted, however, for two reasons. First, both longleaf and slash pines are extremely fire resistant (Wright and Bailey 1982) and rarely have open wounds that record fire scars. Second, very few old trees occur in the region because of extensive logging of old growth stands between the late 1800s and the 1930s

(Frost 1993). The few stands of old growth trees that remain are valuable; damage to living trees from sampling usually is not risked for fire history analysis.

In this study, we examined the historic fire frequency in a slash pine savanna on Little St. George Island, an undeveloped barrier island located off the coast of northern Florida, U.S.A. The trunks of many older pines on this island have open scars produced by turpentine operations, and the tissue surrounding these scars has recorded past fires. A lightning-ignited fire that burned almost the entire island in the summer of 1999 killed a number of the older trees with these scars. We took cross-sections of these trees and used their tree-ring patterns to explore the characteristics of fire regimes on barrier islands.

We had five primary objectives: (1) we constructed a cross-dated tree-ring chronology for the slash pines on Little St. George Island so that we could precisely date scars; (2) we determined the dates of fires on the island and calculated island-wide fire frequencies for the period of the tree-ring record; (3) we dated turpentine operations on the island; (4) we estimated the spatial extent of fires that occurred and used this information to calculate site-specific fire frequencies for three different areas of the island; and (5) we determined the season of burn for these fires. Using this information, we developed hypotheses regarding fire regimes of barrier island slash pine savannas.

Methods

Study Area

Little St. George Island is a narrow barrier island located three to five kilometers off the Florida mainland along the northern Gulf Coast of Florida in Franklin County (Figure 1). The island is currently managed by the Apalachicola National Estuarine Research Reserve, in cooperation with the Florida Department of Environmental

Protection. Little St. George Island has never had a bridge linking it with the mainland and, for the past 150 years, has had few human inhabitants. The only permanent residents to occupy the island since the establishment of the lighthouse on the island in 1848 until 1949 were the lighthouse keeper, assistant lighthouse keeper and their families. During this period the island was stocked with open range cattle, hogs, and goats (Rogers 1986).

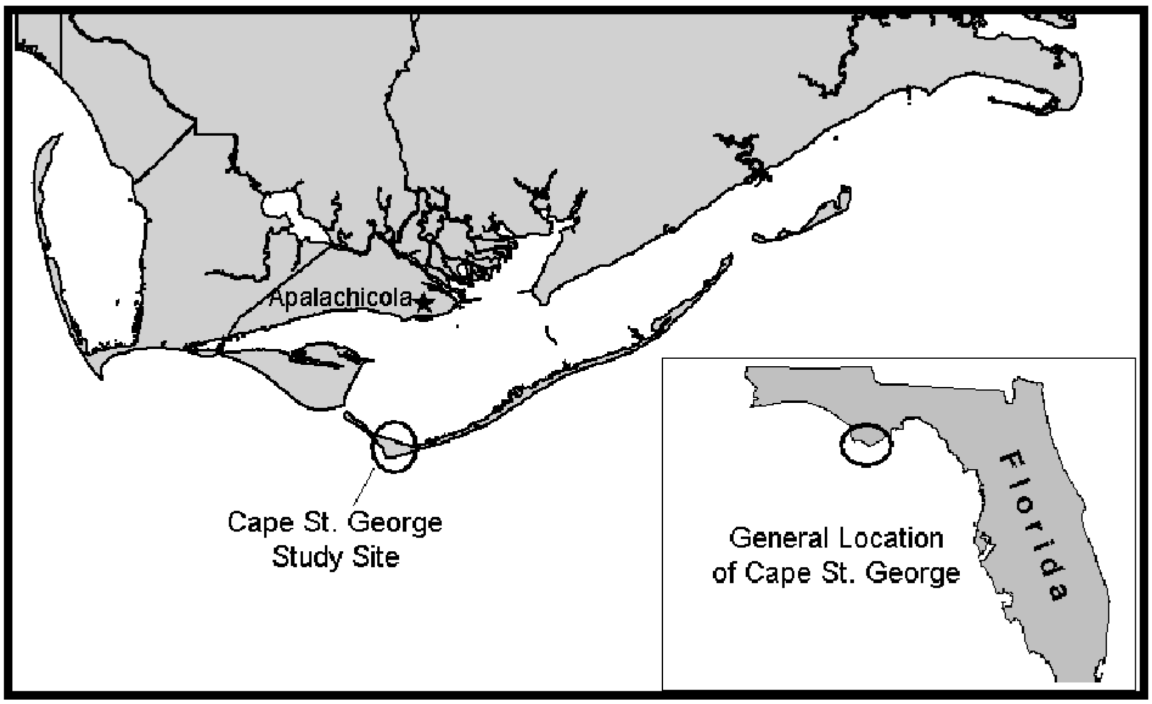


Figure 1. Little St. George Island is a narrow barrier island located two to three miles off the Florida mainland along the northern Gulf Coast of Florida. The Cape St. George study site, circled on map, occurs on Little St. George Island.

Short periods of greater human presence on the island occurred when the slash pines of the island were tapped for resin to make turpentine and related naval stores. Turpentine operations were widespread in the southeastern coastal plain of North America from the middle 1800s through the 1940s, peaking in the first 15 years of the 20th century (Perry 1968). Coastal slash pines were exceptionally rich in resin and were utilized for naval stores production (Perry 1968). During periods when the labor-intensive resin extraction activities were active, a larger group of people who worked the stands occupied the island. Workers would chip away bark and some wood to form one to four open faces, known as catfaces, on pine trees for the extraction of resin. To maintain resin flow the open scars would be periodically augmented by cutting streaks (a single additional narrow cut on the catface) further up the trunk (Figure 2). Trees were usually worked for four to seven years, after which resin production would decline. The trees then would either be logged, or the operation would be abandoned without subsequent logging (Butler 1998). During World War II, the island was used extensively for military training. It was used again for aerial military training in the middle to late 1960s. In 1977, the island was acquired by the state of Florida.

