PRESETTLEMENT VEGETATION AND FIRE IN ESCAMBIA AND COVINGTON COUNTIES, ALABAMA

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PRESETTLEMENT VEGETATION AND FIRE IN ESCAMBIA AND COVINGTON COUNTIES, ALABAMA

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VITA

Stephen Andrew Predmore, son of Anne and Richard L. Predmore, was born April 6, 1978, in Spartanburg, South Carolina. He graduated from Spartanburg High School in 1996. He attended the University of Virginia and graduated with a B.A. in government May of 2000. He married Erin Edwards James, daughter of Dr. Joseph and Sandra James, on July 28, 2001. After working as a legal assistant in Washington D.C., and then a tennis teaching professional in Athens, Georgia, he entered Graduate School at Auburn University in August 2003.

THESIS ABSTRACT

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This study was the first to examine presettlement forests in the lower coastal plain of Alabama. The primary data source is General Land Office public land survey field notes, which contain an unintentional, but systematic sample of presettlement trees. 12,637 witness trees were recorded and geo-referenced from the surveys covering Escambia and Covington counties, Alabama. Cluster analysis was used to derive four witness tree communities including; the pine dominated community, hardwood community, mixed pine-oak community and bay community. Environmental variables, soil suborder, slope, and distance from water, were sampled in a GIS on an individual witness tree basis. Environmental variables were tested for association with witness tree communities using multinomial logistic regression. Each environmental independent variable was found to be important in the distribution of witness tree communities.

The distribution of witness tree communities with respect to environmental variables, coupled with modern knowledge of these systems, pointed to fire as important in shaping presettlement forests. Specifically, the pine dominated and mixed pine-oak communities are fire maintained communities. This notion was further supported by bearing distance and surveyor qualitative descriptions. In an effort to ascertain the ignition source for presettlement fire, archeological information was gathered regarding Native American settlement prior to the surveys. Knowledge of Native American settlement, combined with an understanding of the history of the region, yielded the conclusion that lightning was the primary presettlement ignition source prior to the surveying of the study area.

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INTRODUCTION

Although the Southeast was not devoid of human populations prior to European settlement, the rate of land use change introduced by Western cultures has had a comparatively dramatic impact (Cowdrey 1983). In light of these changes brought about by European settlement, and the rate at which they occurred, most evidence of presettlement ecological systems was lost either through logging or the clearing of land for agriculture (Cowdrey 1983, Frost 1993). In addition, Western cultures, often driven by market demands, had their own ideas of how to manage natural resources, resulting in alterations to longstanding ecological mechanisms, such as fire in the Southeast (Cowdrey 1983). Because of the massive landscape changes following European settlement, efforts to gain information regarding presettlement vegetation are important.

The importance of historic information regarding presettlement landscapes rests primarily with its ability to educate scientists and the public concerning the impact of subsequent alterations of the land. More specifically, this knowledge can serve as a baseline from which to study how European settlement has impacted the abundance and distribution of plant species and communities across the landscape. Additionally, information gained can be used to infer which land use practices are responsible for change. Understanding the repercussions of modern land use has the potential to inform modern management prescriptions. Along the same lines, information on presettlement forests provides insight into the historic range of variability for a given system and may provide insight as to where modern landscapes fall within this range (Swetnam et al. 1999).

One valuable source of information regarding presettlement forests is witness (bearing) tree information taken from early land surveys. Although early surveyors used witness trees as a means of marking the land for sale, unintentionally the data has specific advantages as a sample of presettlement forests. Advantages over other sources of information in regards to presettlement forests include; a general lack of bias, information on abundance of species, and systematic data collection allowing for reconstruction of species or community distributions (Bourdo 1956). The majority of research presented has been conducted using witness tree data from the General Land Office public land surveys. In some cases other survey systems have been utilized (metes and bounds and land lottery surveys), however the overwhelming majority of studies have used GLO surveys. Researcher preference for GLO data is a direct result of their relative standardization and acceptance as a quantitative source of presettlement ecological data (Batek et al. 1999, Black et al. 2002).

Reconstructions of presettlement forests have been limited in the southeastern United States in large measure because the original 13 colonies were surveyed with less reliable systems than the GLO surveys. As a southeastern state, Alabama is an exception because it was surveyed by the GLO public lands survey system. However, this source of presettlement ecological data has been largely untapped by researchers. As evidence of the underutilization of these data, studies conducted in Alabama were never concentrated in the Lower Coastal Plain, as is the case with the chosen study area (Jones and Patton 1966, Rankin and Davis 1971, Black et al. 2002).

The primary data source for this study is GLO public land survey field notes for Escambia and Covington counties, Alabama (Appendix A.1). These surveys were conducted between 1820-1846, prior to widespread European settlement in the area (Black et al. 2002, Frost 1993, Ward 1991). The survey system divided the land into square townships covering 36 square miles (Appendix A.2). Townships were further divided into 36, 1 square mile sections. Typically, four witness trees were recorded at each section corner and two witness trees recorded halfway between each section corner. The two trees located at each half mile are said to be located at the "quarter-corners." The field note data also provides specific information regarding the location of witness trees. This information includes the distance from the section corner or quarter-corner to the witness tree and the direction to the witness tree. For the duration of this study, distance to the witness tree will be referred to as "bearing distance", while direction to the witness tree will be deemed "bearing."

Study Area: Physiographic Characteristics and Climate

The study site is Escambia and Covington counties located in south central Alabama. The study area falls entirely within the coastal plain physiographic province and the general forest type is southeastern pine forest (Fenneman 1938). The region is further divided into four distinct belts within the eastern Gulf coastal plain including; Southern Pine Hills, Dougherty Plain, Buhrstone Cuesta, and the Southern Red Hills (Fenneman 1938).

The soils in the Southern Pine Hills are generally sandy and porous with an underlying Citronelle formation. This belt describes nearly all of Escambia County and the southern third of Covington County (Fenneman 1938). The Dougherty Plain describes the eastern half of southern Escambia County (Fenneman 1938). The Dougherty Plain is an almost entirely flat limestone region with noticeable shallow depressions or sinks (Fenneman 1938). The Burhstone Cuesta belt extends into central Covington County and is characterized by rolling hills (Fenneman 1938). This belt is less than 10 miles wide throughout the study site. Finally, the northern third of Covington County is part of the Southern Red Hills belt (Fenneman 1938). These hills rise several hundred feet above the adjacent flat lands and contain characteristic broad valley floors (Fenneman 1938).

The topography in Escambia County ranges from level to moderately steep. The majority of the relief throughout the county is only gently sloping, and primarily occurs along streams and rivers (Mattox 1979). The elevation ranges from 19.8 meters above sea level to 105.1 meters above sea level (Mattox 1979). Elevation in Covington County ranges from 30.5 meters above sea level up to 137.2 meters above sea level (Cotton 1984). Much like Escambia County, ridge tops in Covington County are broad and gently sloping. Steeper slopes are commonly associated with drainage ways (Cotton 1984).

The climate for both counties is primarily dictated by the moist tropical air from the Gulf of Mexico. Annual precipitation amounts for the two counties are very similar with the average yearly rainfall in Escambia County 155.7 centimeters and 148.6 centimeters in Covington County (Mattox 1979, Cotton 1984). In the summer, thunderstorms are primarily responsible for the rainfall, and it is estimated that thunderstorms impact the two county study area approximately half of all summer days (Mattox 1979, Cotton 1984). In the late summer and early autumn months the region is periodically impacted by tropical depressions or hurricanes from the Gulf (Mattox 1979, Cotton 1984).

The two counties have temperate climates which border on subtropical. The average daily maximum temperature for the two counties is approximately 24° C, while the average daily low temperature is around 10° C (Mattox 1979, Cotton 1984). Summers are hot, with the average daily maximum temperature above 32° C in June, July and August (Mattox 1979, Cotton 1984). Winters are mild with only approximately 45 days in the year experiencing a temperature below 0° C (Mattox 1979, Cotton 1984).

Study Area: Knowledge of Presettlement Forests

Although the presettlement forests of Escambia and Covington counties have never been addressed specifically, there are a variety of sources which can provide general impressions. These sources include historical reconstructions, anecdotal evidence from early explorers, and modern impressions of species site characteristics. Although all worthy of review, each of these sources has limited applicability to our objectives because of their general nature or inherent bias.

Frost (1993), combining data from the Census of Agriculture and early state maps describes the presettlement forests of the Southeastern U.S., with specific concentration on longleaf pine (*Pinus palustris* Mill). According to Frost (1993), South Alabama would have been dominated by a longleaf pine/wiregrass and longleaf pine/bluestem community. More specifically, the study area would be characterized by a primarily longleaf pine overstory and an understory dominated by wiregrass or bluestem grasses. A diverse set of upland habitats including savannahs, flatwoods, and sandhills are included in this community in which longleaf pine was the “prevailing growth” (Frost 1993). Although the bulk of study region is described as longleaf dominated, northernmost Covington County is characterized as a transition area, exhibiting a mixture of longleaf pine, shortleaf pine, loblolly pine and hardwoods (Frost 1993). In the Gulf coastal states, these transitional areas were further defined as typically an equal proportion of longleaf pine and hardwood species (Frost 1993).

Information regarding presettlement species distribution can also be ascertained from the work of early twentieth century botanists. One such source is Roland M. Harper’s (1914) book the “Economic Botany of Alabama.” In compiling his descriptions, Harper visited every county in Alabama by the fall of 1906. This resource also roughly maps the distribution of shrubs and trees as well as soil fertility, natural regions, mean annual temperature, and seasonal rainfall amounts. In similar fashion to Fenneman’s physiographic provinces, Harper (1914) separates Escambia and Covington counties into four distinct natural regions including Southern Pine Hills, Eastern Red Hills, a Lime Sink region, and Lime Hills. He reported the Southern Pine Hills as covering nearly all of Escambia County and roughly 50% of Covington County. The extreme northeast corner of Escambia County is split between the Lime Sink region and Lime Hills (Harper 1914). These two regions also make up relatively small portions of central Covington County, while the northern half of the county is described as Eastern Red Hills (Harper 1914).

Harper’s book also offers specific information on an individual species basis. The distribution of longleaf pine within the Southern Pine Hills portion of the study area is described as “ubiquitous except in swamps, etc. and constituting about three-fourths of the forest." Longleaf was deemed "common" on upland sites in the Red Hills region and dominant in the Lime Sink region (Harper 1914). Harper observed longleaf pine as "scattered on poorer soils" within the Lime Hills natural region (1914).

By the early 1900's the study region had experienced widespread logging and agricultural use (Frost 1993). Although generally well regarded, Harper's estimates of distribution and abundance must be approached with caution; especially given the accelerated pace of land use change during the period (Frost 1993, Schwartz 1994). Given the quantitative, systematic nature of witness tree records, they are an ideal data source with which to validate other impressions of presettlement vegetation.

Another potential source of information regarding presettlement forests is known contemporary vegetation patterns. More specifically, there have been numerous efforts to describe the preferred and likely habitats for endemic tree species and communities of the southeast (Barrett 1980, USDA Forest Service 1990, Christensen 2000). One could roughly recreate presettlement vegetation on the basis of these likely site characteristics. This approach, however, is inherently flawed given the bias in modern notions of habitat preferences. These biases are unavoidable because of the considerable impact of humans on the distribution of species. For example, significant acreage, which was formerly longleaf dominated was cut over, and eventually converted to other pines (Sternitzke 1963). In addition to agricultural and timber land use, the impact of years of fire suppression have produced profound impacts on the soil, and thus may also bias contemporary notions of species habitat preferences (Garren 1943).

Much like contemporary habitat descriptions, historic descriptions, while supplying valuable information, are potentially biased. For example, when interpreting historical evidence one must be wary of a source's perspective, background, and motives (Egan and Howell 2001). There are several descriptions of the study area prior to widespread European settlement. From 1814-1815, during the Creek War, Davy Crockett traveled through the study region. He offered the following brief description:

> "When we marched from Fort Montgomery, we went some distance back towards Pensacola; then we turned to the left [Going south, they turned East into the study site], and passed through a poor piny country, till we reached the Scamby river [Escambia River] (Shackford and Folmsbee 1973)."

In addition to Davy Crockett, early naturalist William Bartram offers this description taken from his travel from the Tallapoosa River to current day Mobile, Alabama. Bartram (1791) provides this description immediately after crossing the Escambia River (spelled Schambe by Bartram):

> "…not unlike the low countries of Carolina; it is in fact one vast flat grassy savannah and Cane meadows, intersected or variously scrolled over with narrow forest and groves, on the bank of creeks and rivulets, or hommocks and swamps at their sources; with long leaved pines, scatteringly planted, amongst the grass; and on the high sandy knolls and swelling ridges."

The three data sources discussed above; retrospective environmental histories, contemporary knowledge of species habitat preferences, and early botanist and explorer descriptions all contribute to a rough idea of the presettlement vegetation of Escambia and Covington counties. Even the synthesis of these sources leaves many essential questions regarding the presettlement forests unanswered. Although they imply a pine dominated forest, they do not provide information on the degree of dominance in the region and which species of pine were responsible for this dominance. Further, the early explorers and travelers (like Bartram and Crockett), only left brief descriptions of a portion of the study area; not a survey of the entire two county region. This makes it difficult to extrapolate these early observations beyond the limited portion of the study area in which they visited. In addition, descriptions offered by contemporary ecologists or post-settlement botanists may be unreliable in that they are describing vegetation assemblages that may or may not have existed prior to European land use.

Study Area: Presettlement Disturbance Regimes

Fire as an important ecological factor affecting coastal plain vegetation has been recognized by many (Garren 1943, Croker 1969, Peet and Allard 1993, Glitzenstein et al. 1995). The importance of fire in South Alabama is largely a result of its known association with the historically dominant longleaf pine. This connection can be partly attributed to the coinciding decline in longleaf pine communities with the onset of fire suppression in the early 20th century (Frost 1993, Peet and Allard 1993, Croker 1969).

The connection between longleaf pine and fire is further supported by the successional changes which take place in a Coastal Plain community given fire exclusion. Specifically, without chronic low intensity fires, longleaf pine dominated communities are invaded by hardwoods and other pines, leading to eventual replacement of longleaf pine (Garren 1943, Gilliam and Platt 1999). Put simply, without fire, longleaf loses its competitive advantage in the Southeast Coastal Plain. The fire tolerance of longleaf pine is a result of several traits including; early development of thick bark, large buds with high heat capacity, buds protected by a sheaf of needles, and a bolting stage as juveniles, which quickly raises the terminal bud above surface fire flames (Grace et al. 2000).

In fact, the regeneration of longleaf pine depends on fire (Heyward 1939, Gilliam and Platt 1999). Fire exposes the mineral soil and diminishes other vegetation which in turn, aides in the establishment of longleaf and the growth of juveniles (Gilliam and Platt 1999). Finally, fire helps control the brownspot needle blight (*Scirrhia aricola*) which attacks longleaf pine in the grass stage and can eventually kill the tree.

It has been hypothesized that fire has been a natural force affecting longleaf pine dominated communities over evolutionary periods of time (Mutch 1970). This hypothesis is supported by the fact that a close relationship exists between fire and longleaf as well as between fire and typical vegetative associates of longleaf communities (Mutch 1970, Gilliam and Platt 1999). It has been shown that the herbaceous groundcover of longleaf communities and typical understory woody vegetation are both extremely flammable (Grace et al. 2000). Further, it has been shown that the proper management of faunal components of longleaf pine communities is dependent upon frequent fire (Engstrom 1993, Guyer and Bailey 1993, Folkerts et al. 1993). The strong relationship between fire and multiple components of a longleaf pine ecosystem, point to the long-standing importance of fire in this ecosystem, and thus, South Alabama.

Although the importance of presettlement fire in the Southeastern Coastal Plain is understood, the source of ignition, whether anthropogenic or lightning, has not been clearly defined. Specifically, the literature provides no clear answers in terms of the relative importance of lightning ignitions versus Native American fire (Martin 1973). Modern studies of Native American land use emphasize the modern concept of a presettlement cultural landscape (Hammet 1992, Wall Kimmerer and Kanawha Lake 2001). In other words, these studies run counter to the early concept of the “forest primeval" prior to European influence (Martin 1973, Kretch 1999). In addition, scholars agree that Southeastern Indians routinely used fire in the manipulation of their environment (Hudson 1976, Foster 2001). At the same time however, Escambia and Covington counties experience some of the highest lightning flash frequencies in the United States (Price et al. 2001). Clearly, the study area has the confounding factors of frequent lightning and Native American use of fire, making the source of presettlement ignitions difficult to discern (Komarek 1964, Hammet 1992, Kretch 1999, Schwartz 1994).

Utility of Witness Tree Data

In addressing many of these unknowns regarding presettlement forests in Escambia and Covington counties, GLO witness tree data is an invaluable primary data source. Previous witness tree studies have been successful in tackling a broad range of questions regarding presettlement vegetation. This data source has been used to address the relative abundance of species, to define presettlement forests communities, and to produce maps of reconstructed presettlement forests (Black et al. 2002, Schwartz 1994, Whitney 1982). Many studies have successfully defined relationships between species and site characteristics like soils or physiographic attributes (Batek et al. 1999, Brugam and Patterson 1996, Black et al. 2002).

In several studies, witness tree data has served as a baseline ecological condition from which researchers have embarked on temporal studies of land use change (Cowell 1998, Hall et al. 2002). In general, these studies have incorporated additional data sources to address more complex questions. Outputs have yielded results regarding the impact of changed disturbance regimes, trends regarding European land use, as well as inferences concerning the impact of Native American land use. For example, Cowell (1998) compared the species composition of modern secondary successional forests with presettlement forests, and attributed a reduction in fire tolerant species to the policy of fire suppression. A study conducted in the Missouri Ozarks, combined witness tree data, fire scar data, and general historical data, to document the role of presettlement fire and to suggest Native Americans as the dominant ignition source (Batek et al. 1999). Similarly, Foster et al. (2004) combined archaeological evidence of Native American settlement with witness tree data to delineate patterns of species distribution in relation to settlement.

Given the need for more information regarding presettlement Gulf Coastal Plain forests, the availability of GLO public lands survey data, and lingering questions regarding the source of presettlement fire, the following study objectives were developed:

Study Objectives

1. Critically assess the methods used in previous analyses of witness tree data and compare these methods to those used in this study.
2. Describe the presettlement forests of Escambia and Covington counties, Alabama with specific emphasis on presenting species abundance, deriving a course classification of witness trees, and analyzing the relationship between witness tree communities and selected environmental variables.
3. Provide evidence of considerable open, fire maintained presettlement forests and address the relative role of lightning and anthropogenic ignitions in sustaining this landscape.

Study objectives were designed to explore the methods typically undergone in witness tree analysis, address weaknesses in our current knowledge of presettlement forests in South Alabama, and to tackle questions of interest regarding presettement disturbance regimes. There are two primary goals for chapter one of this thesis. First, this chapter will provide details regarding the methods undertaken in this study. Secondly, chapter one will summarize the methods used in previous works with witness tree data. This section should address some of the weaknesses and assumptions underlying any witness tree study. A critical review of witness tree methods should clarify limitations of results derived from these data and provide guidelines for future use of witness tree data.