Figure 2. Historical photograph, probably from the 1940s, of the process of cutting a streak on a pine (from Butler 1998). A streak was a cut approximately 1 cm wide cut frequently to keep sap flowing. The series of streaks that were cut resulted in an open "catface". The pine resin was collected and used primarily for the manufacture of turpentine. Healing scars from these catfaces on Little St. George Island recorded subsequent fires.

Humans have influenced the fire regimes on Little St. George Island. Since the early part of the century and before state acquisition, inhabitants of the island attempted to extinguish fires whenever possible (unpublished interview with George Watkins, Apalachicola National Estuarine Research Reserve, Eastpoint, FL). After the island was acquired by the state, fires were extinguished whenever possible until 1999 when a lightning fire was allowed to burn across the island.

The largest area of pines on the island occurs on Cape St. George (Figure 1). This 370 ha area of pines is triangular in shape, approximately 3.9 km long at its longest side and 1.5 km wide at the widest point. Although a few much smaller pine stands occur on the island, sampling for this study only included the large cape stand. The cape stand appears to be unique in the region because it has not been clearcut (at least not in the past 150 years) and therefore contains many old trees. The cape pine stand consists of a linear series of ridges and swales on old dunes extending from Apalachicola Bay to the Gulf of Mexico. Associated groundcover and shrub species vary from the dry old dune ridges to the wet swales. Scrub oaks *(Quercus chapmanii, Quercus myrtifolia)*, conradina *(Conradina canescens)* and rosemary *(Ceratiola ericoides*) are most commonly associated with slash pine on the dry ridges, while a diverse herbaceous groundcover including muhly grass *(Muhlenbergia filipes)* and sawgrass *(Cladium jamaicense)* occurs in the swales. The mesic savannas have a well-developed herbaceous groundcover flora similar to mainland flatwoods with an abundance of saw palmetto *(Serenoa repens)*, wiregrass *(Aristida beyrichiana)* and Ericaceous shrubs *(*e.g., *Vaccinium myrsinites).*

Fire History

Cross-section collection and preparation**.** Cross-sections used to determine fire and turpentine history were collected between 2000 and 2002 from 52 selected dead trees. The majority of sections were cut from what appeared to be the oldest dead trees. In addition, some sections were taken from younger trees that had established in the middle part of the 1900s. Trees were selected from different parts of the cape study area to provide as much spatial coverage as possible. Sections were cut from 0.5 to 1.0 m above the ground. Many trees were dead because fires had burned through the trunk at the open catfaces one to three meters above the base of the tree. Samples were most often obtained from the stumps of these trees because boles were already down on the ground. Many dead trees on the island could not be sampled since fires had burned completely through the tree at the historic catfaced surfaces, including the basal section of the tree. Cross-sections were planed and finely sanded in preparation for dating.

Dating fire and turpentine scars**.** In 2000, cores were collected from 30 living trees of various ages to construct a master chronology of the stand. Standard dendrochronological procedures were used (Stokes and Smiley 1968). Cores were mounted, sanded, and dated. Ring widths were measured, and the computer program COFECHA (Holmes 1983) was used to detect and correct any errors in measurement and cross dating. Later, measurements from tree rings on the cross-sections used in fire history analysis were added to the chronology. Scars caused by making open cut faces on trees for resin extraction were dated when possible, specifically when growth rings had grown over the scar. Turpentine scars were easily distinguished from fire scars because the turpentine scars were characterized by very large, regular areas of dead cambium (see Figure 3). Such scars (catfaces) typically occurred in two to four separate areas around the circumference of the tree; only one such scar was typically present on the very smallest trees. Fire scars were usually found in the wood associated with the healing injuries from turpentine scars or they consisted of much smaller, single areas of dead cambium on young trees (Figure 3). The computer program FHX2 (Grissino-Mayer 1995) was used to graph fire and turpentine scars for each section.

Figure 3. Two cross-sections of slash pine show the difference between fire scars and scars created by turpentine operations. White dashed lines indicate turpentine “catface” scars that kill one to three large areas of cambium. Arrows point to smaller fire scars that are most frequent in the tissue that forms over previously scarred areas.

Calculating fire return intervals. Fire return intervals were calculated for the entire study area by determining the mean interval between the occurrences of successive fires identified from tree rings within different time periods. These return intervals are not spatially explicit and presume that each fire burned the entire study area. Although the study area of 370 ha is quite small by most fire history study standards, we were able to refine this analysis by determining the mean fire return intervals for each of three separate compartments of the study area.

Determining spatial extent of fires**.** Each tree from which a cross-section was collected was located using a global positioning system. The spatial extent of fires (widespread or narrow) was estimated by producing thematic maps of the number and spatial relationship of trees that recorded each fire using MapInfo® (MapInfo Inc.). The spatial extent of fires was determined only for fire years when more than two trees recorded a fire. The 370 ha study area was divided into three compartments bounded by two narrow dirt roads that have been present since at least the early part of the 1900s (Table 2). Fires that occurred within one of these areas were assumed to have burned most of the area within the compartment. Widespread fires were defined as occurring in two or more of these compartments, while limited fires occurred in only one compartment.

Determining season of fire. Whether a fire occurred during the growing season or the dormant season was determined by the position of the scar within the growth ring (Baisan and Swetnam 1990). Most, but not all scars were clear enough to date to season. Only clear and distinct scars were used in seasonal determinations. Scars within the earlywood or latewood of a ring were considered growing season fires. Scars between the latewood and the following year's earlywood were considered dormant season fires. The latter year was used as the fire date in dormant season scars; for example, if a scar occurred between 1933 latewood and 1934 earlywood, it was assigned as a 1934 fire. We considered the growing season for slash pines on Little St. George Island as roughly March through October, based on field observations.

Growing season scars were further examined to determine where they occurred within the growth ring: early, middle or late. Early scars occurred in the first 2/3s of the early wood, middle scars occurred in the final 1/3 of the early wood or the first 1/3 of the latewood, and late scars occurred in the final 2/3s of the latewood. These categories (early, middle, late) would correspond to early growing season (roughly March through May), middle growing season (June through August), and late growing season (September through October or the end of growth for that year). This is an approximation of the timing of growth based on increment cores collected throughout the year (J. Huffman, unpublished data) and should be refined by ongoing studies of growth patterns in slash pines of this area. Individual trees were found to vary in the timing of their growth and so the position of fire scars within the ring can vary from tree to tree. The final determination of scar position within the growth ring was based on the position of the majority of scars from all the individual scars from any particular fire year.

Results and Discussion

Fire and Naval Stores History

Examination of scars revealed two periods of resin extraction on the island during the lifetime of these trees (Figure 4). The first period occurred between 1912 and 1918. Figure 4 shows that the great majority of the trees sampled had scars created from turpentining in 1912 or 1913, but several younger trees had chipping of catfaces as late as 1918. Trees were probably worked until resin production declined to unprofitable levels. During the second resin extraction period, 1949 - 1958, the same trees were tapped again, with the majority of cuts being made in 1950 (Figure 4). Extensive catfaces were cut during both periods, typically with two to four separately cut surfaces that killed one-third to one-half of the living cambium of the tree up to a height of about 3 m or more (Figure 2). Figure 3 shows catface scars on two different cross-sections. Scars from the early period are indicated by finely dashed lines and the later period by more coarsely dashed lines.

Slash pines scarred during turpentine operations were used to reconstruct site fire histories. A total of 159 fire scars from 21 separate years were recorded in all cross-sections (Figure 4). Fire scars were most commonly found in the tissue that formed over physical injuries caused by turpentine operations (Figure 3), but all scars prior to 1912 were in trees that had no previous physical injuries.

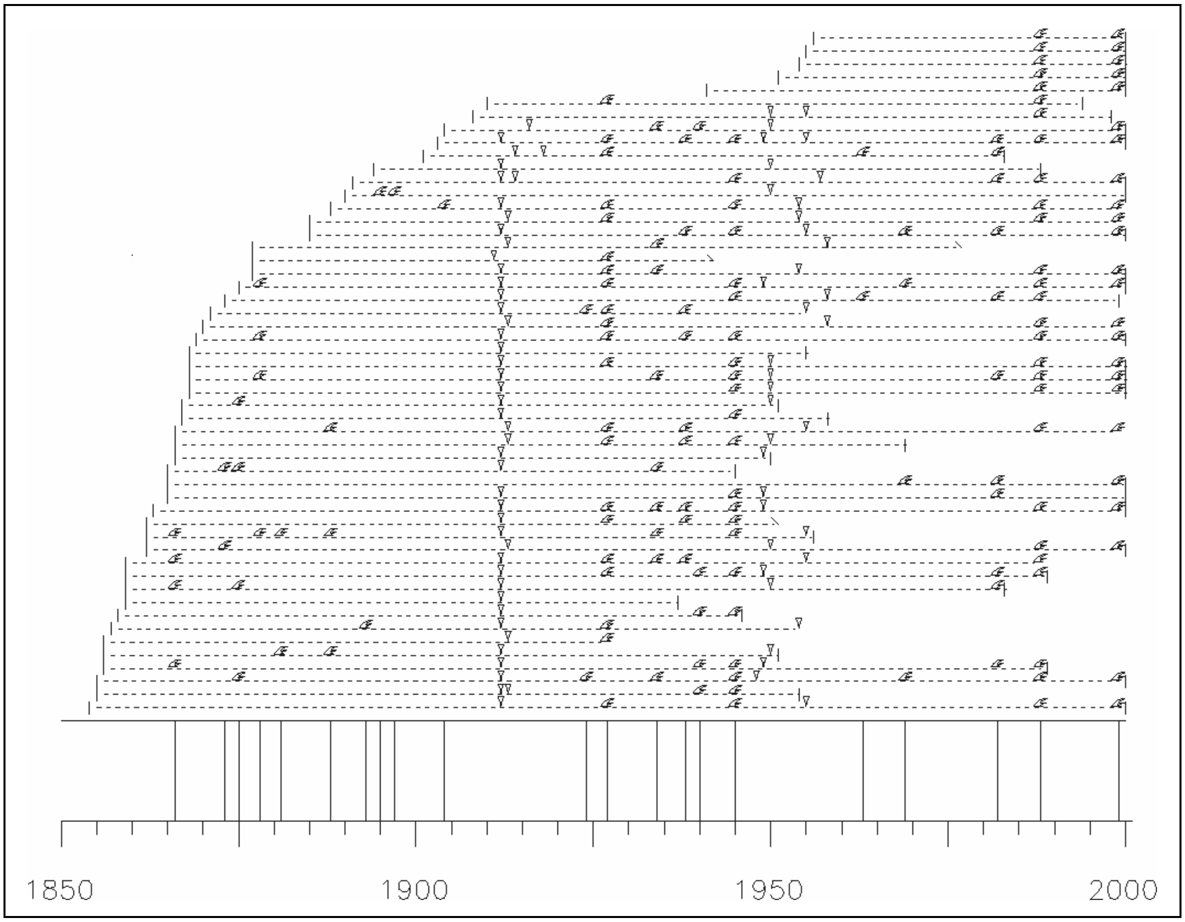


Figure 4. A chronology of fire and turpentine injuries for the Cape region of Little St. George Island, Florida, from scars on each cross-section. Inverted diamonds indicate turpentine related scars and flame symbols indicate fire-scars. Composite fire scar lines at the bottom of the figure indicate years when fire scars were present.