Because information is lacking regarding presettlement South Alabama forests, objective two is needed to fill this knowledge gap. Information regarding species abundance, classification of communities, and relationships with environmental variables will provide a basis from which to support or refute other notions of presettlement forests. In addition, other tasks associated with objective two include producing map outputs for each witness tree community and the generation of area estimates for each witness tree community. This information could be an important resource for land managers, interested in knowing baseline conditions prior to undergoing restoration efforts. Specifically, outputs may further support restoration efforts of longleaf pine ecosystems, which have suffered considerable decline in the Southeast Coastal Plain (Frost 1993).

Finally, objective three provides an opportunity to address a question of interest regarding presettlement forests specific to this study area. In particular, this objective is intended to shed light on the presettlement forest structure. Further, if the forest exhibits a characteristic “open” structure, what role did presttlement disturbance play in maintaining this structure?

This thesis is organized in a manner corresponding to the order of listed objectives above, beginning with an exploration of methods; including rational for the methods used in this study and thoughts regarding optimal use of this data source. In the next chapter, model results, describing relationships between environmental variables and witness tree communities, are presented and discussed. Chapter Two is followed by an attempt to extend the interpretation of witness tree data. Chapter Three incorporates additional qualitative and quantitative survey data, with archaeological data, in order to address the ignition source for presettlement fire. Finally, the results of this thesis will be summarized and discussed with respect to their potential management implications.

CHAPTER ONE

HISTORICAL ECOLOGY USING WITNESS TREE DATA: A METHODOLOGICAL REVIEW

Introduction

Witness trees or bearing trees have been used in a variety of fashions to describe the nature of forests preceding large scale European influence. Many studies have successfully defined relationships between species and site characteristics like soils or other physiographic attributes (Batek et al. 1999, Brugam and Patterson 1996, Black et al. 2002). In addition, this data source has been used to address the relative abundance of species, to define presettlement forest communities, and to produce maps of reconstructed presettlement forests (Black et al. 2002, Schwartz 1994). In several studies, witness tree data have served as a baseline ecological condition from which researchers have embarked on temporal studies of land use change (Cowell 1998, Hall et al. 2002). Outputs have yielded results regarding the impact of changed disturbance regimes, trends regarding European land use, as well as inferences concerning the impact of Native American land use.

The majority of this research has been conducted using witness tree data from the General Land Office public land surveys. In some cases, other survey systems such as metes and bounds, land lottery surveys, or town proprietor surveys are used; however the overwhelming majority of studies have used GLO surveys. Researcher preference for GLO data is a direct result of their relative standardization and acceptance as a quantitative source of presettlement ecological data. Despite the general acceptance of this data source, the records are not devoid of problems. Potential difficulties with GLO records as ecological data include; surveyor bias towards certain species, surveyor fraud, inaccurate tree identification, inconsistent tree identification, difficulty discerning common names, and failure to identify to species (Bourdo 1956). With the acknowledgment of some of these difficulties, GLO witness tree data are still used because they represent a systematic, although unintentional source of information on presettlement tree distributions (Bourdo 1956, Black et al. 2002, Schwartz 1994).

Despite the extensive use of witness trees in describing presettlement forests, there has been little discussion regarding appropriate methods for analyzing these data. Delcourt and Delcourt (1996) discussed presettlement mapping efforts at length; however, their analysis was geared towards understanding an optimal grain of resolution for the use of landscape metrics. Witness tree analyses in general have lacked a complete review of methods which are paramount to the readers understanding of assumptions present in any witness tree analysis.

The goal of this chapter is to provide a critical review of the methods used in describing presettlement forests with witness tree data. Because witness trees have been used to describe a variety of systems in the United States, comparisons of methodologies become difficult because of the varying complexities and functioning of these ecological systems. In other words, in many cases these systems provide varying processes of interest and these differences may drive the ways in which witness tree data should be used.

The use of witness tree data in describing and reconstructing presettlement forests involves a series of steps that have been repeated in the literature. These steps include:

1. Geo-referencing witness tree data.
2. Analyzing the utility of witness tree surveys as a source of ecological data.
3. The decision to group species or analyze on a species basis.
4. Assessing relationships between species and environmental site characteristics.
5. The production of map outputs.

This chapter will cover two primary objectives. First, the methods used in this study will be compared with those used by other witness tree studies with respect to the five primary steps identified. In comparing the methods, I will attempt to identify the reasons behind these varying methods. Potential reasons for inconsistent methods include differences in the survey source of witness tree data, varying complexities of the systems described, differing research goals, and advances in GIS technologies. The second major objective for this chapter is to provide some guidelines for the use of witness tree data in historical ecology. Included in the guidelines will be a detailed discussion of the scale related assumptions incumbent upon any witness tree analysis.

Geo-referencing Witness Trees

The first step required for virtually any witness tree analysis is to geo-reference the witness tree data points. Review of witness tree studies has revealed significant differences among studies in the effort to incorporate all spatial information available for geo-referencing. Specifically, some researchers have incorporated specific information regarding witness tree location, such as bearing and bearing distance, while others have not used these data (Grimm 1984, Schwartz 1994, Batek et al. 1999, Barrett et al. 1995). The decision to incorporate such data in geo-referencing witness trees has generally been constrained by the survey data source and the availability of needed technologies. As I will discuss later in this chapter, the impacts of geo-referencing methods may or may not be important in subsequent analysis steps.

Witness tree studies located in New England and the Allegheny Plateau of Pennsylvania are examples of studies in which geo-referencing efforts were controlled by the data source (Cogbill et al. 2002, Whitney 1990). In each study, the source witness tree data was not General Land Office surveys, but rather town proprietor surveys and early private land company surveys (Cogbill et al. 2002, Whitney 1990). Compass bearing and bearing distance were either not included in the surveys or not used by the researcher. In Whitney’s work (1990), corner locations were traced according to surveyor description and marked on USGS topographic maps. The identified witness tree was given the generalized location of the tract corner. Presumably as a result of the limitations in the town proprietor surveys of New England, Cogbill et al. (2002)

generalized all witness tree information to a point in the central latitude and longitude of the associated town.

In contrast to these studies which were limited by the data source, several studies using detailed GLO surveys have failed to incorporate the spatial data regarding witness tree locations (Grimm 1984, Schwartz 1994, White and Mladenoff 1994, Whitney 1982). In these cases the term "transcribe" was used to describe the manual method of spatially referencing witness trees with respect to modern topographic maps. The modern topographic maps still maintain the township, range, and section lines, and these lines serve as the reference for locating witness trees. Although section and quarter-sections can be accurately located using a topographic map, this method still sacrifices the potential accuracy gained by incorporating compass bearing and bearing distance. In other words, despite the fact that groups of witness trees at section corner and quarter corners are differentiated in field notes by bearing and bearing distance, all associated witness trees are attributed to the generalized section or quarter-corner location.

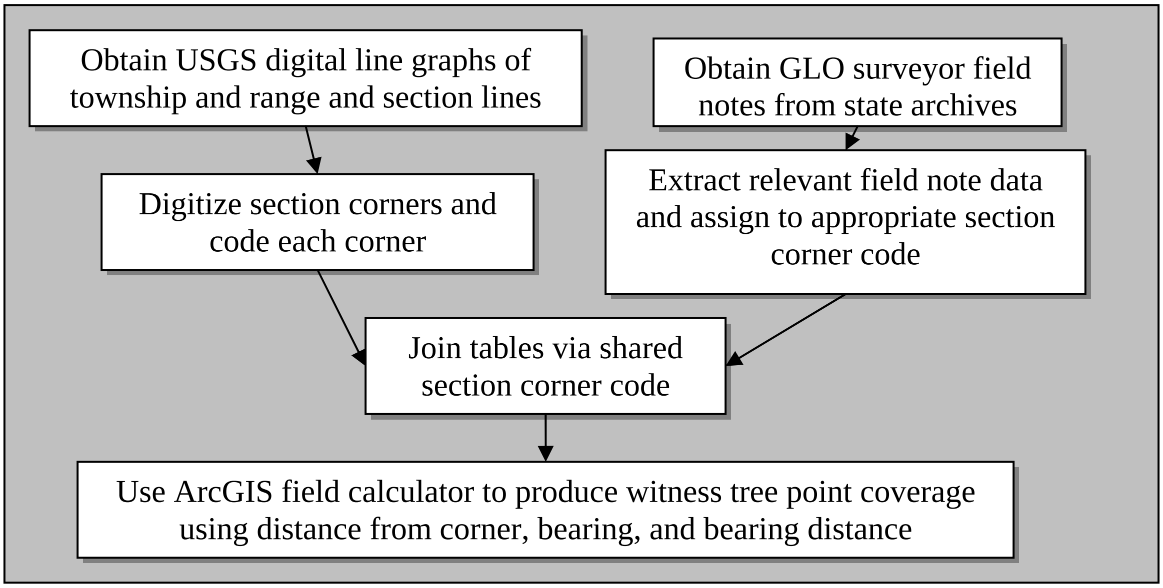
Again, reduced accuracy in geo-referencing witness tree data may or may not impact subsequent analysis; depending on the scale of future analyses. In fact, in some cases, researchers may have chosen not to incorporate bearing and bearing distance because it would not impact their ability to delineate course associations between witness trees and environmental factors.

More recently conducted witness tree studies have incorporated compass bearing and bearing distance in an automated fashion; in the attempt to more accurately depict the location of presettlement witness trees (Batek et al. 1999, Barrett et al. 1995). In each of these studies, GLO surveyor field notes were the data source, and the data included information on bearing and bearing distance to witness trees (Batek et al. 1999, Barrett et al. 1995). In each study, modern representations of the survey section corners served as the starting point from which field note data regarding witness tree location was used (Batek et al. 1999, Barrett et al. 1995). Few details have been provided in the literature in terms of how spatial information in survey field notes has been integrated into the geo-referencing of witness trees (Batek et al. 1999, Barrett et al. 1995).

Geo-referencing Witness Trees: South Alabama

General Land Office surveyor field notes served as the source data for this study, and as a result every effort was made to use all the spatial information provided to accurately represent the presettlement location of witness trees.

Figure 1.1 Processing sequence for geo-referencing witness trees, Escambia and Covington counties, Alabama



As figure 1.1 illustrates, the most important step in this process was to join the geo-referenced section corners from USGS 1:24,000 digital line graphs of townships range, and section lines with the information from the surveyor field notes. Both the digitized section corners and the field note data were coded by section corner (figure A.3). The ArcGIS extension “xtools” was used to determine the coordinates of each digitized section corner. From the section corner coordinates, the location of witness trees was derived using the distance from the corner of origin, compass bearing, and bearing distance. All distances were converted from the surveyor distances in chains and links into meters using the conversions given by Ward (1991). For each direction of surveyor movement, two equations were used to derive a final x and y coordinate for each witness tree (Equations B.1).

Although all spatial information available was incorporated in geo-referencing witness trees in this study, the ability to locate witness trees accurately is still constrained by several factors. First, in using surveyor distances, researchers are assuming that surveyor measurements are accurate. One must keep in mind that the measurements were conducted by dragging a chain through the forest. Obstacles to this procedure were common and had an affect on the accuracy of these measurements (Stewart 1935). Further, the corner of origin is over ½ mile to the quarter corner trees and 1 mile to the corner trees. As a result the accuracy our witness tree locations is determined both by the surveyor’s ability to measure these distances and his ability to maintain a straight course north, south, east or west. Finally, estimates of witness tree location are only as good as the source information regarding the section corner of origin.

The methods chosen for the geo-referencing of witness tree data are important with respect to two issues of experimental design. First, as shown in this section, the data in many cases dictates the method of geo-referencing witness tree data. If surveys other than GLO surveys are used, then data on compass bearing and bearing distance may not be available. When compass bearing and bearing distance are available, researchers must decide whether these data should be incorporated based on their research goals. Of primary concern are scale issues. If defining associations between the witness tree data and relatively fine grain GIS datasets of environmental variables is the goal, then the researcher should seriously consider incorporating compass bearing and bearing distance in the locating witness trees. In sampling fine grain GIS datasets, bearing and bearing distance could potentially change the environmental value sampled for a given witness tree. If the researcher is attempting to examine witness tree distribution with environmental data sets of a broader spatial resolution, then improved witness tree location may be unnecessary. In most cases observed in the literature, researchers seem cognizant of these scale issues, and have analyzed their data accordingly.

Examination of Witness Tree Data as an Ecological Sample

Another important facet of any witness tree data analysis should be an examination of problems with the data as a source of ecological information. The cause of most of these problems stems from the simple fact that witness trees were selected by surveyors to aide the identification of a tract of land. With respect to most of these difficulties in the use of GLO surveys, there is little that the investigator can do to address these problems. The problem of fraud is only of primary importance if the surveys themselves have been fabricated. Obviously, it is the researcher's responsibility to filter out surveyor field notes or township maps that are fictitious (Bourdo 1956).

Much like the difficulty with surveyor fraud, the researcher has few options in the case of inaccurate tree identification. For the most part, the researcher must assume that the trees were properly named. Knowledge of the system in which you are working can be helpful however, as one may notice repetition of one common name, while another species, common today, is strangely absent (Black et al. 2002).

Two other relatively common problems regarding GLO survey data are the failure to identify to species and the difficulty deciphering surveyor script of common names. In most cases, non-specific common names have not been an impediment to witness tree analyses. For example, in two studies, non-specific common names like pine, have been analyzed like other more specific common names and then retrospectively discussed in terms of the habitat preferences of pine species (Black et al. 2002, Schwartz 1994). In instances in which common names could not be discerned or were unknown they have been typically removed prior to any sort of analysis (Schwartz 1994).

The issue of inconsistent witness tree records has been addressed in detail in a few studies, but generally ignored by the literature (Black et al.2002, Cowell 1995). Specifically, the inconsistency across townships and surveyors is of particular importance. The fact that the majority of witness tree studies have ignored this phenomenon is alarming for two reasons: (1) inconsistency could cause significant distortion of species abundances and any subsequent analysis, and (2) most witness tree study sites encompass multiple townships and therefore were probably conducted by multiple surveyors. The likelihood of these inconsistencies is increased with larger study areas and greater number of contributing surveyors. The problem of inconsistency among surveyors was mentioned by Whitney (1986), but has only been more recently specifically addressed. The primary recommendation is to examine individual common name distribution across township lines to identify abrupt changes in abundances (Black et al. 2002, Cowell 1995). When these abrupt changes are identified researchers have recommended combining the common names in question (Black et al. 2002).

The problem of surveyor bias in using GLO surveys has received considerable attention in the literature. Surveyor bias can be an issue with several aspects of the data including bias towards trees of a particular size or species and surveyor aversion to rugged or unpleasant habitats (Bourdo 1956, Black et al 2002). Despite the fact that surveyor bias is considered the most serious potential problem with survey records as ecological data, there is no established method for assessing these concerns (Bourdo 1956, Whitney 1982). The surveying instructions themselves encourage surveyor bias for more durable long-lived trees (Bourdo 1956). So, the question is not whether bias exists in surveys, but rather whether this bias is important or significant (Bourdo 1956).

The most comprehensive review of bias problems was produced by Bourdo (1956). This study encouraged the use chi-square tests to investigate bias by quadrant and bearing distance (Bourdo 1956). In cases when bearing distance is not available, it was suggested that compiling and comparing qualitative descriptions with witness tree abundances could address surveyor bias (Lorimer 1977). In general, these tests for bias were never fully incorporated into most witness tree studies because they are based on the unrealistic assumption that witness trees are a random sample (Grimm 1984).

Examination of Witness Tree Data as an Ecological Sample: South Alabama

Much like other studies, there were no revelations regarding how to approach the potential problems of surveyor fraud or inaccurate tree identification in South Alabama. A comprehensive study of Covington County public land surveys does not mention fraud, only a need to resurvey some townships because a fire at the land office destroyed some field notes (Ward 1991). The fire explains the fact that township 6N, range 15E was completed at a significantly later date than all other townships (Ward 1991). L.O. Stewart's (1935) review of the public land surveys discusses major cases of fraud in early surveys, but makes no mention of such problems within Covington and Escambia counties. This work documents cases of fraud in the West from 1875-1890, but in general endorses the validity of earlier eastern public land surveys. (Stewart 1935). The assumption was made that the common names listed by surveyors relate properly to one or several potential species (table 2.1).

Although major surveyor fraud can be effectively ruled out in Escambia and Covington counties, the field note data did present some problems regarding the common names given by the surveyors. In cases in which their associated species could not be determined, witness trees were grouped into an unknown category. Although uncommon in these surveys, there were also some instances when the witness tree names were deemed illegible (table 2.1). Another difficulty encountered, was in differentiating the surveyor script of the common name beech and birch. Out of necessity, these two common names were grouped into a beech/birch category. It is worth noting that my interpretation of the script points to beech being the far more common of the two names.

One of the most troubling problems with surveys in Escambia and Covington counties is the lack of specificity in assigned common names. In particular, the surveys contain substantial records of the non-specific common names oak and pine (table 2.1). Some studies have approached this problem by grouping all species by genus, however, given the dominance of pine in my study area, it was determined that all specificity regarding common names should be maintained when possible (Cogbill et al. 2002). Like other studies, the likely species associated with the oaks and pines listed were addressed in my results, with discussion guided by relationships with environmental variables and modern concepts regarding species habitat preferences (Black et al. 2002, Schwartz 1994).

Inconsistencies across township and surveyor were assessed visually by township and by filtering the witness tree data by surveyor group. The term surveyor group is used because in a few cases more than one surveyor worked on a given township. Although examining species distribution visually can be helpful, I would argue that filtering the data by surveyor group is a more effective means of screening the data for inconsistencies (Black et al. 2002, Cowell 1995). Simply put, abrupt changes in witness tree abundance are a result of different biases or knowledge among surveyor groups, not because they are working in different townships. Abrupt changes were examined only for the 10 most commonly recorded witness trees, as abrupt changes for the smaller common name samples could be merely be a result of chance.

Several inconsistencies across surveyor groups were noted in the GLO data for Escambia and Covington counties. There were differences in the way in which oak species were handled by the surveyor groups. Some surveyor groups only recorded oak or blackjack oak, while other surveyor groups provided several common names for oak species (red oak, white oak, spanish oak, water oak, etc.), in addition to recording the general term oak. In the interest of maintaining information, common names were recorded as provided by the surveyor.

Another inconsistency occurring in the witness tree identification concerns the common name green bay. One surveyor group reported the common names green bay and bay, while all other surveyor groups only identified bay. The search for an associated species with the common name green bay was unsuccessful. For this reason, and because the majority of the surveyors were not attempting to differentiate bays, witness trees named green bay were grouped into the bay/green bay category.

The problem of surveyor bias was very difficult to evaluate in the GLO surveys for Escambia and Covington counties. In looking at witness tree common name abundances by surveyor group, the idea of bias towards a certain species is indirectly addressed. Because diameter information was not recorded in the Escambia and Covington county surveys, testing for equal distribution of witness trees across diameters classes was not possible. Further as previously noted, chi-square tests of abundance by quadrant are based on the assumption of a random sample throughout the study site (Grimm 1984). Further, testing the hypothesis that the nearest tree to a corner should occur with equal frequency in all quadrants would be troublesome because it could only be tested at quarter corners in which two trees were recorded. Tests for bias by landform were not conducted because of the regular distribution of our witness tree points. Some bias regarding wetland areas is clear in the surveys, as surveys would sometimes identify a wetland by name (creek, river, or swamp) without recording a witness tree.