Fire Return Intervals During Different Time Periods

We delineated five distinct periods with different fire return intervals (Figure 5). Fire return intervals were calculated for the entire 370 ha study area.

<u>Early fire period - Frequent fire (1866-1904).</u> This 38-year long period was a time of relatively frequent fire with a mean fire return interval of 4 years. The trees sampled for this study were young during this time period, all having established after 1851. Younger trees have much thinner bark than older trees, and thus some trees recorded fires, even though there were not yet any open wounds from resin-extraction operations.

The only known residents of the island during this period were the lighthouse keeper, his assistant and their families.

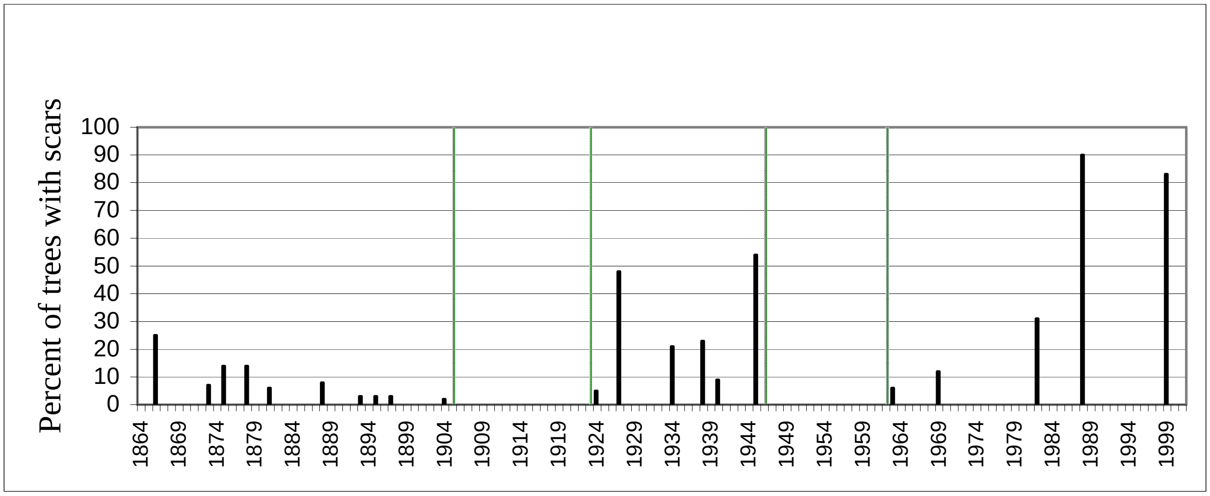


Figure 5. Fire scar data for all trees indicates that from 1864-2000 there were five distinct fire eras on the Cape region of Little St. George Island, Florida. Two periods of no fire scars corresponded to times of active pine resin extraction on the island. The first two fire eras had mean fire return intervals of four years, while the current era has a longer nine-year fire return interval. Turpentine scars, indicated by dashed horizontal lines, were found from 1911-1918 and 1948-1958.

Early resin-extraction period – No fire scars (1905-1923). No fires were recorded in the tree-ring record for this 18-year period. During the early part of this period, many trees were reaching more mature stages with characteristic fire-resistant bark. It is unlikely that intact trees would record low-intensity fires after they were more than 25 to 35 years old, which occurred between 1889 and 1916 for most sampled trees.

Furthermore, the latter part of this period, 1911-1918, was a time of intense pine resin extraction activity in the region (Butler 1998). Nearly all of the older trees on the island appear to have been chipped for turpentining during the 1912 extraction period. Because open, catfaced trees were extremely vulnerable to damage by fire, trees in active resin-extraction areas were protected by manually removing all vegetation from around them and by initiating frequent fires to keep fuels low in the surrounding stand (Butler

1998). Because of this protection of vulnerable trees, fires could have occurred during this period but would not have been recorded in the tree rings. Therefore, the fire history for this time period is unknown but likely was a period of very frequent, low intensity fires.

Middle fire period – Frequent fire (1924-1945). The abandonment of turpentine/resin extraction activities on the island allowed the regrowth of vegetation to serve as fuel around the extensively scarred pines. Therefore, frequent fires were again recorded during this period, with a mean fire return interval of 4.2 years. The last fire of this period occurred in 1945 and was likely a large and intense fire, based on the number of trees that recorded this event.

Second resin-extraction period – No fire scars (1946-1962). Resin extraction operations were again active during this period with catfaces being cut from 1949-1958. Again, as in the first resin-extraction period, the actual occurrence of fire is unknown. However, it is likely that fuel-reduction fires occurred during this time; interviews with local residents confirmed that turpentiners burned on the island to reduce fuels (Fred Sawyer, Apalachicola, FL, unpublished interview).

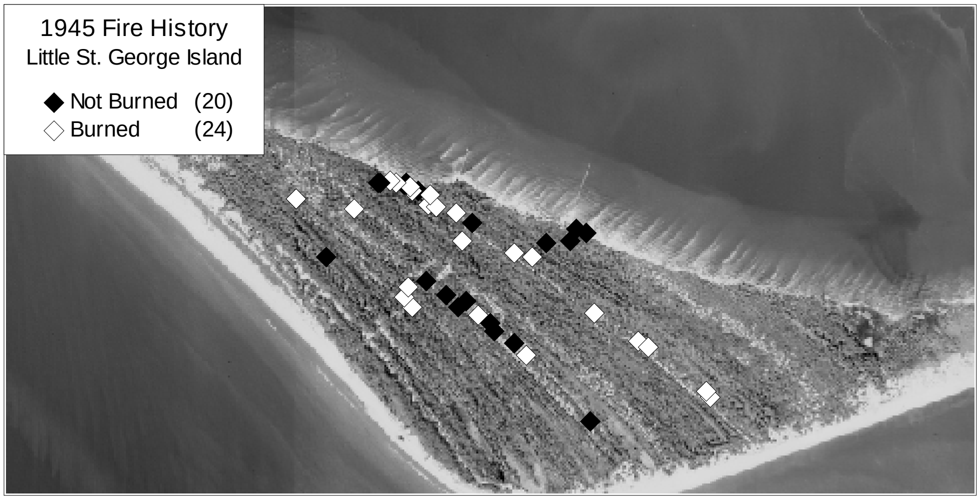
Recent fire period – Less frequent fire (1963-2001). In this final period, fire was less frequent than during earlier fire periods, with a mean fire return interval of 9 years. Although no people lived on the island during most of this period, there has been an active effort to suppress fires, using suppression equipment and personnel. Two known lightning strike fires occurred during this period in 1988 and 1999. Current management policy is to allow lightning-initiated fires to burn without suppression except around one historic structure.

Fire Spatial Extent and Fire Return Intervals

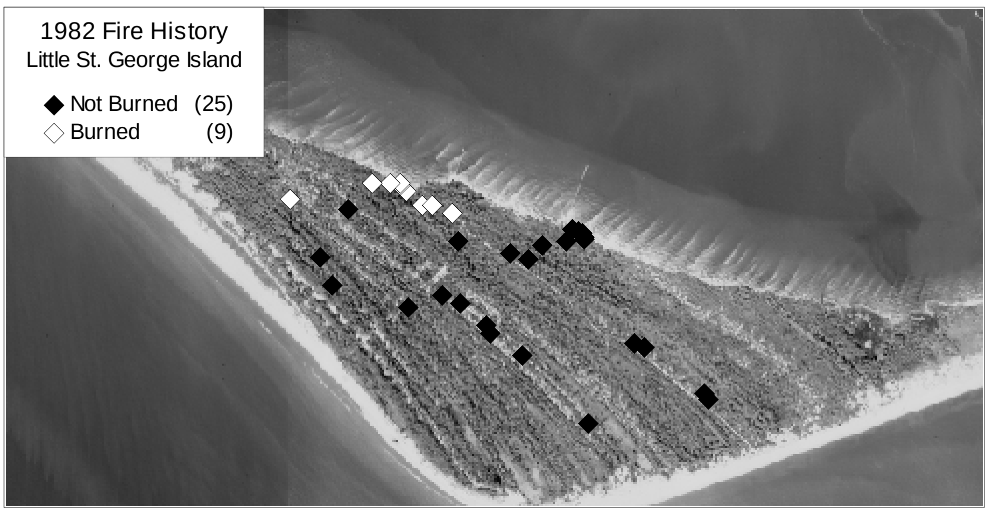
The fire-scar record shows that, of the total of 14 fires that had more than two trees recording scars, 8 fires were widespread (occurred in two or more compartments), and 6 were of limited spatial extent (Table 1). The fire that occurred in 1945 is an example of a widespread fire (Figure 6) that scarred a large number of trees over a range of dune/swale conditions in all three compartments of the study area. In contrast, the fire in 1982 was limited in extent, with trees scarred only within a small area in one compartment of the study area (Figure 6). This fire was suppressed using one of the dirt roads that cross the island.

Table 1. Spatial extent and season of each recorded fire on Little St. George Island, Florida.

	Year of Fire	*Extent*	*Fire Extent Summary*	*Season*	*Position of Scar*
1st Fire Era: 4 year fire-return interval	1866	Widespread	Widespread:2	Growing season	Early
	1873	Unknown	Limited:2	Growing season	Late
	1875	Limited		Growing season	Middle
	1878	Limited		Growing season	Middle
	1881	Unknown		Growing season	Late
	1888	Widespread		Growing season	Middle
	1893	Unknown		Growing season	Middle
	1895	Unknown		Growing season	Middle
	1897	Unknown		Dormant season	Late/Early transition
	1904	Unknown		Dormant season	Late/Early transition
2nd Fire Era: 4 year fire-return interval	1924	Unknown	Widespread: 4	Growing season	Middle
	1927	Widespread	Limited: 1	Growing season	Middle
	1934	Widespread		Growing season	Middle
	1938	Widespread		Growing season	Middle
	1940	Limited		Growing season	Late
	1945	Widespread		Growing season	Middle
3rd Fire Era: 9 year fire-return interval	1963	Limited	Widespread: 2	Dormant season	Late/Early transition
	1969	Limited	Limited: 3	Growing season	Middle
	1982	Limited		Growing season	Middle
	1988	Widespread		Growing season	Middle
	1999	Widespread		Growing season	Late