In the attempt to ascertain the overall ecological utility of the witness tree data, a graph of surveyor sample size versus the number of common names recorded was constructed for the total witness tree sample (figure 1.2).

Figure 1.2. Number of witness tree common names identified by each surveyor group in Escambia and Covington counties, Alabama.

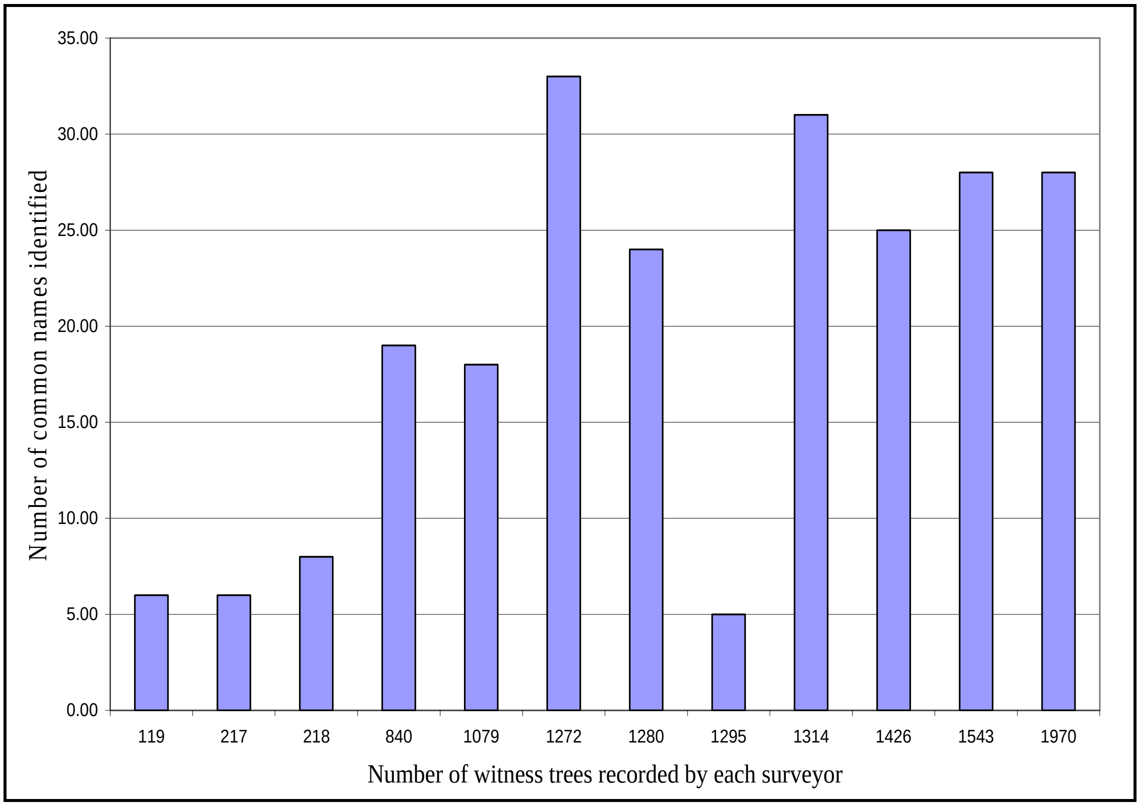


Figure 1.2 illustrates several things about the data as a whole. Although the graph is not a species-area curve, it is helpful to think of the data displayed in these terms. In viewing a typical species-area curve one would expect increased numbers of species as the area sampled is increased (Barbour et al. 1999). The information in figure 1.2 illustrates the increase in the number of common names recorded in relation to increasing witness tree sample size. This is similar to a species area curve in that the total witness

tree sample per surveyor is a direct indication of how much area was sampled by that surveyor. In general, the survey is performing as one would expect. In addition, it is noted that a relatively large number of different common names provided by surveyors points to a lack of bias in the data (Black and Abrams 2001).

There is one glaring exception to these trends, in which an unusually low diversity of common names was recorded by surveyor Simpson Harris. In recording 1295 witness trees, Mr. Harris only recorded 5 common names. Of these common names, pine comprised 98.92% of the total sample. This may point to some bias towards large and easily identifiable pines or the inability to identify a range of species. The locations of the townships surveyed by Mr. Harris, however, are in west and central Escambia County in which the topographic and soil variability is very low when compared to other portions of the study area. In addition, the townships surveyed by Harris lack any major water systems, which will be shown later to be strongly associated with areas of increased diversity of overstory tree species. Put simply, the characteristics of the area surveyed by Mr. Harris indicate that low diversity of tree species are likely a true sample of the region, rather than an artifact of surveyor bias.

Forest Community versus Species Analysis

In describing presettlement forest patterns, a common step taken by researchers using witness tree data was to attempt to classify forest communities or associations. The decision to classify or not was generally related to each investigator's research objectives. In some cases, studies attempted to define species-site relationships, while other works have been more interested in defining presettlement forest communities and describing the distribution of these communities with respect to environmental variables. I will argue, however, that the nature of the witness tree data should be considered in addition to researcher objectives in defining classification methods.

Before addressing the different approaches to classification in the literature, studies in which the researcher did not attempt to classify witness trees should be discussed. As noted previously, the main reason for not classifying was simply a difference in researcher goals and interests. In most studies of this nature, the researcher narrowed down the species (or common names) analyzed to only those which comprised an adequate sample size (Barrett et al. 1995, Black and Abrams 2001, Whitney 1986). The primary strength of this species approach is that it cuts out an intermediate step in any sort of analysis of associations between witness trees and environmental variables. In analyzing relationships between defined communities or associations, the researcher must be wary of the potential that, as a broader ecological group, derived communities may not be significantly associated with any environmental variables or that the classification itself is flawed.

The weaknesses of a species approach outweigh the noted positives. First, in working with species (or common names), the researcher's results are more exposed to the problems of surveyor bias and inconsistency than investigators working on a community basis (Maines and Mladenoff 2000). As previously noted, these concerns of surveyor bias and inconsistencies are significant. Secondly, in regions like South Alabama, in which one species (common name) is dominant across the landscape, surveyors may record only a few species of adequate sample size. This would limit the information gained in any analysis of species-site relationships.

When researchers have decided to classify witness trees into communities or associations, objective classification techniques have been most common (Black et al. 2001, Batek et al. 1999, Cogbill et al. 2002). Objective methods of defining presettlement forest communities based on witness trees include ordination techniques, cluster analysis, and GIS groupings based on species co-occurrences (Black et al. 2001, Batek et al. 1999, Grimm 1984, Cogbill et al. 2002, Cowell 1995). One exception to this rule of objectivity is a study in North Florida, in which broad associations were based on modern species habitat preferences and species associations in the witness tree data (Schwartz 1994). Although the outcome classification appears adequate in this study and the researcher did not attempt to define the relationships between these communities and environmental variables; this study is open to one important criticism. Specifically, why group presettlement witness trees based on habitat preferences or species associations which may not have been important or existent in presettlement times?

In their simplest sense, each of the objective methods of classification listed (ordination, clustering, GIS techniques) are a means of grouping the witness trees on the basis of co-occurrences. Or more specifically, the ordination and clustering techniques organize data on the basis of species abundance within samples (Gauch 1982). What constitutes a witness tree sample is defined by the researcher and can have a profound affect on any classification. Also acknowledged are the different algorithms used in the ordination and clustering techniques to be described. Discussion of these algorithmic distinctions is beyond the scope of this review of methods and external to its central purpose; to determine the most appropriate analyses of witness tree data.

In many cases ordination techniques have been used in witness tree studies to discern the dominant environmental gradients in the data (Cowell 1995, Black et al. 2002). In a study in east-central Alabama however, the ordination technique detrended correspondence analysis was used identify a perceived moisture gradient and to delineate communities of witness trees (Black et al. 2002). Classification of witness trees from this study was produced by examining the grouping of species in two-dimensional ordination space. In other words, the classification was derived by looking at the distribution of species with respect to the two dominant gradients (axes) in the data. The axes displayed by Black et al. (2002) explain a total of 6.3% of the variation in the data. This low percent variance associated with these two primary axes may be an artifact of the sampling of witness trees in a 1-km grid. While this sampling provides for easily produced map outputs, 1-km samples may not be an ecologically meaningful sample. With a 1-km grid derived sample, witness trees may have up to 0.8 km separating corner and quarter-corner witness trees. There is potential for extreme habitat variability within this sample, and therefore the trees grouped in a sample may have no clear relationship.

A second method of classification, executed entirely within a GIS, also potentially suffers from the lack of a spatially explicit sample. In this method a grid of 511 X 511 meter cells was used to resample probability surface maps for each species (Batek et al. 1999). Witness tree associations were defined based on the probability of each species falling within each grid cell (Batek et al. 1999). Again, much like the methods described by Black et al. (2002), samples of large spatial extent may not separate meaningful groups.

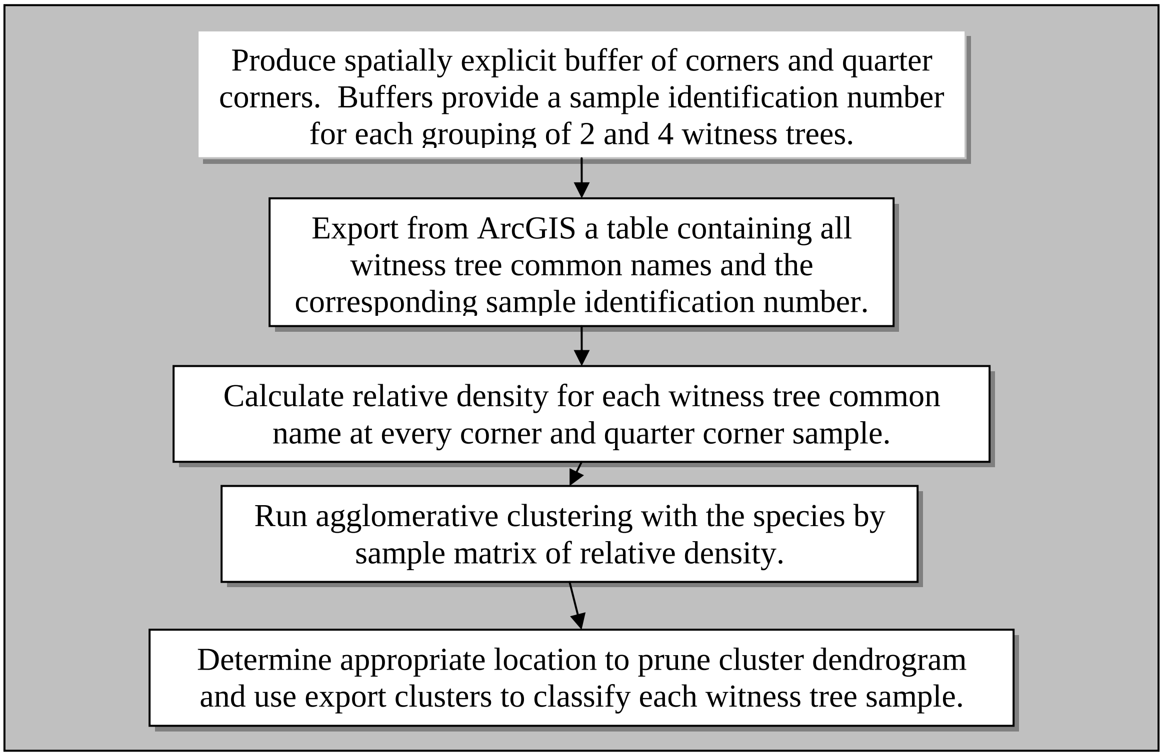
Hierarchical cluster analysis has also been used as a technique to classify witness trees (Cogbill et al. 2002). In this objective procedure, a series of clusters is produced by joining units which have a minimal between-group variance (Cogbill et al. 2002). The output dendrogram from cluster analysis provides the researcher with the advantage of a visual assessment of the hierarchy of defined clusters. Much like the previous methods described, the large scale sampling in this study may have hindered the creation of meaningful clusters. In this particular study, the lack of spatial information regarding witness tree location, forced the researcher to use each town as a sample (Cogbill et al. 2002).

Forest Community versus Species Analysis: South Alabama

Witness tree data from Escambia and Covington counties used in this study were classified using hierarchical cluster analysis. Cluster analysis was used to derive classes based on the matrix of samples by witness tree common name groupings. Cluster analysis is a commonly used procedure for grouping entities based on the homogeneity of a certain characteristic (Sharma 1996). In this study, the characteristic distinguishing the samples is relative density of common name groupings. Relative density was used to improve clustering and to allow the integration of differing sample sizes (McCune and Grace 2002).

Euclidean distance and Ward's linkage method were used for the cluster analysis (Cogbill et al. 2002, McCune and Grace 2002). Clustering begins with the formation of a similarity matrix. In this study, similarity is based on euclidean distance or the squared distance between two samples (Sharma 1996). The linkage of groups was determined using Ward's method, which adds samples to a cluster so that within cluster sum of squares is minimized (Sharma 1996). The pruning of the output dendrogram and the decision to choose four clusters was based on two factors. First, the percent information remaining as shown by the output dendrogram was consulted (McCune and Grace 2002). And secondly, four clusters were chosen based on their ecological interpretability.

Figure 1.3. Processing sequence required to produce witness tree communities through cluster analysis in Escambia and Covington counties Alabama.



Unlike other studies in which classification was used, the samples used for cluster analysis here were spatially explicit. Specifically, buffers were created within a GIS that established a unique sample number for each grouping of 4 trees at section corners and 2 trees at quarter-corners. The average bearing distance across all samples was 8.1 meters, which illustrates that these samples are more tightly defined than samples of a spatial extent of ½-square km or greater defined in other studies (Black et al. 2002, Batek et al. 1999).

The problem of varying sample size at the section corners (4) and quarter corners (2) was handled by calculating the relative density of each common name grouping at each sample. For example, a corner sample containing 2 post oaks and 2 pines would result in relative density of .50 for the post oak and pine common name grouping while all other common name groupings for the sample would have a relative density of 0. Relative density was used rather than abundance so that the section corner samples and quarter corner samples were equally weighted. In other words the above example of relative density of a section corner would be equivalent to a quarter-corner sample in which there was 1 post oak and 1 pine. The use of relative density allows for the use of both types of samples, while maintaining the extent to which samples are spatially explicit and thus ecologically meaningful.

The dendrogram produced by the agglomerative cluster analysis was pruned to produce four witness tree communities. Although based on different methods, a witness tree study describing similar habitats in northern Florida produced 3 broad communities and it was determined that more refined classification was difficult because of the small sample size at each corner and quarter corner (Schwartz 1994). Further evidence of a meaningful and interpretable classification, is the extent to which the species fall entirely or mainly into one community. The success of the classification in this regard is presented in chapter two (table 2.2). The output dendrogram provides a scale bar detailing the percent of information remaining as it relates to the clusters (McCune and

Grace 2002). With four clusters, the scale bar associated with the output dendrogram indicated that about 60 % of the information in the data was retained in this grouping (McCune and Grace 2002).

The decision to use hierarchical cluster analysis for classification was based on several factors. First, the overall dominance of pine within the study area contributed to the decision to classify. Because of the dominance of pine in these surveys, only a small number of additional species would have provided adequate sample size to analyze species-site relationships. Clustering provided four communities of adequate sample size for further analysis. Secondly, researcher objectives played an important role in the choice to classify witness trees. Of central interest to this study was describing the presettlement distribution of pine with respect to environmental variables. Clustering was helpful here in that it allocated a portion of the pine common name into all four clusters. Each of the four clusters has distinct relationships with environmental variables, allowing for the inferential discussion of the distribution of pine species across the landscape. Finally, the inconsistencies in our survey data also made classification a viable alternative to species analysis. The theory here is that these broader communities are less likely affected by inconsistencies across surveyor groups.

Environmental Site Relationships

A common goal in most witness tree studies is to define relationships between environmental variables and witness tree species or defined communities. Two facets of this step require review. First, the environmental variables chosen in analysis will be addressed. Of primary importance regarding these environmental variables is the researcher's rational for choosing environmental variables, and whether the scale of the chosen environmental variables is appropriate for defining relationships with witness trees. In addition, the statistical methods required for this work will be reviewed, with particular focus on the utility of outputs.

Past studies have successfully defined relationships between witness trees (by species or community) with a variety of environmental variables including; slope, aspect, elevation, topographic indexes, physiographic region, broad climatic patterns, as well as soil drainage, texture, parent material and soil series (Black and Abrams 2001; Black et al. 2002, Batek et al. 1999, Barrett et al. 1995, Cowell 1995, Grimm 1984, Whitney 1990). In most of these studies researchers have provided little in the way of an explanation regarding how environmental variables were chosen. In many cases, these environmental variables appear to have been chosen simply because of their availability for sampling within a GIS. This is not surprising as sampling environmental variables for presettlement data is inherently problematic. Researchers are limited to studying environmental factors that exhibit little change over time and those with available data on a landscape scale.

In some studies it appears that questions of scale have dictated which environmental variables are sampled and the way in which the data is sampled. In particular witness tree studies have commonly categorized fine grain GIS environmental data (DEM, slope, aspect of generally 30 m resolution) before sampling at witness tree locations (Cowell 1995, Black et al. 2002). The categorization of environmental data may be undertaken to allow for certain analysis, such as with contingency table analysis. Alternatively, these categories may have been produced to mitigate a lack of confidence in the method of witness tree geo-referencing. The logic here is that in categorizing fine scale environmental variables, a researcher may reduce the likelihood of assigning an incorrect environmental attribute to a given witness tree. Regardless of the motives for sampling environmental variables in a certain manner, some studies have made it clear that the accuracy of witness tree location should match the resolution and accuracy of the sampled environmental variables (Cogbill et al. 2002).

In addition to choosing environmental variables of appropriate scale, it can be inferred that these decisions are also made according to researcher knowledge of the system studied and the need to define a hierarchy of factors impacting vegetation distribution. In particular, researchers have worked to elucidate vegetation patterns in response to edaphic and topographic factors in order to clarify the impacts of presettlement disturbance regimes on forest communities (Whitney 1986, Cowell 1995). More specifically, researchers have worked to clarify the role of disturbance in dictating presettlement vegetation patterns by separating them from environmental factors operating at different spatial and temporal scales (Batek et al. 1999).

Although a variety of methods have been used to define relationships between witness tree distribution and environmental factors, the output information has been consistent. Ordination techniques constrained by environmental information, such as detrended conical correspondence analysis and canonical correspondence analysis, have been used sparingly to define the impact of environmental variables on species distribution (Batek et al. 1999, Cowell 1995). By far the most common method used to define associations between environmental variables and witness trees is contingency table analysis (Black et al. 2002, Black and Abrams 2001; Barrett et al. 1995, Whitney

1990). In this method, presence-absence tables are constructed with respect to each environmental variable. From these tables standardized residuals are calculated to determine a positive or negative association and the relative strength of this association. Both the ordination techniques and contingency table analysis provide insight into environmental associations or gradients and in some cases, their relative strength (Black et al. 2002, Gauch 1982).

Environmental Site Relationships: South Alabama

The choice of environmental variables examined in South Alabama stemmed from the consideration of a variety of factors. First, environmental variables sampled were chosen based on their availability in a GIS compatible format. Secondly, variables were chosen based on the degree to which they likely affect the distribution of these communities in South Alabama. Environmental independent variables within the model were also chosen in order to maintain model simplicity and interpretability. Finally, the choice of environmental independent variables was considered with respect to the multinomial logistic regression (MLR) model. In discussing MLR in this section, the focus will be restricted to understanding its outputs regarding the relationship between witness tree communities (dependent variable) and the chosen environmental independent variables.

The environmental independent variables sampled include soil suborder, slope, and distance from water. Thirty meter resolution raster data of soil suborder was derived from the State soil geographic database (USDA Natural Resources Conservation Service

1994) using the feature to raster function in Spatial Analyst. Options within Spatial Analyst were set so that cell size and extent matched the digital elevation model used.

Slope was derived from the USGS 1:24,000 digital elevation models using ArcGIS spatial analyst. Like the soil suborder raster data, cell size was set to 30 meters. The distance from water raster surface also derived in ArcGIS using the straight line function in the Spatial Analyst extension, with the output raster data set snapped to match the extent and cell size of the original digital elevation model. The source dataset for distance from water was USGS 1:24,000 hydrology coverage. Each of these surfaces were sampled using the ArcGIS script Gridspot producing an output file that contained environmental attribute values for each witness tree.

There are several studies which support the notion that relationships between soil characteristics and witness tree distribution can be defined (Barrett et al. 1995, Whitney 1986). Typically, these studies have focused on soil parent materials, texture, or even soil series. Soil suborder was used within the model, as opposed to soil series, because it captures most of the variability in soils across the study site, eases interpretation compared to using soils series, and roughly distinguishes upland from bottomland habitats (table 2.4). Additionally, soil order is divided into suborders partly on the basis of their differing importance to plant growth (Cotton 1984). Only the Udults contain a large number of component soil series and these component series contain only subtle differences (Cotton 1984, Mattox 1979). Finally, soil suborder was also chosen because each suborder has an adequate sample size. Smaller sample sizes associated with the use of soil series would have negatively affected the logistic regression outputs (Hosmer and Lemeshow 1989).

Continuous environmental independents included in the model are distance from water and slope. It was thought that distance from water as a variable would be indicative of several ecological conditions or processes affecting the presettlement distribution of established communities. Most importantly fire has been widely accepted as a dominant process involved in maintaining presettlement communities in the Southeastern Coastal Plain (Frost 1993, Glitzenstein et al. 1995). In these systems, it has been surmised that low intensity fires could burn vast areas of contiguous forests with the only significant presettlement fire break being water systems (Slocum et al. 2003). Distance from water also may also be related to soil characteristics, elevation, flood regime and potentially other factors impacting community distribution.

The association between slope and witness tree distribution has been addressed in many previous witness tree studies (Batek et al. 1999, Cowell 1995). In several cases, slope was combined with elevation and aspect to derive an index of moisture (Cowell 1995). Slope was considered in this study for its potential in delineating known coastal plain vegetation communities (Penfound 1952). Additionally, it was thought that slope may help identify sinks and depressions which are common through most of the study site (Cotton 1984). Because these depressions are highly related to specific forest communities, slope may be helpful in defining their distribution.

Multinomial logistic regression was used to address relationships between chosen environmental variables and derived witness tree communities. Logistic regression was chosen because the data contains a mixture of continuous and categorical variables and because the environmental independent variables do not satisfy the assumption of multivariate normality (Sharma 1996). In addition this technique is suitable for predicting discrete dichotomous dependents (Hosmer and Lemeshow 1989). The outputs from this technique, although more complex in interpretation, are similar to those gained in using contingency table analysis. In fact, with only one categorical independent, binomial logistic regression can be reduced to contingency table analysis (Sharma 1996, Hosmer and Lemeshow 1989).

In multinomial logistic regression, slope estimates or maximum likelihood estimates describe the relationship between the independent variable and the log odds of one dependent variable rather than the reference dependent variable (Sharma 1996). The role of the reference dependent variable is discussed in the next section. To aide in the interpretation of slope estimates, they are often converted to odds ratio estimates. This transformation is accomplished by taking the exponent of the output coefficient or slope estimates (Hosmer and Lemeshow 1989, Sharma 1996). The odds ratio estimate refers to the increase in odds of locating one dependent variable rather than the reference dependent variable, given the influence of the independent variable (Hosmer and Lemeshow 1989). So, an odds ratio of one means that the independent is having no effect, while an odds ratio greater than one increases the odds of finding the one dependent as opposed to the reference dependent (Sharma 1996). Odds are decreased with an odds ratio less than 1 (Sharma 1996). Interpretation of odds ratio estimates for continuous and categorical independents are slightly different and require some explanation.

With continuous independent variables (or covariates) the odds ratio estimate describes the effect of an increase in one unit of the independent variable (Hosmer and Lemeshow 1989). So, with our continuous independent variables distance from water, and slope; the odds ratio estimates describe the effect of an increase of 1 meter for distance from water and an increase in 1 degree slope. In order to further aid in interpretation, slope estimates presented in chapter 2 and the resulting odds ratio estimates were standardized.

The interpretation of odds ratio estimates for polytomous independents is more complex than that required with continuous covariates. Specifically, because soil suborder has four categories, interpretations of slope estimates or odds ratios require some explanation. In handling multiple categories, SAS Proc Logistic, used for data analysis, chooses the largest category and sets this category as the reference group (SAS Institute Inc. 2001, Hosmer and Lemeshow 1989). So, odds ratio estimates measure the impact of the presence of one category of the independent variable as opposed to the reference category of the independent variable (Hosmer and Lemeshow 1989).

Analysis Outputs

Although contingency table analysis provides easier interpretation of the impact of environmental independents, logistic regression provides outputs which can be mapped within a GIS (Bailey et al. 2003). The advantages of using logistic regression are in its ability to predict probabilities of locating a given community based on environmental independent variables (Bailey et al. 2003). Before describing these methods and the utility of these outputs, it is important to briefly describe the methods used in previous witness tree studies. Specifically, a critical review of map outputs derived from witness tree studies is needed.

Typically, attempts to map presettlement forests have been constrained by the sparseness of witness tree samples across the landscape (Brown 1998). Researchers have addressed this impediment to mapping presettlement forests in a couple different ways. One approach has been to develop a grid sampling pattern across the entire study area. In this method, witness trees are classified based on their occurrence within samples and each grid cell is depicted according to the classification scheme (Batek et al. 1999, Black et al. 2002). Methods of classification in these studies differ, but the maps produced are similar. Maps produced through this method suffer from low resolution and discrete boundaries between forest types. The large grain size used in these maps is appropriate in this type of analysis because of the broadly spaced witness tree samples (Delcourt and Delcourt 1996). These maps however, are often an unrealistic representation of presettlement forest in that they depict abrupt changes in forest types. This masks potential ecotones and implies that vegetation is distributed in discrete units rather acknowledging Gleason’s continuum concept (Barbour et al. 1999).

Another commonly used approach in mapping witness tree data is interpolation. Interpolation is another tool through which researchers have addressed the essential problem in mapping witness tree data; the broadly spaced distribution of data points. Interpolation techniques used include kriging and inverse distance weighting interpolation (Black et al. 2002, Brown 1998). Although different algorithms are involved with each method, they each rely on the assumption that entities that are closer together are more alike (Childs 2004, Burrough 2001). In terms of witness trees, these techniques can predict the surface between witness tree data points, but these surfaces may not have any relation to environmental variables driving the distribution of species or communities.

Analysis Outputs: South Alabama

Before discussing the advantages of the MLR modeling approach used in this study, it is important to carefully review the appropriateness of logistic regression and the methods necessary to produce raster probability maps for each witness tree community. In addition, the methods used to asses overall model significance and the significance of each environmental independent variable require review. The steps required to translate logistic regression outputs into GIS generated maps will also be presented. Finally, the outputs of this approach will be compared to those of previous witness tree studies.

Multinomial logistic regression is a suitable technique to use with these data for several reasons. First, unlike linear regression, logistic regression is well suited to models in which the dependent variable is dichotomous rather than continuous (Hosmer and Lemeshow 1989). In addition other techniques such as discriminate analysis could not be used because they require the assumption of multinomial normality (Sharma 1996). A mixture of continuous and categorical independents were chosen in this study which violate the assumption of multivariate normality; because logistic regression makes no such distributional assumptions the technique was well-suited for this analysis (Sharma 1996).

Multinomial logistic regression was performed in SAS with the cluster groups (communities) as the dependent variables and the environmental attribute data as the independent variables or covariates (SAS Institute Inc. 2001). Logistic regression does not assume a linear relationship between the independents and dependent variables, but rather assumes linearity between the logit of the dependents and the independents (Hosmer and Lemeshow 1989, Sharma 1996). The following steps will explain how multinomial logistic regression outputs were used to produce probability raster surfaces for each witness tree community. Explanation will begin with binary logistic regression before describing the multinomial logistic regression used in this study.

First, the binary logistic regression model is given by equation 1 for k independent variables (Sharma 1996):

1. $\ln[odds(event \mid X_1, X_2, ...X_k)] = \beta_O + \beta_1 X_1 + \beta_2 X_2 + ...\beta_k X_k$

Equation 2 shows that the logit can be viewed in terms of probability rather than odds (Sharma 1996).

2. $\ln[odds(event \mid X_1, X_2, ...X_k)] = \ln[prob(event) / prob(nonevent)]$

Given equation 2, the binary logistic regression model can be written as the following:

3. $\ln[prob(event) / prob(nonevent)] = \beta_O + \beta_1 X_1 + \beta_2 X_2 + ...\beta_k X_k$

Multinomial logistic regression takes on a slightly different form than binary logistic regression in one main respect. In the case of binary logistic regression, the logit refers to the log odds of an event occurring, while with MLR a reference category is adopted (Bailey et al. 2003). In this study, the model was coded so that the largest community and the community of most interest, the pine dominated community, serves as the reference community (Hosmer and Lemeshow 1989). Three regression equations are provided by SAS describing the impact of environmental independent variables on the logit or log odds of the hardwood, bay and mixed pine-oak communities rather than the reference pine dominated community. Equation 4 is an example of the form of this equation for the hardwood community. Subscripts are given to identify the community associated the logits or independent variables (i.e. H or hardwood community).

4. $prob(hardwood)/prob(pine) = e^{B_{HO}+B_{H1}X_1+B_{H2}X_2+....B_{Hk}X_k}$

In order to derive a raster probability surface for the reference pine dominated community, a series of rearrangements of these basic equations are needed. Specifically, in order to isolate the probability of the hardwood, bay, and mixed-pine oak communities, the probability of the pine dominated reference community must be derived. To understand these steps refer to Appendix B (Equation B.2). The equation for the probability of the pine dominated community is given in equation 5. The equation is in terms of odds rather than probability, which is possible because of the relationship explained in equation 2.

5. $prob(pine) = 1/[1 + odds(hardwood) + odds(bay) + odds(mixed)]$

Finally, with the probability of the pine dominated reference community established, the probabilities of the other 3 communities can be derived. Equation six is an example of how this is accomplished.

6. $prob(hardwood) = prob(hardwood)/prob(pine) * prob(pine)$

Equations four, five and six were used within ArcGIS spatial analyst to produce probability maps for each community. As explained in the previous section, the categorical independent variable, suborder is handled differently than continuous variables. Specifically, with suborder, a slope estimate is given to describe the impact of each soil suborder compared to the reference suborder (Hosmer and Lemeshow 1989). As a result, raster data of presence and absence for each soil suborder were created using the raster calculator. The raster data for soil suborder combined with datasets of distance from water and slope were used in equation 4. Equations used in the raster calculator can be viewed in Appendix B (Equations B.3).

The likelihood ratio test was used to asses the overall significance of the model (Hosmer and Lemeshow 1989), while the Wald chi-square statistic was used to test the significance of environmental independent variables soil suborder, distance from water, and slope (Hosmer and Lemeshow 1989). Additionally, the significance of each slope estimate associated with each soil suborder was determined by the Wald statistic (Hosmer and Lemeshow 1989, Ramsey and Shafer 2002). These results are presented in chapter two (table 2.5).

A logistic regression model was used to depict the distribution of derived forest communities across the study area. I believe this approach has several advantages. First, the output community distribution maps are at a higher resolution (30 meters) than other maps of presettlement forests. Each map shows the probability of finding one of the derived communities based on relationships with the three independent variables. This is different from traditional witness tree map outputs which display actual location rather than probability of a community at a given location. Additional benefits of this technique are that these maps are able to portray the gradual shifting of forest communities and can aid in identifying ecotones across the study site. Finally, the resolution of these maps coupled with the probabilities allows for the calculation of area estimates for each witness tree community. In fact, because the maps are on cell by cell probability basis estimates of area allocated to each community are more reliable than the exact location of communities. Area estimates and raster probability maps for each community are provided in the results chapter.

Discussion and Guidelines for Future Witness Tree Studies

The review of methods in witness tree studies and those used in this study have revealed some important guidelines for the future use of these data in historical ecology. The first recommendation I have to offer is for researchers to allow the data source to guide analysis. This step may be uncomfortable for some scientists, but is necessary with the use of historical data. This means taking the time to examine flaws which may exist in witness tree data. The acknowledgement of imperfection in the data source is an essential step in deciding appropriate analyses.

The GLO surveys of Covington and Escambia counties were a perfect example of why researchers should, at the outset, gain an understanding of the data flaws. Specifically, the dominance of pine in the study site and the inconsistencies between surveyors pushed the analysis to start with a classification of witness trees. In allowing the data source to guide analysis, researchers should also be upfront with regards to how witness tree locations are derived. More explicit methods regarding geo-referencing of witness trees can allow the reader to understand methods chosen for sampling of environmental variables and determine if scale related concerns have been appropriately handled. Although researchers may feel that too much emphasis on witness tree data flaws may weaken the influence of their results, readers deserve to know the basis of conclusions. In fact, supplying the reader with information on the methods used to handle flaws in the data serves to strengthen the investigators arguments rather than weaken them.

An additional suggestion for future research with witness tree data is for researchers to be aware of scale concerns and explicit in their descriptions of sampling. Scale problems were at the forefront of two common steps in witness tree analysis; the derivation of communities and sampling of environmental variables. Researchers need to make witness tree samples as spatially explicit as possible, especially if the samples are to be used in classification. Further, in terms of sampling environmental variables, investigators should sample at a grain size which is commensurate with the perceived accuracy of witness tree locations.

The third guideline for subsequent witness tree studies is for scientist to be forthright with the assumptions underlying analysis. I am not referring to the assumptions regarding the utility of the witness tree data itself, but rather the steps in analysis following the collection of such data. In previous witness tree studies these assumptions have not been adequately presented to the reader.

The logistic regression modeling approach presented in this study has numerous underlying assumptions. These assumptions begin with steps taken before hierarchical clustering. The used of relative density at quarter corners and section corners operates under the assumption that a sample of one post oak and one pine and two post oaks and two pines are ecologically equal. Further it was assumed that witness trees were located accurately enough to expect successful sampling at 30 meter resolution. Next the methods used in this study rely on the assumption that the derived witness tree communities are distributed with respect to only the chosen environmental variables. In particular, map products are only depicting the distribution of witness tree communities in regards to the environmental independents. Like other studies, this work has also relies on the assumption that presettlement environmental conditions match those represented in modern GIS datasets of these variables. It is doubtful that soils and topographic factors have changed substantially, however modern impact on hydrology may have distorted the output community maps to a degree.

Although being forthright with assumptions regarding witness tree analysis is important, I believe efforts to extend the utility of this unique data set are also vital. A central challenge in historical ecology is to gain as much information as possible from limited data. This is a worthy pursuit that can yield valuable information, as long as researchers are frank regarding underlying assumptions. Opportunities to broaden the relevancy of witness tree data abound with advances in GIS technologies, providing new avenues through which researchers can explore an old data set. Increased information regarding presettlement forests can supplement our understanding of the ways in which post-European settlement land use has altered ecological systems. This knowledge may have important implications for land management prescriptions or restoration efforts.

CHAPTER TWO

PRESETTLEMENT FORESTS OF ESCAMBIA AND COVINGTON COUNTIES, ALABAMA

Introduction

Witness trees or bearing trees have been used in a variety of fashions to describe the nature of forests preceding large scale European influence. Many studies have successfully defined relationships between species and site characteristics like soils or other physiographic attributes (Batek et al 1999, Brugam and Patterson 1996, Black et al. 2002). In addition, this data source has been used to address the relative abundance of species, to define presettlement vegetative communities, and to produce maps of reconstructed presettlement forests (Black et al. 2002, Schwartz 1994). In several studies, witness tree data have served as a baseline ecological condition from which researchers have embarked on temporal studies of land use change (Cowell 1998, Hall et al. 2002). Outputs have yielded results regarding the impact of changed disturbance regimes, trends regarding European land use, as well as inferences concerning the impact of Native American land use.

The majority of this research has been conducted using witness tree data from the GLO public land surveys. In some cases other survey systems have been utilized (metes and bounds and land lottery surveys), however the overwhelming majority of studies have used GLO surveys. Researcher preference for GLO data is a direct result of their relative standardization and acceptance as a quantitative source of presettlement ecological data. Despite the general acceptance of this data source, the records are not devoid of problems. Potential difficulties with GLO records as ecological data include: surveyor bias towards certain species, surveyor fraud, inaccurate tree identification, inconsistent tree identification, difficulty discerning common names, and failure to identify to species (Black et al. 2002, Bourdo 1956). With the acknowledgment of some of these difficulties, GLO witness tree data are still used because they represent a systematic, although unintentional source of information on presettlement tree distributions (Bourdo 1956, Black et al. 2002, Schwartz 1994).

The goals of this study are largely concerned with describing the presettlement forests for the study area. The rational for undertaking such work is to expand and increase the depth of knowledge concerning the presettlement forests of South Alabama. Witness tree data are available for the entire state, but studies describing presettlement forest using these data are limited (Black et al. 2002, Jones and Patton 1966, Rankin and Davis 1971). There are some widely accepted generalities regarding South Alabama forest communities, including the idea that pines (probably longleaf pine) were dominant. More specific information however, like the degree of pine dominance and the distribution of presettlement communities, remains unclear. Using these data can assist in developing land management prescriptions, guiding restoration efforts, and increasing our understanding of contemporary human impacts on these systems.

The objectives for this chapter are as follows: (1) describe the witness tree data in terms of species abundance, (2) describe witness tree communities derived from hierarchical cluster analysis, and (3) describe logistic regression results including relationships between environmental variables and community distribution, map outputs, and descriptive statistics regarding the total area encompassed by each forest community.

Materials and Methods

The study area is Escambia and Covington counties located in south central Alabama. It falls entirely within the coastal plain physiographic province and the general forest type is southeastern pine forest (Fenneman 1938). The region is further divided into 4 distinct belts within the Eastern Gulf coastal plain including; Southern Pine Hills, Dougherty Plain, Buhrstone Cuesta, and the Southern Red Hills (Fenneman 1938).