6A



6B

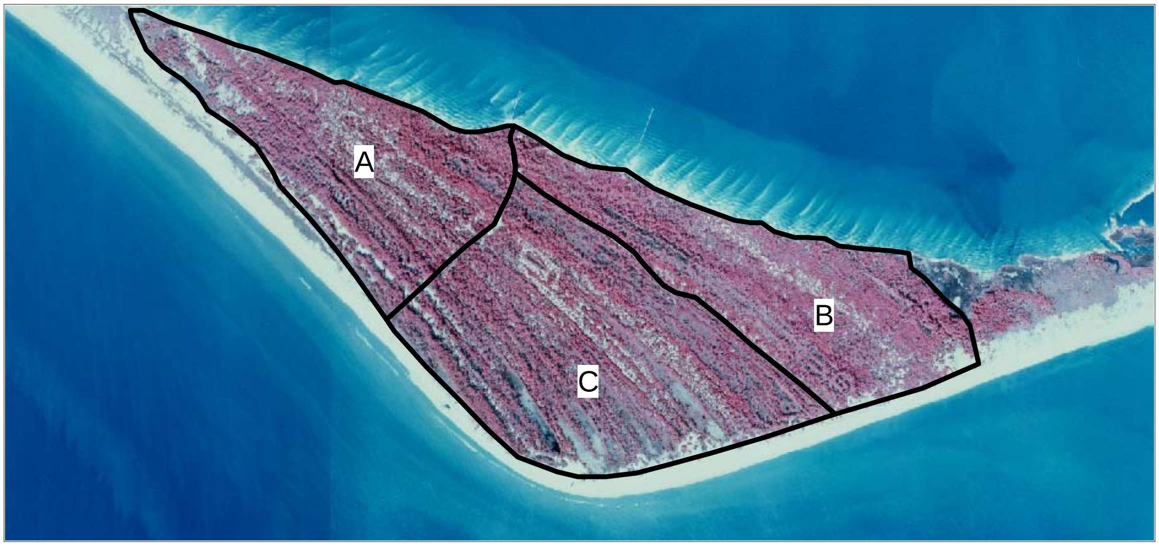
Figure 6. Distribution of fire scars for a widespread and a limited fire. A white diamond indicates the location of each tree with a fire scar. Black diamonds show those trees that were sampled but did not have a fire scar. **6a.** Widespread fire, 1945. The distribution of scarred trees shows that the 1945 fire was widespread on the island and probably intense since trees were scarred over a range of dune/swale conditions and a large proportion of trees were scarred. **6b.** Limited area fire, 1982. The distribution of scarred trees shows that the 1982 occurred only in a limited area.

The spatial extent of fires differed between the three fire periods (early, middle, and recent) (Table 1). In the early period, 50% of fires were widespread, and 50% were limited. The middle period had more widespread fires (80%) and fewer fires that were limited in extent (20%). Frequent widespread fires would be expected if ignition of fires occurred under more extreme weather conditions and if there was no effective suppression because few people were on the island during much of this period. In the recent period, there was a shift to more limited fires (80%) and fewer widespread fires (20%), presumably resulting from more effective suppression by the army and Florida park service.

We identified two potential problems with our analyses of the spatial extent of fires. First, most of the older trees on the island are on the two dune ridges nearest the bay, and thus a large proportion of the sampled trees were in this area. Fewer turpentined trees occurred on other ridges, which might have biased the data towards fires of limited extent. Also, fires of greater intensity would have a greater chance of scarring trees than less intense fires, so fire intensity may complicate the analysis of historical fire spatial extent. We note, however, that this would only result in wider spatial extent and higher fire frequencies than those obtained from our analyses.

Mean fire return intervals were slightly longer using more spatially explicit data to estimate which fires occurred in each of the three compartments of the study area (Table 2). During the first fire era (1866-1904) 60% of fire dates did not have enough trees to determine spatial extent and therefore fire return intervals for the different compartments were not calculated. For the second era (1927-1945) mean fire return interval was 4.5-5.2 years, only slightly longer than the 4-year interval for the island as a whole. During the recent fire era (1963–1999) the mean fire return interval was 12-18 years, which is three to five years longer than the 9-year interval calculated for the island as a whole.

Table 2. Fire return intervals for three compartments of the Cape St. George study area. X indicates that fire scars were recorded from trees within this compartment for the specified fire year. O indicates no fire scars were recorded from trees within this compartment for that fire year. Numbers following symbols indicate number of years since previous fire.



	Fire Year	Section A	Section B	Section C
Second Fire Era (1924 –1945)	1924 1927 1934 1938 1940 1945	O X X 7 X 4 X 2 X 5	X X 3 X 7 X 4 O X 7	X X 3 X 7 X 4 O X 7
Mean Fire Return Interval		4.5	5.25	5.25
Recent Fire Era (1963-1999)	1963 1969 1982 1988 1999	X O X 19 X 6 X 11	O X O X 19 X 11	O O O X (25+) X 11
Mean Fire Return Interval		12	15	18.5

Fire Season

Dormant vs. growing season. The proportion of all fires on the island from 1866-1999 that occurred during the growing season (86%) was larger than would be expected if fires occurred randomly throughout the year (67%). Only three fires (1897, 1904, and 1963) or 14 percent of all fires detected as fire scars occurred during the dormant season (Table 1). Dormant-season prescribed fire was not common through the recent history of the island, at least not in fires that appear in the tree-ring record. It may be possible that fires set by turpentine crews were set in the dormant season, but no fire scars would have occurred if trees were protected from fire during that period.

Position of fire scars within the growing season and probable origin of fires. Most of the 17 growing season fires occurred in the middle growing season (13). Only 1 fire occurred early in the growing season, and 3 occurred in the late growing season (Table 1). Fires that occur in the growing season throughout this tree ring record could have been started either by lightning, which occurs frequently each year on the island and is known to start fire, or by humans. The source of most fires is unknown. The last two fires on the island were ignited by lightning, and the one previous to those was set by visitors to the island. For the earlier fires the position of fire scars give clues as to possible origins. Dormant-season and early growing-season fires have traditionally been used by cattlemen and turpentiners, at least in the past century, therefore scars from these fires would likely occur between the previous years latewood and the next years early wood (dormant season) or in the early part of the early wood. Lightning strikes are infrequent from November through April (the dormant season and early growing season) and are more frequent from May through October, peaking in July and August (Hodanish et al. 1997), so lightning-ignited fires would be likely to occur within either the early or latewood, but not between rings. In recent years (1988 and 1999), lightning fires on the island have occurred in the middle growing season.