The soils in the Southern Pine Hills are generally sandy and porous with an underlying Citronelle formation (Fenneman 1938). This belt describes nearly all of Escambia County and the southern third of Covington County (Fenneman 1938). The Dougherty Plain describes the eastern half of southern Escambia County (Fenneman 1938). The Dougherty Plain is an almost entirely flat limestone region with noticeable shallow depressions or sinks (Fenneman 1938). The Burhstone Cuesta belt extends into central Covington County and is characterized by rolling hills (Fenneman 1938). This belt is less than 10 miles wide throughout the two counties. The northern third of Covington County is part of the Southern Red Hills belt (Fenneman 1938). These hills rise several hundred feet above the adjacent flat lands and contain characteristic broad valley floors (Fenneman 1938).

The topography in Escambia County ranges from level to moderately steep. The majority of the relief throughout the county is only gently sloping, and primarily occurs along streams and rivers (Mattox 1979). The elevation ranges from 19.8 meters to 105.1 meters above sea level in Escambia County (Mattox 1979). Elevation in Covington County ranges from 30.5 meters to 137.2 meters above sea level (Cotton 1984). Much like Escambia County, ridge tops in Covington County are broad and gently sloping. Steeper slopes are commonly associated with drainage ways (Cotton 1984).

The climate for both counties is impacted by the moist tropical air from the Gulf of Mexico. Annual precipitation amounts for the two counties are very similar with the average yearly rainfall in Escambia County 155.7 centimeters and 148.6 centimeters in Covington County (Mattox 1979, Cotton 1984). In the summer, thunderstorms are primarily responsible for the rainfall, and it is estimated that thunderstorms impact the two county study site approximately half of all summer days (Mattox 1979, Cotton 1984). In the late summer and early autumn months the region is periodically impacted by tropical depressions or hurricanes from the Gulf (Mattox 1979, Cotton 1984).

The two counties have temperate climates which border on subtropical. The average daily maximum temperature for the two counties is approximately 24° C, while the average daily low temperature is around 10° C (Mattox 1979, Cotton 1984). Summers are hot, with the average daily maximum temperature above 32° C in June, July and August (Mattox 1979, Cotton 1984). Winters are mild with only approximately 45 days in the year experiencing a temperature below 0° C (Mattox 1979, Cotton 1984).

Background and Historical Context

In covering the two counties, field note data were recorded from 57 Townships. All surveys were conducted between 1820 and 1846, with over 98% of all witness tree points recorded between 1820 and 1826.

Creek Indians did not officially surrender this land until 1814 (Ward 1991). It was not until 1819 that Alabama gained statehood and the Cahaba and Sparta land districts were established to begin surveying the area (Ward 1991). Land sales to white settlers were limited until the late 1830's and early 1840's (Ward 1991). In light of this timeline, the surveys are indeed representative of the forests prior to any substantial European land use.

In accordance with GLO standards, the area composing Covington and Escambia counties was divided into the Township and Range system. Each township is 36 square miles and contains 36 sections each 1 mile square. Four witness (bearing) trees were recorded at each section corner, while two trees were recorded at each quarter corner or approximately ½ mile from the section corner. The surveyors within the study area were very consistent in following this protocol, with the exception of one township, 6 North, 15 East, in which quarter corner bearing trees were not recorded. Twelve different surveyor combinations were responsible for conducting the surveys within the study area. In most cases one surveyor was responsible for the entire township, however in a few cases multiple surveyors worked on a single township. As a result the term "surveyor group" will be used.

Witness Tree Species Information

A total of 12,637 witness trees were tabulated from the field notes within the two county study area with 70 different common names listed. These common names were combined into 48 common name groups which are listed in table 2.1. The common names used in analysis were grouped and thus reduced in number for several reasons: First, common names were either illegible or unknown. There were three illegible entries and 6 common names that were grouped into the category unknown trees. Secondly, the common names were grouped because the potential corresponding species identifications were indistinguishable. And finally, if the surveyor handwriting consistently made differentiating between common names difficult, as the case with beech and birch, the names were grouped.

Table 2.1. Common names provided by surveyors and likely corresponding species (Godfrey 1988). The only exception to the use of Godfrey was with regards to the common name "whortleberry," in which Schwartz was consulted (1994).

Common Name	**Scientific name(s)**	**Frequency**	**Percent**
Ash	*Fraxinus americana, F. caroliniana, F. pennsylvanica, F. profunda*	17	0.13
Bay, Green Bay	*Persia borbonia, P. palustris, Magnolia virginiana*	360	2.85
Beech/Birch, Water Birch	*Fagus gradifolia, Betula nigra*	88	0.70
Blackgum	*Nyssa sylvatica*	38	0.30
Blackjack Oak	*Quercus marilandica*	255	2.02
Black Oak	*Quercus velutina*	72	0.57
Cedar	*Chamaecyparis thyoides, Juniperus virginiana*	2	0.02
Chestnut	*Castanea dentate*	48	0.38
Chinquapin	*Castanea pumila, C. ashei, C. floridana*	12	0.09
Cucumber	*Magnolia acuminate*	6	0.05
Cypress	*Taxodium ascendens, Taxodium distichum*	26	0.21

Common Name	**Scientific name(s)**	**Frequency**	**Percent**
Dogwood	*Cornus alterniflolia, C. asperifolia, C. foemina, C. amomum, C. florida*	149	1.18
Elm	*Ulmus alata, U. americana, U. rubra, Planera aquatica*	8	0.06
Fetterbush	*Leucothoe racemosa, Lyonia lucida*	4	0.03
Gum	*Nyssa aquatica, N. biflora, N. sylvatica*	65	0.51
Hackberry	*Celtis laevigata*	4	0.03
Haw	*Crataegus spp.*	4	0.03
Hickory	*Carya aquatica, C. glabra, C. ovata, C. pallida, C. tomentosa*	73	0.58
Holly	*Ilex opaca*	75	0.59
Hornbeam	*Ostrya virginiana*	21	0.17
Ironwood	*Carpinus caroliniana*	16	0.13
Laurel	*Kalmia latifolia*	7	0.06
Linden	*Tilia Americana*	1	
Magnolia, Bull Bay	*Magnolia grandiflora, M. macrophylla, M. tripetala*	3	0.02
Maple	*A. rubrum, A. saccharinum, Acer sacharrum*	45	0.36
Mulberry	*Morus rubra*	2	0.02
Myrtle	*Myrica cerifera, M. inodora, Ilex myrtiflolia*	6	0.05
Oak	*Quercus spp.* 27 species *Q. alba, Q. austrina,Q.muehlenbergii, Q. michauxii, Q. stellata, Q. margaretta, Q.chapmanii, Q. virginiana, Q. geminata, Q. minima, Q. pumila, Q. hemishperica, Q. laurifolia, Q.phellos, Q.myrtifolia, Q. incana, Q. nigra, Q. marilandica, Q.laevis, Q. falcata, Q. pagoda, Q. velutina, Q. rubra, Q. shumardii, Q. nuttallii, Q. coccinea*	202	1.60
Open	*Sections corners or quarter sections recorded as open in the survey*	41	0.32
Persimmon	*Diospyros virginiana*	5	0.04
Pine	*P. echinata, P. elliotti, P. glabra, P. palustris, P. serotina, P. taeda,*	10558	83.55
Plum	*Prunus americana, P. angustifolia, P. umbellate*	1	0.01
Poplar	*Populus deltoides, P. heterophylla, Liriodendron tulipifera*	28	0.22
Post Oak	*Quercus stellata, Q. margaretta*	110	0.87
Red Bay	*P. borbonia*	3	0.02
Red Oak	*Quercus rubra, Q.falcata*	74	0.59
Sassafras	*Sassafras albidum*	9	0.07
Sourwood	*Oxydendrum arboretum*	28	0.22
Spanish Oak	*Q. falcate*	2	0.02
Swamp Oak	*Q. laurifolia, Q. michauxii, Q. pagoda,*	3	0.02
Swamp-privet	*Forestiera acuminate*	4	0.03

Common Name	**Scientific name(s)**	**Frequency**	**Percent**
Sweetbay	*Magnolia virginiana*	9	0.07
Sweetgum	*Liquidambar styraciflua*	38	0.30
Sycamore	*Platanus occidentalis*	4	0.03
Tupelo Gum	*Nyssa aquatica*	4	0.03
Water Oak	*Quercus nigra*	12	0.09
White Oak	*Quercus alba*	32	0.25
Willow Oak	*Quercus phellos*	18	0.14
Whortleberry	*Ilex* cf. *pauciflora*	5	0.04
Unknown tree	occurring less than 5 times	28	0.22
Illegible		3	0.02
Descriptions given rather than common name	Such as swamp or cypress swamp	9	0.07

The most striking information given by table 2.1 is the dominance of pine in the region. Pines make up over 83 percent of all witness trees in the region. The next most common tree identified in the surveys was the bay/green bay group with 360 trees recorded comprising only 2.85 percent of the total sample. Other relatively common witness trees were blackjack oak and the general term oak, comprising 2.02 and 1.60 percent of the total sample.

Cluster Analysis Results

The dendrogram produced by the agglomerative cluster analysis was pruned to produce four overstory tree communities. The output dendrogram provides a scale bar detailing the percent of information remaining as it relates to the clusters. The scale bar indicates that four clusters account for approximately 60 % of the information in the data. The relevance of this classification is further supported by the abundance of species within each cluster.

Table 2.2 provides information on the composition of witness tree common names within the communities produced by cluster analysis. The table gives information on the 10 most common species within each community and the percent that each species contributes to the overall community. In addition, the table provides information regarding the extent to which each common name falls completely or mostly into a specific community. For example, within the mixed pine-oak community, the second most abundant species was blackjack oak. The 250 blackjack oaks in the community comprise 21.76% of trees recorded in the community and this sample comprises 98.04 % of all blackjack oaks recorded in the study site.

Table 2.2. Witness tree common name allocation produced through cluster analysis, Escambia and Covington counties, Alabama

Pine Dominated Community	**Abundance**	**% of Community**	**% of total sample**
Pine	9783	100.00	92.66
Total	9783	100.00	77.81
Mixed Pine-Oak Community	**Abundance**	**% of Community**	**% of total sample**
Pine	594	51.70	5.63
Blackjack Oak	250	21.76	98.04
Post Oak	93	8.09	84.55
Oak	71	6.18	35.15
Dogwood	26	2.26	17.45
Black Oak	15	1.31	20.83
Bay	12	1.04	3.33
Red Oak	10	0.87	13.51
Hickory	10	0.87	13.70
Gum	10	0.87	15.38
Total	1149	94.95	9.14
Hardwood Community	**Abundance**	**% of Community**	**% of total sample**
Pine	157	11.67	1.49
Bay	127	9.44	35.28
Oak	131	9.74	64.85
Dogwood	123	9.14	82.55
Beech/Birch	84	6.25	95.45
Holly	70	5.20	93.33
Red Oak	64	4.76	86.49
Hickory	63	4.68	86.30

Hardwood Community	**Abundance**	**% of Community**	**% of total sample**
Gum	54	4.01	83.08
Black Oak	52	3.87	72.22
Total	1345	68.77	10.70
Bay community	**Abundance**	**% of Community**	**% of total sample**
Bay	218	73.65	60.56
Pine	24	8.11	0.23
Poplar	7	2.36	25.00
Maple	7	2.36	15.56
Water Oak	6	2.03	50.00
Black Oak	5	1.69	6.94
Myrtle	5	1.69	83.33
Holly	3	1.01	4.00
Sassafras	2	0.68	22.22
Sweetbay	2	0.68	22.22
Total	296	92.91	2.35

The first community established with cluster analysis was a community composed of 100% pine. At first glance, the lack of any other species within this community was troubling, but early descriptions of the presettlement landscape indicate vast savannahs in which longleaf pine was "ubiquitous" (Harper 1914). Further, although this community may have also contained some scrubby oak species, their absence in the community is not surprising given surveyor bias towards larger, healthier, long-lived trees (Bourdo 1956).

The second community (named mixed pine-oak) produced through cluster analysis is composed mainly of pines, blackjack oak, post oak, and the general common name oak. Other species in the community comprise less than 3% of the total sample within the community. It is important to note that nearly all of the blackjack oaks (98.04%) and the vast majority of post oaks (84.55%) found in the complete survey fall within this community.

A community of diverse hardwood species was also delineated in cluster analysis. Again pine is the most common tree in the community; however there are numerous hardwood species that contribute substantially to the composition of this community. It is important to note that the component hardwood species are consistently grouped into this community. In other words, for hardwoods comprising a substantial portion of this community, a high proportion of that species sample is grouped into the hardwood community. This statement is true of the dogwood, beech/birch, holly, red oak, hickory and gum in which over 82% of the respective species sample is grouped into this community. This phenomenon was also true of less dominant species in the community including chestnut, cypress, hornbeam, ironwood, sourwood, sweetgum, white oak, and willow oak. For each of these common names listed, over 83% of the total species sample was grouped in this community by cluster analysis.

The last community identified by cluster analysis was named the bay community purely because of the dominance of this common name within the community (73.65%). Cluster analysis categorized only 296 or 2.35% of the total witness tree sample into this community. The next most common witness tree identified within the community is pine comprising only 8.11% of the community. Other species were grouped in the community, but only in very small proportions.

Figure 2.1. Description of witness tree communities derived with cluster analysis, Escambia and Covington counties, Alabama.

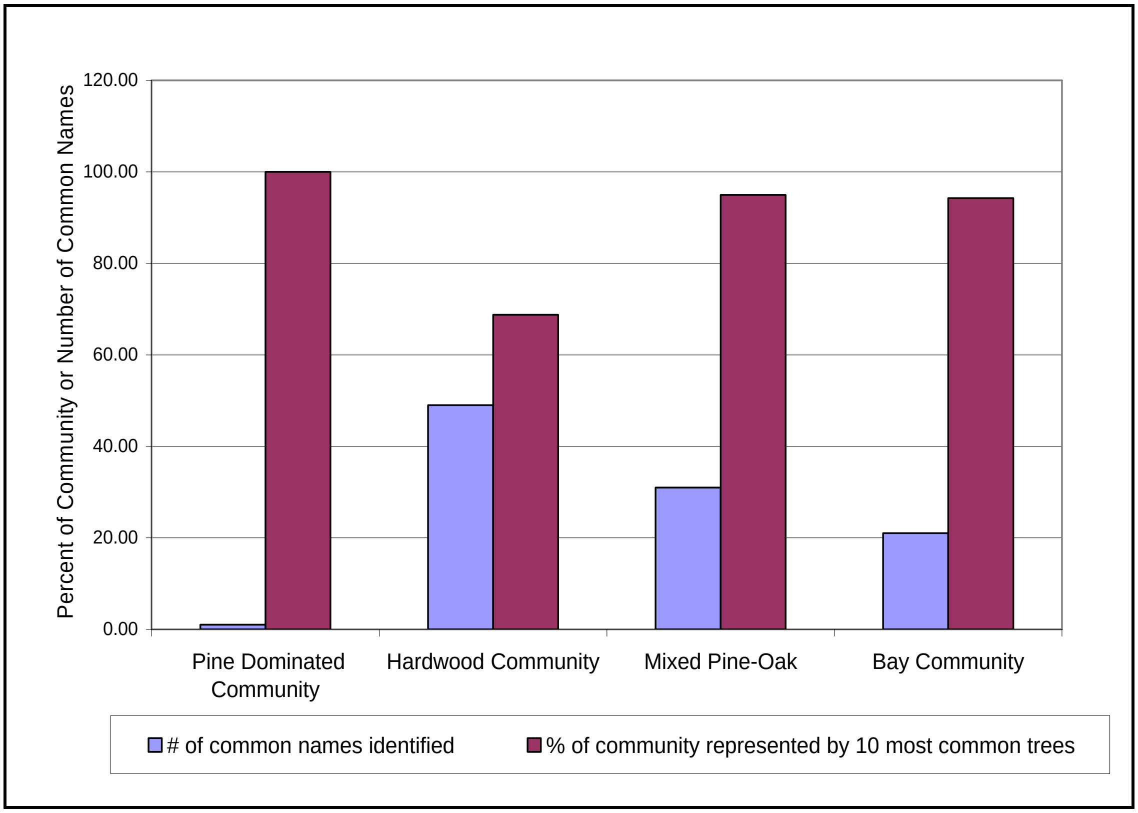


Figure 2.1 illustrates the diversity of common names falling within each community type produced in cluster analysis. Of the common names given by surveyors, 41 were recorded that were classified in the hardwood community, while the mixed pine-oak and bay communities registered 31 and 21 common names respectively. In the pine dominated community, mixed pine-oak and bay communities, the 10 most abundant species within the community comprise the bulk of all trees within the respective communities.

Multinomial Logistic Regression Results

As discussed in chapter one, multinomial logistic regression was run with the witness tree communities as the four dependent variables, and the environmental variables as the independent variables or covariates. The likelihood ratio test reported by SAS is 1582.48 with 15 degrees of freedom, indicating an overall significant model ($p < 0.0001$). The likelihood ratio chi-square however does not assure the significance of every independent variable (Hosmer and Lemeshow 1989). Using the Wald chi-square statistic, table 2.3 shows the significance of each environmental independent variable.

Table 2.3. Significance of environmental independent variables in determining witness tree community distribution, Escambia and Covington counties, Alabama. * indicates significance of Wald chi square statistic at $p < 0.0001$

Environmental independent variables	D.F.	Wald chi-square
Soil Suborder	9	1068.35*
Distance from Water	3	182.36*
Slope	3	154.00*

With overall model significance established, the focus of this chapter shifts to understanding the estimated coefficients or slope values. These estimated coefficients are indicative of the linear relationship between the logit and environmental independent variables (Sharma 1996, Hosmer and Lemeshow 1989). Before describing the communities in these terms, however, one must have an understanding of the different soil suborders used in the model. To aide in interpretation, table 2.4 describing the soil suborders, has been included.

Table 2.4. Description of soil suborders for Escambia and Covington counties (USDA Soil Conservation Service 1975, USDA Natural Resources Conservation Service 1994, Cotton 1984, Mattox 1979).

Soil Suborder	**Parent Soil Order**	**Suborder characteristics and associate soil series**
Udults	Ultisols	**Common soil series:** Dothan, Malbis, Orangeburg and Troup series. **Suborder characteristics:** little to moderate organic matter, well-drained, very low to medium water capacity, often formed from marine sediment. **Typical location:** upland sites.
Saprists	Histosols	**Common soil series:** Dorovan and Ponzer series **Suborder characteristics:** high organic matter, very slow permeability, generally associated with high water table, and once named “bog soils.” **Typical location:** drainage ways near streams and creeks.
Ochrepts	Inceptisols	**Common soil series:** Chewacla and Riverview series **Suborder characteristics:** medium organic content, medium permeability, and medium to high water capacity. **Typical Location:** level alluvial flood plains of substantial creeks.
Aquents	Entisols	**Common soil series:** Bibb, Muckalee, Osier series. **Suborder characteristics:** medium organic matter content, poorly drained, moderately to rapidly permeable, high water capacity, and experience frequent flooding of short duration. 0-2% slope **Typical location:** stream flood plains and in wet sandy deposits.

Soil suborder was used within the model as opposed to soil series, because it captures most of the variability in soils across the study site, while easing interpretation compared to using soils series (Cotton 1984, Mattox 1979). As the table 2.4 indicates, the Saprists, Ochrepts, and Aquents have a small number of component soil series. Additionally, soil order is divided into suborders partly on the basis of their differing importance to plant growth (Cotton 1984). Only the Udults contain a large number of component soil series and these component series contain only subtle differences (Cotton 1984, Mattox 1979). Many of these subtle differences between soil series are related to topographic differences, including slope and elevation (Cotton 1984, Mattox 1979). Slope is specifically included in this model, while elevation differences can be roughly inferred from the rough distinctions between suborders. For example the Udult soils within the study area are almost uniformly in “upland” sites indicating differences in elevation (Cotton 1984, Mattox 1979).

Table 2.5 provides information on the slope estimates associated with each environmental independent variable included in the model. The maximum likelihood estimate or slope estimate refers to the log of the odds of locating the listed witness tree community rather than the reference community given the environmental independent variable. As explained in chapter one, the pine dominated community serves as the reference community. Also, as indicated in chapter one, all slope estimates can be converted to odds ratio estimates by simply taking the exponent of the slope estimate. This conversion allows for a more intuitive discussion of the odds of locating a community given the independent variable (Hosmer and Lemeshow 1989, Sharma 1996). For a table containing all odds ratio estimates, refer to Appendix C (table C.1).

The odds ratio estimates are provided for each environmental independent variable. For the categorical variable soil suborder, the odds ratio estimate describes the increase in odds given the presence of one suborder as opposed to the Udult suborder. For continuous independents the odds ratio estimate is given to describe the impact of a one unit increase in the model effect. Maximum likelihood estimates (slope estimates) for slope and distance from water were standardized to allow comparison of the strength. Logistic regression results will be discussed in terms of odds ratios and with graphical displays.

Table 2.5. Parameter estimates for each environmental independent variable in logistic regression, Escambia and Covington counties, Alabama. Significance of parameter estimates is determined by the Wald Chi-square. * Denotes significance at $p < 0.05$. The pine dominated community is the reference community.

Environmental Independent Variables	**Witness Tree Community**	**Slope Estimate**	**Standard Error**	**Wald Chi-square**
Saprists v. Udults	Hardwood	1.3943	0.1243	*19.5633
Saprists v. Udults	Mixed Pine-Oak	0.3867	0.2217	0.4817
Saprists v. Udults	Bay community	1.3878	0.1938	0.0004
Ochrepts v. Udults	Hardwood	2.4761	0.1166	*20.7933
Ochrepts v. Udults	Mixed Pine-Oak	0.8077	0.2171	1.5712
Ochrepts v. Udults	Bay community	1.4167	0.1926	0.0285
Aquents v. Udults	Hardwood	3.9064	0.3045	*41.5233
Aquents v. Udults	Mixed Pine-Oak	0.9526	0.5945	0.4922
Aquents v. Udults	Bay community	2.7323	0.4713	*8.1815
Distance from water	Hardwood	-0.1980	0.0002	*92.0189
Distance from water	Mixed Pine-Oak	-0.0510	0.0001	*7.9952
Distance from water	Bay community	-0.5371	0.0004	*98.4754
Slope	Hardwood	0.1419	0.0146	*76.6804
Slope	Mixed Pine-Oak	0.0968	0.0148	*34.5715
Slope	Bay community	-0.3223	0.0428	*46.0400

Hardwood Community Distribution

As table 2.5 shows, soil suborder was important in distinguishing the hardwood community from the pine dominated community. The odds of finding the hardwood community are significantly (pine dominated community as reference) increased given soils that are generally poorly drained, have medium to high organic matter content, and have high water capacity (see table 2.5). Of these soil suborders, the odds of finding hardwoods increases most, in comparison with the pine dominated community, with the presence of Aquent soils rather than Udults (see table 2.5).

Figure 2.2. Hardwood community distribution with respect to slope and soil suborder, Escambia and Covinton counties, Alabama. On the y-axis, the pine dominated community is the reference dependent variable. For soil suborders, suborder 2 equals Saprist soils, suborder 3 refers to Ochrepts soils, suborder 6 equals Aquent soils, and suborder 7 equals Udult soils.

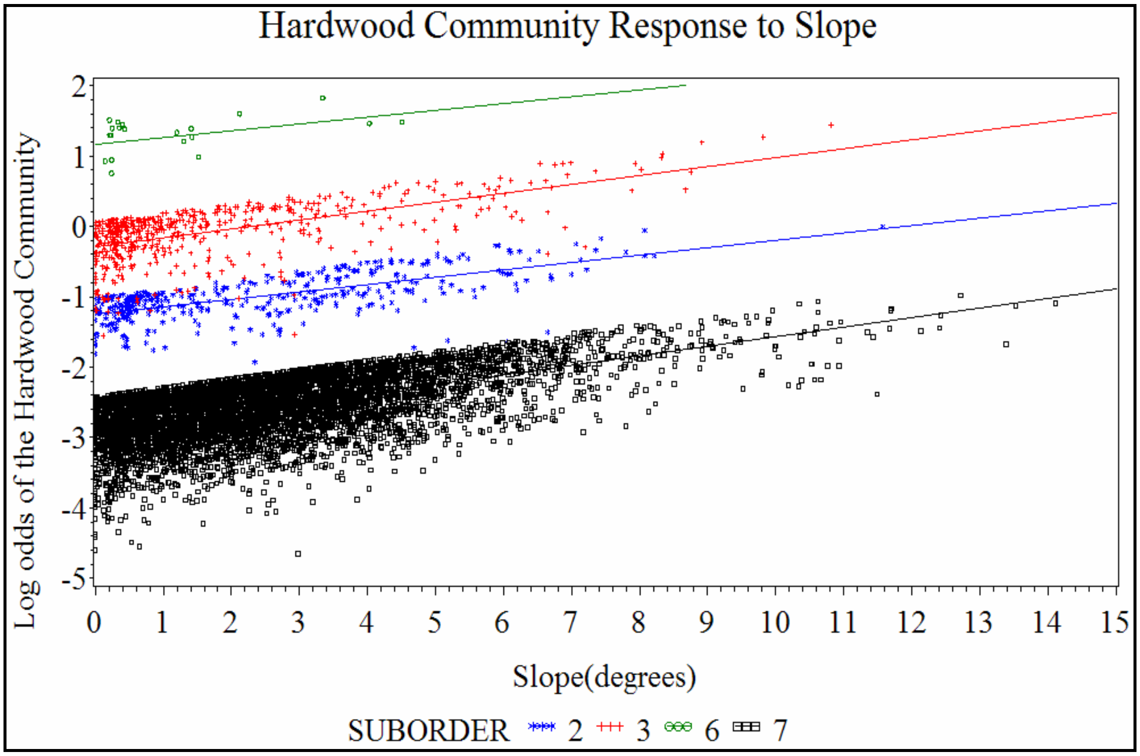
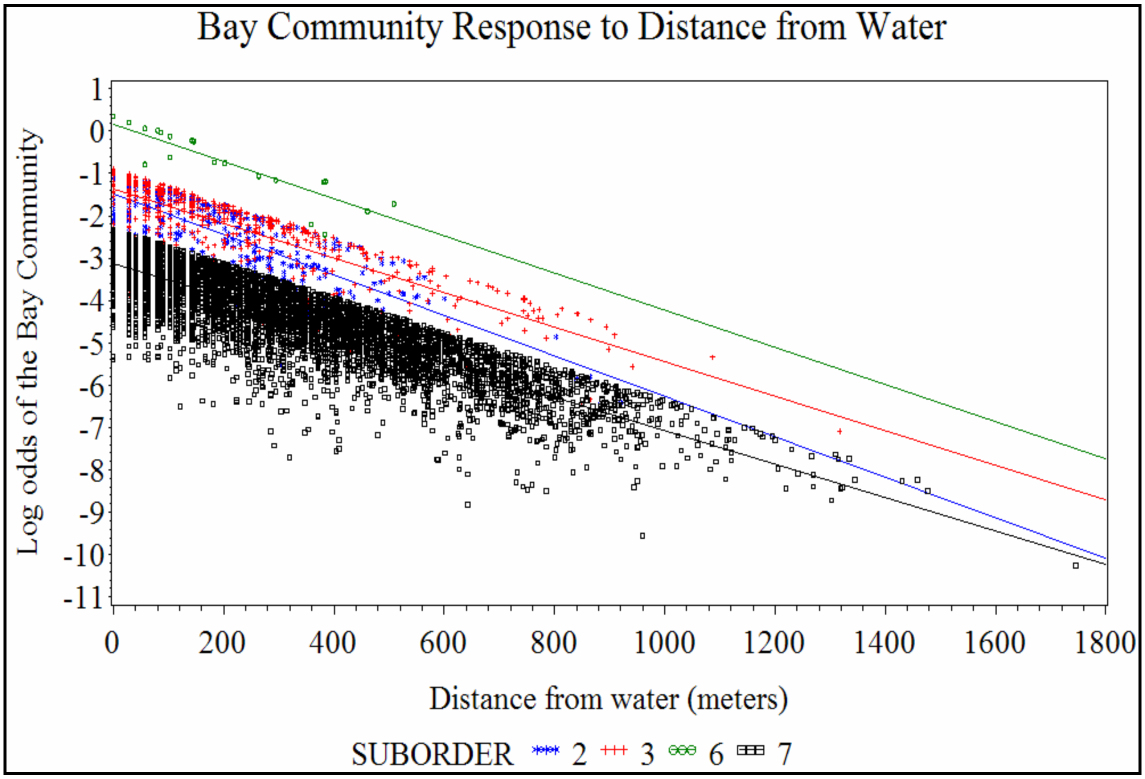


Figure 2.2 shows the positive relationship between increasing slope and the log odds of the hardwood community. The odds of locating the hardwood community is increased with increasing slope compared to all other communities. Slope was more important than distance from water in distinguishing the hardwood community from the bay community. Distance from water was most important in distinguishing the mixed pine-oak and pine dominated communities from the hardwood community. Specifically, with increased distance from water, the odds of locating the hardwood community compared to the mixed pine-oak and pine dominated communities were reduced.

Bay Community Distribution

With only a few exceptions, soil suborder was not important in distinguishing the distribution of the bay community from the other witness tree communities. Suborder was not important in differentiating the bay community from the mixed pine-oak community. The only distinction between the bay community and the pine dominated community was an increase in the odds of locating the bay community given medium organic matter, poorly drained Aquent soils rather than Udult soils (table C.1). The odds of locating the bay community compared to the hardwood community are reduced given Saprist or Ochrept soils rather than Udult soils. In general, odds ratio estimates show a strong association between the bay community and lower slope areas adjacent to water (figure 2.3).

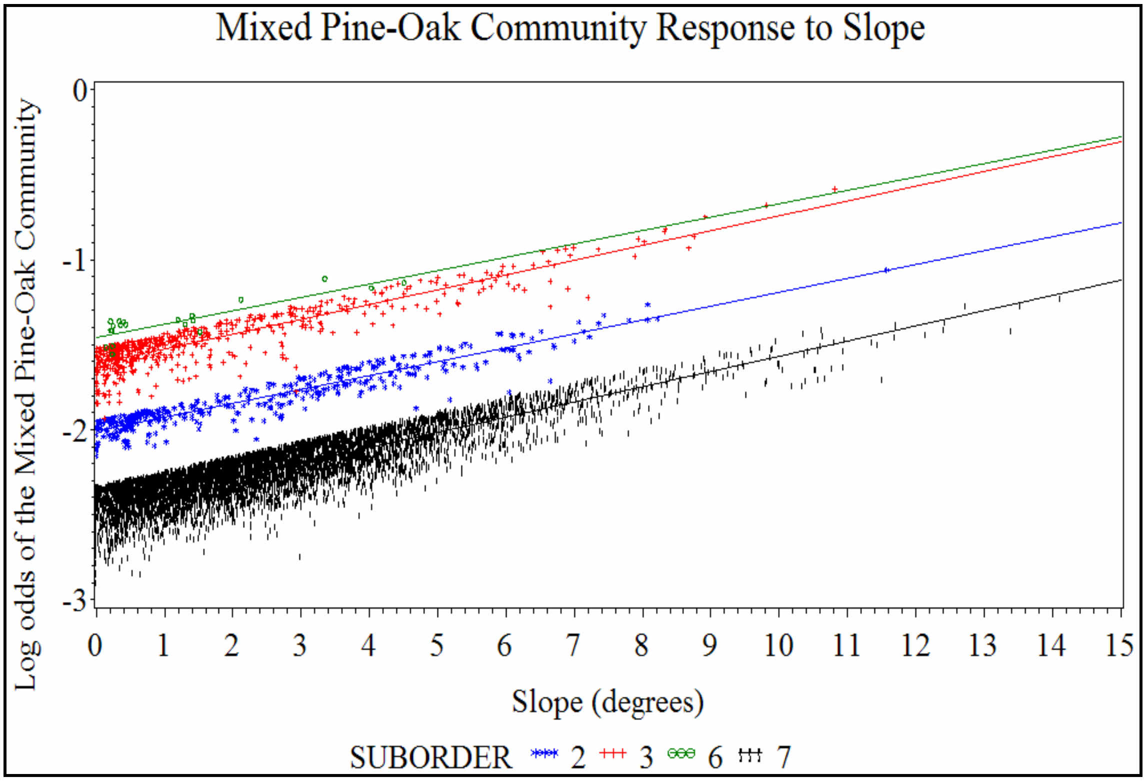
Figure 2.3. Bay community distribution with respect to distance from water and soil suborder, Escambia and Covington counties, Alabama. On the y-axis, the pine dominated community is the reference dependent variable. For soil suborders, suborder 2 equals Saprist soils, suborder 3 refers to Ochrepts soils, suborder 6 equals Aquent soils, and suborder 7 equals Udult soils.



Mixed Pine-Oak Distribution

The distribution of the mixed pine-oak community could not be distinguished from the other witness tree communities on the basis of soil suborder (see Appendix C, table C.1). The mixed pine-oak community can be characterized with the continuous independent variables distance from water and slope. The mixed pine-oak community is generally located at greater distance from water compared to the bay and hardwood communities. In addition, the mixed pine-oak community is located slightly closer to water than the pine dominated community, although distance from water was less important than slope in differentiating the two communities. Additionally, the mixed pine-oak community is characterized by greater slopes than the pine dominated community or bay community, but reduced slopes compared to the hardwood community (figure 2.4).

Figure 2.4. Mixed pine-oak community distribution with respect to slope and soil suborder, Escambia and Covington counties, Alabama. On the y-axis, the pine dominated community is the reference dependent variable. For soil suborders, suborder 2 equals Saprist soils, suborder 3 refers to Ochrepts soils, suborder 6 equals Aquent soils, and suborder 7 equals Udult soils



Pine Dominated Community Distribution

In comparison to the hardwood community, the pine dominated community is more closely associated with the low to medium fertility, upland Udult soils rather than the Saprist, Ochrepts or Aquents. In comparison to the bay community, the odds of locating the pine dominated community were reduced given the more fertile, poorly drained Aquent soils. The pine dominated community and mixed pine-oak community could not be distinguished by soil suborder. The odds of locating the pine dominated community are increased with greater distance from water when compared to all other communities. This community was associated with increased slope compared to the bay community, but decreased slope in comparison with the hardwood and mixed pine-oak communities.

Discussion

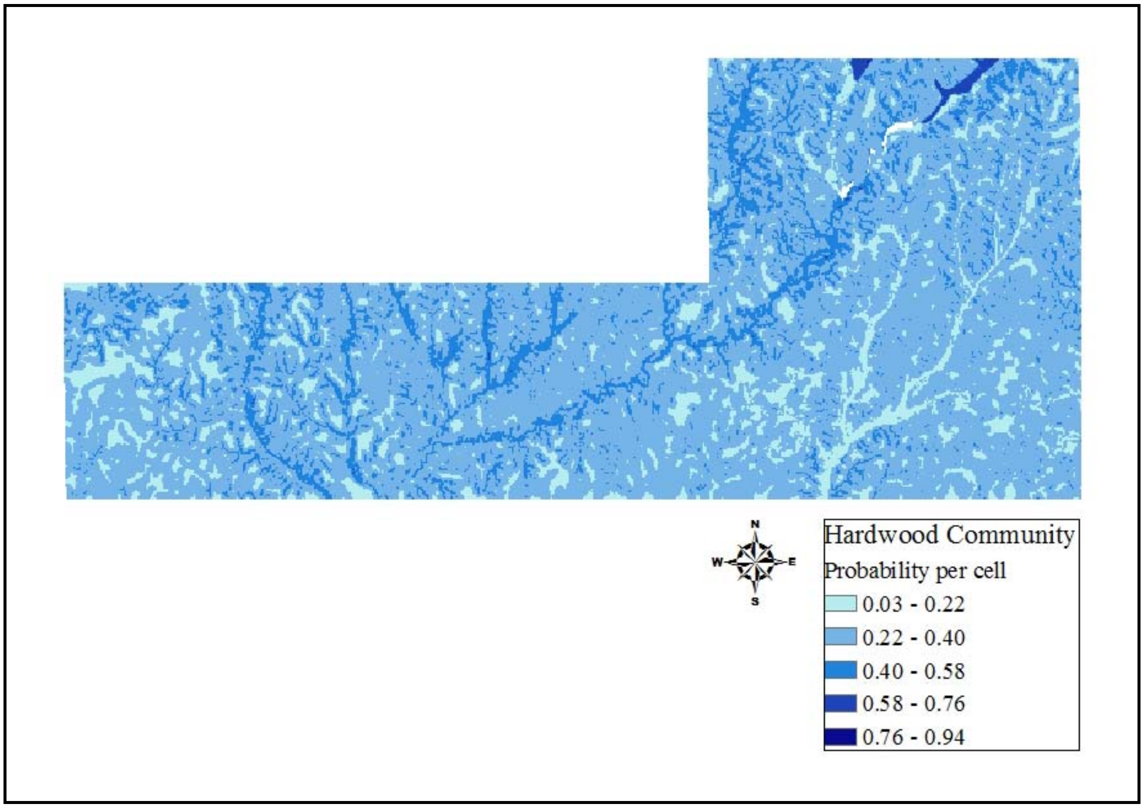
The classification results and model results describing the component presettlement communities are largely verified by a range of sources including contemporary ecological knowledge concerning the communities, modern estimates of presettlement community distribution, and evidence from early botanists and explorers concerning the presettlement landscape.

The composition of the hardwood community produced through cluster analysis is well supported in the literature. The classification results show the hardwood community as the most diverse in terms of witness tree common names identified (see figure 2.1). Reviews of the composition of southern mixed hardwood forests in the

Southeastern Coastal Plain, and these forests in north-central Florida both indicate that stands generally contain high diversity of species and a wide range of dominant species compared to other coastal plain communities (Monk 1966, Quarterman and Keever 1962). In addition, species lists provided in these studies of mixed hardwoods are similar to the list of witness tree common names in the hardwood community presented in this study (see table 2.2) (Monk 1965, Monk 1966, Quarterman and Keever 1962).