Based on this information we suggest the origin of fires during the different fire periods. It is likely that the fires from the 1920s through the 1940s were lightning-ignited fires because the owners of the island during this time tried to prevent fire (pers. com. George Watkins, Apalachicola National Estuarine Reserve, Apalachicola) and because all of these fires occurred in the middle to late growing season, not a likely time for people to set fires in this region. Fires during the early period were probably a mix of possible human and lightning caused fires. Three of the ten fires were dormant season or early growing season, likely human-caused. Five fires during this time were middle growing season and two were late growing season; these were likely to have been ignited by lightning.

In summary, although humans certainly influenced fire regimes, it is unlikely that human-set fires would have occurred so consistently during the middle and late growing season. We propose that lightning was the ignition source for many, if not most of the historic growing season fires on the island.

Tree Ages

No trees on the island were found that had established before 1853. We propose two possible explanations. First, major hurricanes probably affected the pine stands on Little St. George Island. The major hurricane of 1851 is known to have destroyed the Cape St. George lighthouse, as well as lighthouses at nearby Dog Island and Cape San Blas, and it also damaged the nearby mainland town of Apalachicola (Rogers 1986). Such a strong hurricane might have felled many of the older trees on the island and could have opened the space that allowed establishment of the older trees of the current stand. We base this hypothesis on effects of Hurricane Andrew on old-growth slash pine stands

(Lostman's Pines) in Big Cypress National Preserve (Platt et al. 2000). Another hurricane hit the island in 1850. This hurricane undermined the Cape St. George lighthouse and might also have felled trees on the island. One possibility is that one or both hurricanes may have caused erosion and loss of dunes older than those currently on the bayside of the island. Hurricane-related mortality of older trees, especially on bayside dunes destroyed by the storms, would have produced oldest trees dating from the mid-1800s. If intense fires resulting from downed trees followed such hurricanes, hurricane-fire interactions might also have accentuated hurricane-related mortality (Myers and Van Lear 1998; Platt et al. 2002).

Second, tree harvest in the middle to late nineteenth century may have removed trees that established before 1853. Although we have not found records of logging on the island during the 1900s, larger trees in the stands could have been removed in the 1880s when much of the area was first cut. It is also possible that an episode of resin extraction occurred on the island in the late 1800s. Methods of extraction before 1909 were crude and usually resulted in the death of the trees (Butler 1998). Thus, if trees were used for resin extraction in the 1860s or 1870s, trees more than 10 to 20 years old at that time (trees originating in 1850s) might not have survived.

Implications for fire management of barrier islands.

Fire-scar data from our study provides a first step in addressing some of the questions surrounding fire management of barrier islands. We obtained information on historic fire frequency, fire season, and some indications of the spatial extent of fires, thus elucidating the historic role of fire on a Gulf Coast barrier island. Although the trees on the 370 ha area of Little St. George Island we studied were not old enough to determine presettlement fire frequencies, two early periods of the fire history, both times without known turpentine operations, may reflect a fairly “natural” fire regime. Four- to five-year fire intervals occurred within this small area during periods when there was only limited human activity on the island. In addition, most of these fires occurred during the growing season. Data from this study thus suggest that the natural fire regimes of similar barrier island slash pine savannas may also have consisted primarily of frequent, growing season fires. These fires thus may have resembled those in mainland longleaf pine savannas (see Platt 1999), even in small barrier island pine savanna stands.

Natural fire regimes of barrier islands probably were influenced primarily by climatic conditions and characteristics of vegetation on that island. Size of the island, configuration of the dunes and swales, as well as the nature and contiguousness of the fine fuels should have influenced fire frequency. In addition, the local frequency of lightning strikes and weather conditions should have influenced the timing of ignition, as well as the frequency of fires. The high fire frequency within the small areas that comprise barrier islands suggests very frequent lightning strikes and the long-term presence of flammable vegetation on these islands. The presence of a widespread and diverse herbaceous groundcover layer with species such as wiregrass and numerous other species that require frequent fire for long-term competitive survival over shrubs also strongly suggests a long history of frequent fire on Little St. George Island.

Should prescribed fires be conducted on barrier islands? Changes in fuels on barrier islands may have resulted from past management, including turpentining and fire suppression. Prescribed fires may be needed to reduce fuel loads and enhance fine fuels while shifting to a natural fire regime. After fuel loads are reduced on uninhabited, nonfragmented islands, prescribed fires should no longer be needed; naturally ignited fires should be allowed to occur and burn without suppression. Where part of an island has been subjected to human occupancy and alterations of the original habitats, the remaining habitats are likely to be both fragmented and fire suppressed. On these islands prescribed fires would be needed to reduce fuel loads and maintain fire dependent habitats.

Chapter 4

CONCLUSIONS

The studies I conducted on fire history document historical fire regimes in southeastern pine savannas and can resolve outstanding questions regarding past fire regimes. The very high frequencies of lightning season fires that were found indicate that the fire regime was primarily driven by synoptic climatic conditions, rather than by cultural burning practices. Both the mainland and the island site recorded frequent, growing season fires, suggesting that lightning fires were occurring frequently both before and after settlement despite one site being a very small and isolated island and the other in a much larger mainland landscape of similar flammable habitat. Lightning season fires were the only kind of fire recorded prior to European settlement so there is no conclusive evidence of fires ignited by people for the presettlement period. If humans were not present and setting fires in the vicinity of the mainland pine savanna in the 16th and 17th centuries, the fire scars indicate that lightning alone was sufficient to burn this savanna with great frequency. It is impossible to say for certain the source of ignition of lightning season fires and people may have been burning during the lightning season. Regardless of ignition source, the background climatic and fuel conditions resulted in frequent, growing season fires and overwhelmed any potential human influence.