In addition to information regarding species composition, the presettlement hardwood community described in this study is similar to modern descriptions of mixed hardwoods in terms of its distribution with respect to environmental variables. To aid in the interpretation of the presettlement distribution of hardwoods, figure 2.5 is included. The figure represents a raster surface in which the probability of hardwoods per cell (900 square meters) is given. Therefore, the lighter shades represent low probability of the hardwood community, while darker shades indicate higher probability of the community. Probabilities were grouped into 5 equal intervals. The white section located the northeast portion of the study area is an area outside of model parameters in which cells could not be predicted.

Figure 2.5. Probabilities of the hardwood community in Escambia and Covington counties, Alabama. Each 30 meter raster cell has an assigned probability from the multinomial logistic regression model. Probabilities were grouped into five equal intervals.

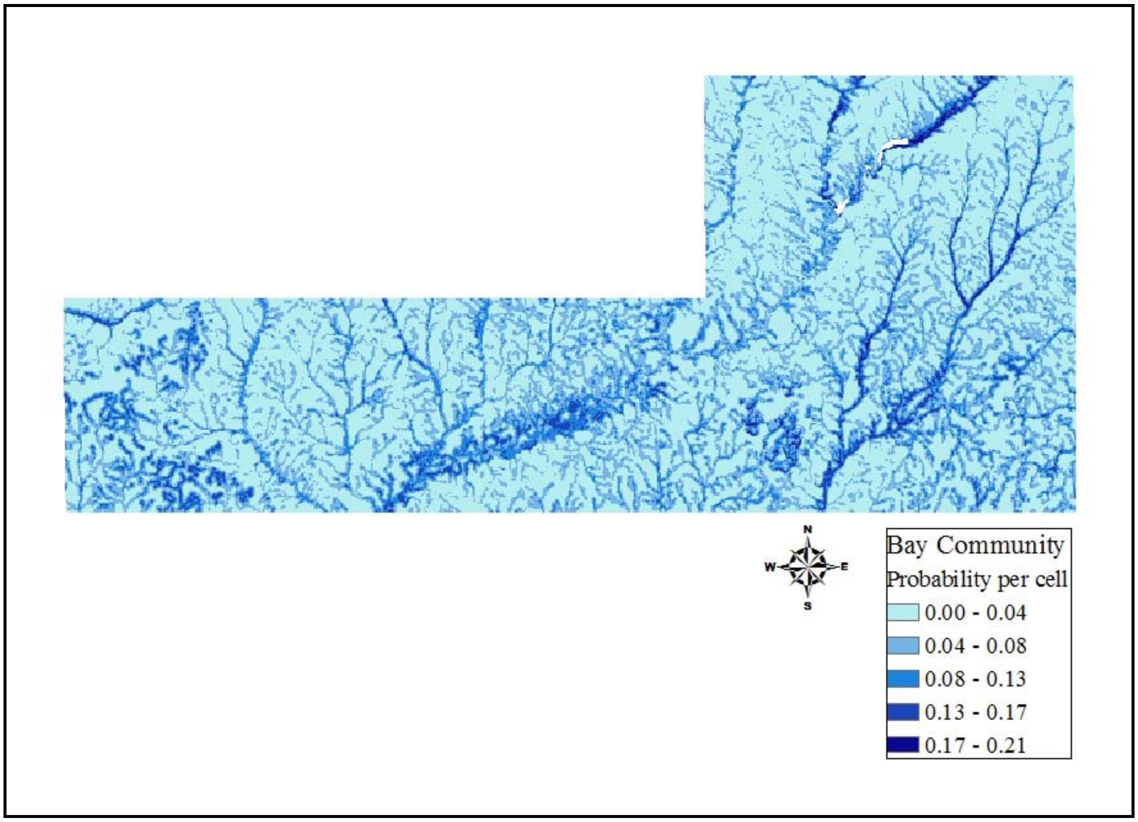


The raster surface is a visual depiction of the odds ratio estimates regarding the environmental independents discussed earlier. In understanding the map, it is important to know that the dominant feature is the Conecuh River flowing northeast through the study site. In looking at the map, it is clear that the hardwood community is primarily located around rivers and streams. Many of the streams are located near to areas of higher slope and increased moisture compared to drier upland habitats (Mattox 1979). This association of the hardwood community with higher slope is revealed in our data and supported by the literature (Quarterman and Keever 1962). It was hypothesized that this modern association between higher slopes and hardwoods was the result of difficulty for humans in using these higher slope sites for agricultural use (Quarterman and Keever 1962). The witness tree data however indicate that this association was present prior to widespread agricultural use.

Much has been written regarding the role of fire in controlling the distribution of the hardwood community in the Coastal Plain (Garren 1943, Quarterman and Keever 1962). Contemporary knowledge of successional trends indicates that hardwoods will encroach upon pine dominated communities when fire is suppressed (Quarterman and Keever 1962). In other words, without the influence of modern fire suppression, fire may have been a strong factor in isolating the hardwood community to the habitats shown in figure 2.5. In many ways, the independent variables can be viewed as environmental variables influencing habitat susceptibility to fire. Prior to European influences, distance from water could be viewed as distance from a fire break. In addition, habitats with poorly drained Saprist, Ochrept, and Aquent soils would be less susceptible to fire. To summarize, the environmental independents selected model fire to some extent, and as a result, it is not surprising to see presettlement hardwood communities primarily isolated to riparian corridors.

In terms of odds ratio estimates regarding environmental independents, the distribution of the bay community is most closely related to the hardwood community. As a result, it is expected that the raster depiction of the bay community probability per cell should be similar to that of the hardwood community (figure 2.6).

Figure 2.6. Probabilities of the bay community in Escambia and Covington counties, Alabama. Each 30 meter raster cell has an assigned probability from the multinomial logistic regression model. Probabilities were grouped into five equal intervals.



In the classification of the witness trees the bay community accounts for a very small proportion of the total sample. As a result, the model does not predict a high probability of the bay community in any one cell. As expected however, the probability of the bay community is highest in cells that are adjacent to water and where slope is minimal. Odds ratio estimates indicated that the habitats of the bay community and hardwood community are somewhat similar with respect to environmental independents. The primary distinctions are that the bay community is less abundant across the study area, is more tightly aggregated around water, and in areas of reduced slope compared to hardwoods. The association of the bay community with water and the more poorly drained soils (which experience periodic flooding or wetness) indicates that like the hardwood community the bay community is located in fire protected habitats.

The existence of this bay community is supported in a study in northcentral Florida distinguishing hardwoods swamps into a mixed hardwood group and an evergreen hardwood dominated “bayhead” group (Monk 1966). In the context of the classification used in this study, the mixed hardwood swamps fall into the hardwood community, while the bay community is similar to the “bayhead” described by Monk (1966). In terms of species composition, the two communities are differentiated by increased importance of evergreen hardwood species and characteristic lower number of regularly occurring species in the bay communities (Monk 1966). This distinction is readily apparent in the classification of witness tree data; the witness tree common names bay and green bay comprise 9.44 % of the hardwood community and 73.65% of the bay community (see figure 2.1 and table 2.2). Finally, Monk (1966) differentiates the two communities on the basis of the accumulated peat soils associated with the bayheads or bay community.

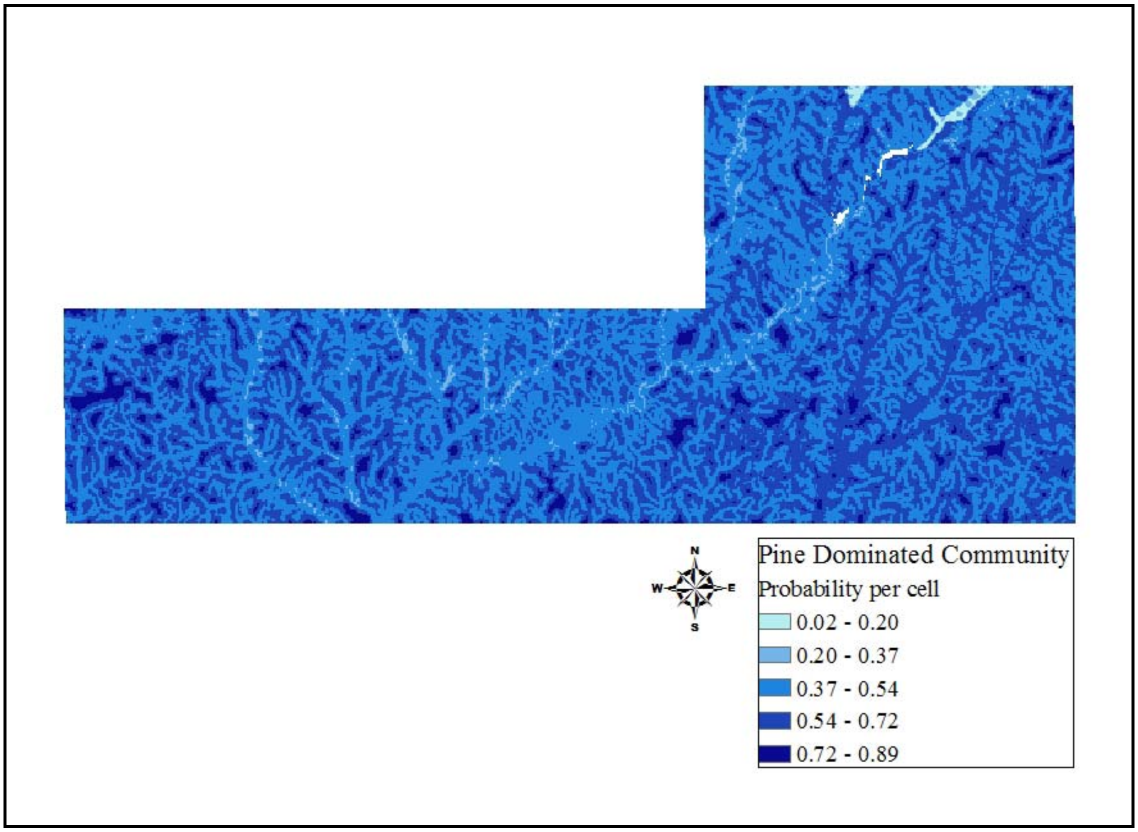
In light of the apparent association between the bay community and peat or bog soils, odds ratio data regarding the bay community revealed some unexpected results. Specifically, the Wald statistic indicated an insignificant association between the bay community and saprist soils in comparison to the mixed pine-oak and pine dominated communities. The most difficult to explain odds ratio with respect to the bay community, is the slightly reduced odds of locating the bay community compared to the hardwood community given saprist or “bog soils.”

I believe the ambiguities regarding the impacts of soil on the distribution of the bay community are a result of the broad scale nature of the STATSGO soil database. At the 1:250,000 scale, the soil database is only intended to depict multi-county or regional patterns (USDA Natural Resources Conservation Service 1994). In other words, although this dataset was converted to a raster dataset with 30 meter cells, it was not expected that variation in soils at 30 meters would be identified by this data source. In some instances, the database likely depicts all soils in a given area as Udults when they may contain small pockets of peaty Saprists soils. These soils simply were not picked up in the database and therefore indicate an association with Udult soils that is non-existent. This idea is supported by the fact that the 30 meter resolution digital elevation model was able to pick up the bay community low slope habitats compared to the other communities. These bay communities were likely located in flat areas close to water, or in the sinks and depressions common in the study area (Cotton 1984, Mattox 1979).

The bay community and hardwood community are both associated with the streams and rivers and their associated soils. These two communities are closely related in their distribution with respect to environmental independents, and thus it is not surprising that the larger group (hardwoods) would be more strongly associated with the broad scale mapping of Saprist soils than the less common bay community. Witness tree data point to the bay community being of overall lower abundance and narrower distribution with respect to environmental gradients compared to the hardwood community. The literature points to this tightly defined habitat being flat and very poorly drained (Penfound 1952).

The distribution of the pine dominated community is shown by figure 2.7. The vast majority of witness trees were classified into this community by cluster analysis, and the dominance of pine is reflected in the probability per cell estimates. The lightest shades represent a low probability of pine. Even in regions along riparian corridors, where probability of pine is lowest, the probability of locating the pine dominated community could be as high as 0.20.

Figure 2.7. Probabilities of the pine dominated community in Escambia and Covington counties, Alabama. Each 30 meter raster cell has an assigned probability from the multinomial logistic regression model. Probabilities were grouped into five equal intervals.



This pine dominated community likely includes diverse habitats such as upland pine and flatwoods (Frost 1993). In general historic evidence indicates that the dominant pine within the study area was longleaf (*Pinus palustris* Mill.) (Frost 1993, Harper 1914, Bartram 1791). In three of the four physiographic provinces within the study area, Harper (1914) described longleaf as common or dominant. Harper's estimates indicate a longleaf dominated region even after the considerable European impacts which had occurred by 1914 (Frost 1993).

As already indicated the classification producing this pine dominated community separated samples that were 100% pine. In light of this classification and the relationships between the community and environmental independents, one must consider which pine species are components of this pine dominated community. In addressing this question, it is important to consider that pines were important components of all 4 communities defined by cluster analysis. Of the 6 species of pines that are endemic to the study site, 4 can potentially form monospecific stands including shortleaf pine (*P. echinata*), slash pine (*P. elliottii*), longleaf pine (*P. palustris*), and pond pine (*P. serotina)* (Schwartz 1994). The likely presettlement range of the remaining two species loblolly pine (*P. taeda)* and spurce pine (*P. glabra*), can be clarified with a discussion of known habitat characteristics.

Spruce pine is considered a minor species in the Southern Coastal Plain typically located in swamps or hummocks along river banks (USDA Forest Service, 1990). The habitat preferences point to spruce pine being only a minor component of the hardwood community. Loblolly pine prefers wet sites or swampy areas with moisture hodling clay or clay loam soils (Barrett 1980). Additionally, in terms of presettlement distribution in the Southern Coastal Plain, loblolly pine is thought to have been confined to pond margins and creek bottoms (Croker 1969, Quarterman and Keever 1962). With this information considered, loblolly pine and spruce pine can be safely eliminated as significant component of the pine dominated community defined by this study.

The habitat preferences of these pine species which form single species stands are helpful in further defining their distribution among the four distinct communities. Contemporary descriptions of the habitat of pond pine, indicate that this was a relatively minor species in South Alabama, typically isolated near water and in areas of wet, poorly drained soils (USDA Forest Service 1990, Croker 1969). In light of this information, this species would likely be a component of only the bay or hardwood community.

Much like the pond pine, slash pine is typically located in low sites near streams, in flatwoods, and depressions (Garren 1943, Monk 1966). The pine dominated community defined in this study is generally located at great distances from water and is associated with low fertility, typically upland Udult soils. In light of the habitat characteristics of slash pine and those associated with the pine dominated community defined in this study, slash pine was likely a very minor component of the pine dominated community. Given this information, slash pine is likely a component of the hardwood or bay community as defined by this study.

The potential role of shortleaf pine within the pine dominated community is more difficult to discern. Although generally considered more important in the piedmont, Escambia and Covington counties fall within the native range for shortleaf pine (Grace et al. 2000, Frost 1993, USDA Forest Service 1990). In terms of habitat characteristics, this species has a relatively broad ecological amplitude, with the exception for its low tolerance of poorly drained soils (Grace et al. 2000). Additionally, the ability to resprout, abundant seed crops, and rapid growth as a juvenile, allow shortleaf to regenerate following fire. Shortleaf pine, like other southern pines, experiences negligible mortality once it reaches 10 cm dbh (Grace et al. 2002). Given these characteristics, shortleaf pine may have been a component of this pine dominated community. As odds ratio estimates indicated, the pine dominated community was associated with the generally upland Udult soils. These upland sites were thought to have been overwhelmingly longleaf dominated, with mixtures of native pines historically occurring on fertile sites (Frost 1993). Although in some ways well-adapted to the upland habitat defined in this study, historical evidence indicates shortleaf as only a minor component of the pine dominated community.

The odds ratio estimates associated with environmental independent variables indicate that the pine dominated community is in habitats that were likely dominated by fire maintained longleaf pine. Soon after crossing the Escambia River in the southwest portion of the study area, early naturalist William Bartram (1791) described the presettlement landscape in these terms:

> "….not unlike the low countries of Carolina; it is in fact one vast flat grassy savannah and Cane meadows, intersected or variously scrolled over with narrow forest and groves, on the bank of creeks and rivulets, or hommocks and swamps at their sources; with long leaved pines, scatteringly planted, amongst the grass; and on the high sandy knolls and swelling ridges."

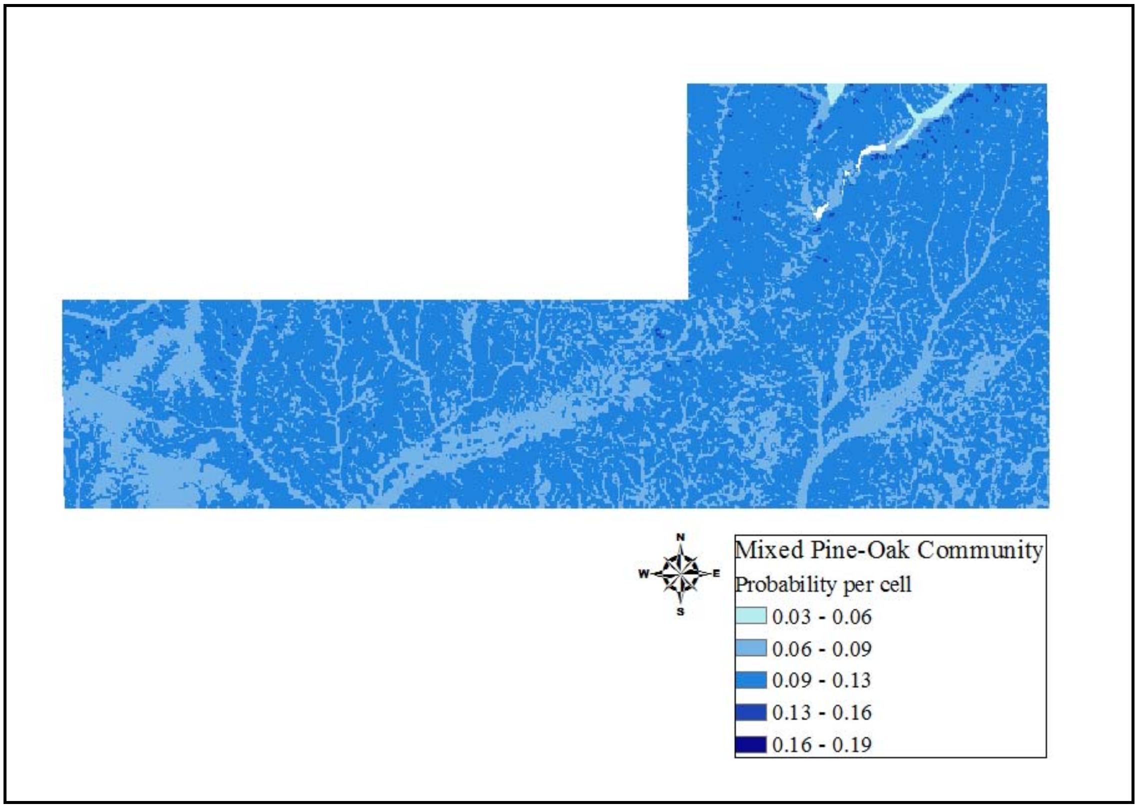
This landscape description fits well with the model of the pine dominated community and supports the assumption of longleaf pine being dominant in upland habitats. Longleaf pine as the dominant upland pine species is further supported by Schwartz's work (1994) with GLO witness tree data in north Florida.