Human influence on fire regimes was slight even after EuroAmerican settlement. Before the early 1800s, fire regimes at the St. Joseph Bay mainland savanna consisted entirely of growing season fires. Fire regimes changed after settlement in the early 1800s. On the mainland site 21% of scars were in the dormant season (for the period of 1831-1868), and on the Little St. George Island site 14% of scars were in the dormant season (for the period 1866-1999). I infer that people were burning pine savannas once settlement occurred, but that lightning-season fires were still occurring, and much more often than human-caused dormant season fires. I found that fires occurred at very frequent intervals in both the mainland and barrier island pine savannas. Frequency of fires differed only slightly between the island (4 year mean return interval before 1942) and mainland (3 year mean fire return interval) and, between presettlement (3.2 year mean fire interval) and post settlement (2.9 year mean fire interval) on the mainland site. Evidence that human influence on fire regimes was slight even after EuroAmerican settlement also supports the argument that human caused fires were not as important as lightning fires in southeastern pine savannas.

These results regarding frequency and season of past fire regimes solidly support ecological fire models based on climate and fuels. These models show that fuels in pine savannas can re-burn again within 1-2 years and that these fuels dry in the late spring to early summer dry period when lightning increases, providing ignition sources. My results that most fire intervals were 3 years or less and occurred within the lightning season supports the past fire regime inferred from climate/fuels models. As in the southwest, direct evidence of fires has shown that synoptic climate and fuels are of primary importance in determining fire regimes (Allen 2002). It follows that climatic analyses should provide the best base for deducing historical fire regimes in regions lacking direct evidence of past fire regimes, especially other fire-frequented savannas.

This direct evidence of fire history in southeastern pine savannas can resolve some outstanding questions regarding ecological fire management. Currently ecological fire management of southeastern pine savannas is guided by climatic and especially, biotic-response models of fire regimes. This has caused a fair amount of uncertainty about how fire should be applied in terms of season, frequency and variation in fire frequency. The results of this study show clearly that presettlement fire regimes consisted of lightning season fires. This evidence combined with the abundant biotic-response evidence that characteristic pine savanna species evolved with lightning season fire should clear the way for managers to plan for a major part of prescribed pine savanna fires to occur within the lightning season.

With these studies, fire managers now have direct as well as indirect evidence that supports frequent fires in pine savanna. The results of this study show that presettlement fire occurred at very frequent intervals, most often every 2 years, but with some annual fires and occasional longer intervals ranging up to 5-6 years. Longer intervals were very infrequent (5%). This information, along with climate models, gives a very strong basis for determining prescribed fire intervals in pine savanna and can serve as a guideline for fire frequency intervals and variance in fire frequency intervals for prescribed fire in upland pine savanna.

As we start to understand past fire regimes and how climate has determined fire regimes in the southeast, the climate continues to change. Climate change is likely to place further challenges upon fire managers in the future. Global warming is expected to influence disturbance regimes in southeastern savannas through its effect on the ENSO cycle. The El Niño phase of ENSO is expected to become increasingly frequent with global warming, with La Niña events decreasing in frequency (Timmermann et al. 1999, Tsonis et al. 2003). Increased El Niño frequency should result in increased seasonal inundation of lowland pine savannas in a warmer world. As a result, there should be fewer, but more intense fires in pine savannas. Dendrochronological reconstructions of fire history such as the ones in this dissertation should result in greater accuracy of prediction of how fire regimes would likely change in response to changes in climate and may be used as the basis for ecological fire management models that offset effects of global climate change.

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APPENDIX A. Release from Natural Areas Journal for Chapter 2 paper:

NATURAL AREAS ASSOCIATION

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February 20, 2006

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Dear Jean,

We are pleased to hear about your interest in using the article that you co-authored for the Natural Areas Journal as part of your dissertation. You have the permission of the Natural Areas Association to use the following article from Natural Areas Journal Volume 24/Issue 3 pages 258-268 for your dissertation: "Fire History of a Barrier Island Slash Pine (*Pinus elliottii*) Savanna".

Thank you for contacting us.

Best wishes,

Deb Kraus
Operations Manager

VITA

Jean Marie Huffman was born in 1958. As a child she spent time in her Grandmothers garden and explored creeks, forests and farms in Illinois, Wisconsin and Hawaii. She went to high school in Florida and before graduating started a tofu-making business with her mother Marvel. Eventually she was lucky enough to attend New College in Sarasota, Florida where she was allowed the freedom to pursue her true interests and was introduced to fire and Florida pine savannas by Dr. John Morrill. After graduating from New College in 1982 she lived and worked in Belize and was able to canoe the Bladen Branch of the Monkey River and the Macal River, and work on a study of Baird's tapir. Upon returning to Florida she became the biologist at Myakka River State Park where, thanks to Robert Dye, she learned to burn and appreciate Florida dry prairie. She was able in 1991 to spend a year exploring Brazilian forest and savanna and worked on a study of white-lipped peccaries and tapir seed dispersal. In 1995 she undertook a study of fire resistance of tropical dry forest trees in Bolivia. She returned to Florida and completed her Master's degree at the University of Florida in 1997 on the effects of fire and mechanical treatments on pine lilies and then decided to pursue her Ph.D. at Louisiana State University with Dr. William Platt. Now living and working in the Florida panhandle, she plans to continue to burn the woods and study savannas, fire ecology and fire history.