The habitat characteristics of this pine dominated community correspond well with descriptions of southern xeric longleaf woodlands and southern subxeric longleaf woodlands. These two series as described by Peet and Allard (1993) are both upland sites, maintained by frequent low intensity fires, with only a few subtle distinctions. The xeric longleaf woodlands are typically located on ridges and summits, have reduced clay and silt content, and a reduced understory of xeric oaks compared to the subxeric longleaf woodlands. Generally speaking, the subxeric longleaf woodlands are considered to have been more dominant in presettlement times (Peet and Allard 1993).

Given this information regarding the xeric and subxeric longleaf woodlands, if these series are components of the pine dominated community defined by this study, one would expect some xeric oaks (turkey oak, bluejack oak, sand post oak, blackjack oak) to be components of the community. In explaining the lack of xeric oaks, understanding surveyor tendencies is of primary importance. Put simply, these xeric oaks were probably present in the pine dominated community, but because of their diminished, scrubby stature, were not recorded by surveyors.

The odds ratio estimates show the distribution of the mixed pine-oak community as having similar distribution to the pine dominated community. Noted exceptions are the mixed pine-oak community in areas of greater slope and slightly reduced distance from water. Fewer samples were classified into this community compared to the pine dominated and hardwood communities and this is reflected in low probability per cell values illustrated in figure 2.8.

Figure 2.8. Probabilities of the mixed pine-oak community in Escambia and Covington counties, Alabama. Each 30 meter raster cell has an assigned probability from the multinomial logistic regression model. Probabilities were grouped into five equal intervals.



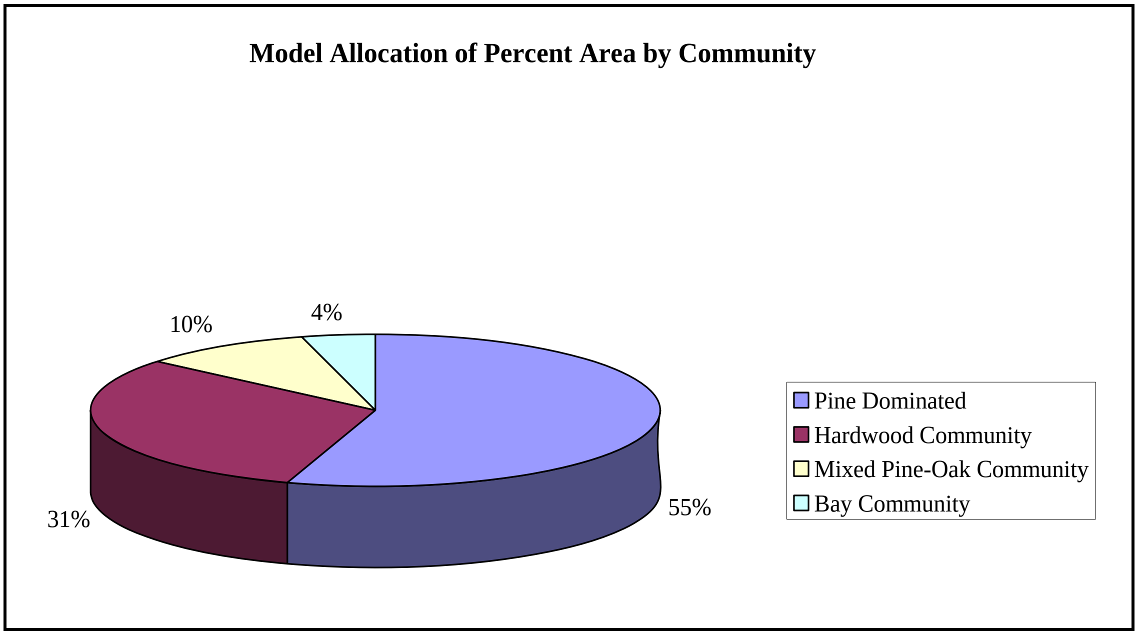
The most notable observation regarding this distribution map is the higher probability cells aggregated in northeast portion of the study area. This portion of northern Covington County falls into the Red Hills physiographic region, and according to Frost (1993) was a transition area in which longleaf pine and hardwood species were equal components of the community. The abundance data concerning this community show closer to a 60-40 pine-oak percentage.

More specifically, this mixed pine-oak community seems to correspond best with the southern subxeric longleaf woodland (Peet and Allard 1993). In terms of the surveyor recording of witness trees in this community, blackjack oak and post oak must have been considered of substantial size to serve as a witness tree. Peet and Allard (1993) list post oak and blackjack oak as common broad leaved associates of longleaf pine within this community. The distribution of blackjack oak is thought to correspond with upland soils with higher clay contents, while the distribution of post oak within this community is associated with the clay hills (Peet and Allard 1993). The association of blackjack oak with increased clay content cannot be confirmed with the soil suborders. Post oak, however, is clearly more commonly distributed in the Red Hills physiographic region of northern Covington County.

Finally, the association of post oak, blackjack oak, and longleaf pine within the mixed pine-oak community is supported by a study in lower piedmont of Alabama (Golden 1979). These species were found together where topography and soil characteristics produced a dry soil moisture regime (Golden 1979). The study also notes the importance of fire in the region, with increased fire favoring longleaf rather than post oak or blackjack oak (Golden 1979). In combining the habitat characteristics and species composition data from this study, with modern perceptions of this community, a general characterization of the mixed pine-oak community can be derived. This community is a dry, upland community differing from the pine dominated community in its increased clay content of soils, increased slope, and possibly an increased fire return interval. As a result, a xeric oak component is maintained in association with the dominant longleaf pine.

In producing maps of presettlement distribution of derived communities, data concerning the total area allocated to each community can be computed (figure 2.9).

Figure 2.9. Model Allocation of percent area by witness tree community for Escambia and Covington counties, Alabama.



Caution is recommended in interpreting the area estimates by community. In interpreting any reconstruction of presettlement forests, the source of the data must always be at the forefront. As an example, surveyors avoided swampy habitats in some cases, thus reducing the overall sample of species associated with these habitats. In the raster surfaces shown, this bias is partially corrected because associations between swampy habitats and certain communities are considered across the landscape, despite the fact that surveyor sampling of these habitats may have been unusually low and isolated. Correction for the sampling is not complete; however, as the abundance of samples allocated to given class affects the community probability value per cell.

I believe that the multinomial logistic regression model was improved with the reconstruction of presettlement forests on a community basis. Some studies have attempted to test associations with environmental variables on a species basis. In these studies, the results are even more susceptible to surveyor bias and deficiencies in identifying species. In this study, the modeling of communities is the most reliable way of producing high resolution maps of presettlement forests. Put simply, analysis on a forest community basis reduces the impact of witness tree data problems, while providing a basis for comparison with previous notions of presettlement forests.

CHAPTER THREE

THE ROLE OF FIRE AND ANTHROPOGENIC DISTURBANCE IN PRESETTLEMENT SOUTH ALABAMA FORESTS

Introduction

It is widely accepted that fire was an important mechanism impacting the distribution of vegetation in the Gulf Coastal Plain prior to European settlement (Glitzenstein et al. 1995). Fire was the primary factor acting to maintain longleaf pine ecosystems and in controlling the encroachment of hardwoods into the understory, mainly confining hardwood communities to riparian corridors protected from fire (Heyward 1939, Gilliam and Platt 1999). The idea of extensive presettlement open pine forests or savannahs in the region is supported by several sources.

Late 18th century botanist William Bartram described South Alabama as dominated by widely spaced pines, with hardwoods or hammocks located in close proximity to water (1791). Although after the influence of European land use, early 20th century botanist R.M Harper also offered a detailed account of the vegetation in South Alabama, which mirror that provided by Bartram. Harper (1914) describes the distribution of longleaf pine as ranging from dominant to ubiquitous except in swamps and along riparian corridors. Finally, contemporary historical research using Census of

Agriculture records and logging records also point to presettlement dominance of longleaf pine throughout the study area (Frost 1993).

The presettlement dominance of pine has been further supported by witness tree records. Witness tree data from Escambia and Covington counties in Alabama show that of the 12,637 common names recorded, 83.55% were pine. Further, classification of witness trees produced four communities, two of which exhibit environmental relationships and species compositions which suggest the importance of presettlement fire. Odds ratio estimates (table C.1), discussed in Chapter Two, which point to the importance of fire, will be discussed in this chapter.

Native Americans and Fire

While there is general agreement that fire played an important role in shaping the pine dominated presettlement coastal plain landscape, there is much discussion regarding the source of these fires. Closely linked to this debate surrounding potential ignition sources are three hypotheses consistently provided regarding the establishment of open pine dominated forests prior to European settlement. These ideas are scattered throughout the literature but were summarized as follows by Schwartz (1994).

1. Extensive pine forests are the result of Native American abandonment of agricultural fields.
2. Native Americans routinely set fires which substantially contributed to the extension of fire maintained pine ecosystems.
3. Extensive fire maintained habitats are the primarily the result of lighting ignitions.

Typically, characterizations of pre-Columbian Native American land-use have suffered from a variety of faults. Among the most important faults are the lack of data to support arguments and the tendency to make sweeping statements regarding the extent of aboriginal land-use. Broad statements regarding the Native American land use, and especially fire, are unreasonable given the variation in Native American cultures across time and space (Williams 2000). Further statements such as Native American burning was "almost universal," fail to account for spatial variation in vegetation, which dictates optimal land-use for a particular ecoregion (Kretch 1999). Often literature containing broad statements regarding the extent of Native American land use were a reaction to early writings discounting the potential for this type of impact (Martin 1973). Regardless of the reasons, these generalities can be misleading. Additional problems with past studies of Native American land use include; focus on land-use practices that would not result in broad ecological changes, ignoring natural explanations for ecosystem change, misinterpretation of historical sources, reliance on secondary sources, dependence on hearsay or third-party accounts, and imprecision regarding the study area and the tribe of interest (Williams 2000).

Despite these weaknesses in the literature, a consensus has been reached regarding the main reasons for Native American use of fire, the benefits yielded, and the need to integrate more diverse sources to address the role of presettlement Native American land use. In describing the need for diverse data sources to characterize burning in Virginia, Brown (2000) states that the "…study of the role that Indian fire use played in Virginia's presettlement ecosystems would require examining evidence, both qualitative and quantitative from multiple sources." Recent efforts have accepted this advice, and worked to combine witness tree data with archaeological or historical data (Batek et al. 1999, Foster et al. 2004).

Quantitative evidence is of primary importance in any discussion of the use of fire. All too often, anecdotal evidence from early explorers, characterizing the open structure of forests has been the baseline from which a discussion on Native American use of fire proceeds (Hammett 1992, Brown 2000). This is especially problematic because this information provides little evidence of fire’s spatial scope or even that this disturbance operates on a landscape scale.

The literature on Native American land use and fire has essentially agreed on two, related points. First, there is a general recognition that Native Americans operated as practical managers of their environment. Wall Kimmerer and Kanawha Lake (2001) describe the relationship between Indians and their environment as “an adaptive symbiosis” while Hammet (1992) refers to Native Americans’ sculpting of a“functional landscape.” Whatever the name given for this phenomenon, there is agreement both in the US and abroad, that native peoples have a long history of managing the environment in a sophisticated manner, geared towards their benefit (Laris 2002, Yibarbuk et al. 2001).

A second, related point, consistently reported in the literature, is the idea that Native Americans often developed patchwork or mosaic landscapes through burning (Wall Kimmerer and Kanawha Lake 2001, Hammett 1992, Lewis and Ferguson 1988, Laris 2002). The practical benefit for employing this type of burning regime is in producing a heterogeneous landscape, through variation in successional status; which leads to an increase in the diversity of food sources and the overall abundance of food (Wall Kimmerer and Kanawha Lake 2001).

One area in which the literature provides no clear answers is in the discussion of the relative importance of lightning ignitions versus anthropogenic fire (Martin 1973). As mentioned by Williams (2000), in some cases the potential of natural causes of disturbance have simply been overlooked. In other instances, weather patterns associated with the study area easily eliminate lightning as a plausible, chronic ignition source (Brown 2000). Study areas such as South Alabama clearly have the confounding factor of lightning ignited fires, making the unique role of Native American fire use difficult to address (Komarek 1964, Hammet 1992, Schwartz 1994). In addressing the relative role of lightning and anthropogenic ignitions, data concerning season of burn coupled with the natural history of pyrogenic species may help clarify the dominant ignition source. The specific difficulties of delineating the role of lightning versus Indian ignition and other challenges associated with studying the Eastern ecosystems are described here by Kretch (1999):

> "...determining the ecological consequences of fire, and the precise Indian role, is a more daunting task than unearthing the widespread anecdotal evidence of burning. Yet even where the relationship between fire and forest is relatively inaccessible, there is much about which one can speculate. The East is one such region that is difficult to approach, in large measure because at a very early date, the Indians succumbed to epidemics and the Europeans altered landscapes, and the earliest written historical sources are frequently anecdotal or ambiguous."

With specific regard for these difficulties, the weaknesses in the literature regarding Native American land use, and the three hypotheses relevant to this study site, the following objectives were defined:

1. Witness tree data will be used to establish the importance of fire on the presettlement landscape. A portion of this objective will be completed using data already presented, with a particular focus on fire related environmental variables. Additional information such as witness tree bearing distance and qualitative surveyor descriptions will also be presented.

2. Provide a characterization of Native American settlement and land use in the study site immediately prior to the General Land Office surveys.

3. Discuss the three hypotheses presented given our characterization of the landscape with witness tree data, and the knowledge imparted regarding Native American settlement.

Methods

The methods required for classification of witness trees into communities, analysis of relationships between communities and environmental variables, and map outputs are described in detail in chapter one of this thesis. Relationships between environmental variables and witness tree communities are discussed in a general nature in this chapter, for detailed information see Appendix C (table C.1). For detailed description and analysis of these results refer to chapter two.

The distance from a section corner to witness trees is generally referred to as bearing distance. Examination of these data is used to describe the relative openness of the forest (Nelson 1997). Differences in bearing distance between communities as well as pairwise comparisons were made using the non-parametric Kruskal-Wallis tests. This procedure, which allows for analysis despite violations in normality, determines significant differences among groups by ranking independents (Ramsey and Schafer 2002). Because significance is determined by rankings, no conclusions are made regarding the extent of differences among witness tree communities (Ramsey and Schafer 2002).

Associations between witness tree communities and surveyor qualitative descriptions were assessed using 2 X 2 contingency tables. Qualitative surveyor descriptions were coded and cell counts with respect to community were analyzed using the SAS Proc Freq statement (Stokes et al. 2000). The likelihood ratio chi-square was used to determine significance of association, while odds ratios were used to determine whether associations were positive or negative and their relative strength (Stokes et al. 2000). It is important to note that only approximately 13% of all witness tree samples had a corresponding qualitative description. Associations with descriptions occurring infrequently were not tested.

The primary source of information regarding the location of Native American settlement was the Alabama State Site Files managed by the University of Alabama Office of Archaeological Research. Information regarding the location of the Mitchell site and the Conecuh River site were taken from personal communications with the AASF coordinator (personal communication, Futato). Additional information regarding the Mitchell site was accessed through personal communication with the site archaeologist (personal communication, Jenkins). Details regarding Native American settlement are presented later in this chapter.

The location of the presettlement town of Montezuma was derived from instructions given in *Dead Towns of Alabama* (Harris 1977) This location was verified and additional information regarding the settlement was provided by an archaeologist working at Troy University (person communication, Brooms). A review of historical literature was used to further define the potential land use impacts of Native Americans in Escambia and Covington counties.

Evidence of Open, Fire Maintained Presettlement Forests

The argument for a fire maintained and largely open structured presettlement forest is based on 3 different data sources all derived from the GLO public lands surveys. The first evidence is taken directly from Chapter Two. Specifically, species composition of witness tree communities and their relationships with selected environmental variables as reported in Chapter Two will be discussed with respect to fire. The second source of evidence of open forest is derived from surveyor qualitative evidence. This information will be tested for association with derived witness tree communities. Finally, information on bearing distance will also be introduced in support of the idea of open, fire maintained forests.

Several important inferences can be made regarding the role fire played in the distribution of presettlement witness tree communities using the information presented in Chapter Two. The classification of witness trees produced 4 discernable communities including the pine dominated community, hardwood community, mixed pine-oak community and the bay community. Of these, the mixed pine-oak and pine dominated communities both exhibit the characteristics of a pyrogenic system. Specifically, the species compositions of the two communities as well as their relationship with certain environmental variables indicate that they are both fire maintained communities.

According to witness tree survey records, the most dominant community across the landscape was a pine dominated community, comprising approximately 55% of land mass within Escambia and Covington counties. The community was derived from cluster analysis using a sample by species matrix of relative density. This output community is composed of 100% pine. The distribution of this community with respect to environmental variables allows for inferences regarding which species of pine are components of this derived community. The speciation of pines is discussed at length in the Chapter Three and thus will be only briefly reviewed here.

Odds ratio estimates from the logistic regression model provide information regarding the distribution of these communities in relation to environmental variables. Examination of odds ratio estimates concerning the pine dominated community support the idea that the main component species of this community is longleaf pine. In comparison to the non-pyrogenic bay and hardwood communities, the odds of locating the pine dominated community were increased given low organic matter/fertility, typically upland Udult soils and greater distance from water. Longleaf dominance in the low fertility soils of the coastal plain is well documented (Grace et al. 2000). Further, because of increased distance from water and upland location, one can infer that an upland longleaf pine community has been defined by cluster analysis. The distance from water and association with “upland” soils reduce the likelihood that slash pine, generally associated with “flatwoods” habitats, is major component of this community (Grace et al. 2000). Further, these relationships with environmental variables of low slope, high distance from water, and upland, well-drained soils indicate a community primarily distributed in xeric habitats.

The odds ratio estimates have essentially provided a description of a dry upland longleaf pine community. Observation of remnant longleaf stands coupled with modern experience regarding fire suppression point to the fact that longleaf pine communities persist because of fire (Garren 1943, Grace et al. 2000). Longleaf exhibits a variety of characteristics which make it well-adapted to frequent fires. Fire resistant adaptations include; buds which have a high heat capacity and are protected by the sheaf of long needles, thick bark as a juvenile, and “bolting” from the grass stage, which lifts the terminal bud above potential surface fire (Grace et al. 2000). Among these adaptations, longleaf is set apart from other southern pines in its high fire tolerance as a seedling and its increased regeneration given an active fire regime (Grace et al. 2000, Gilliam and Platt 1999). Further, the interaction between this dry environment and the vegetation itself (pyrogenic leaf litter and flammable grass ground cover) likely produced a chronically combustible habitat (Mutch 1970).

Much like the pine dominated community, the mixed pine-oak community derived from witness trees was also likely a pyrogenic community. Again, the species composition coupled with the distribution of this community in relation to environmental variables leads one to infer the importance of fire. This community is composed of 51% pine, 22% blackjack oak, 8% post oak, and 6% non-specific common name “oak” (see Chapter 3).

According to odds ratio estimates from logistic regression, this presettlement community should be found in greater proportions in a xeric habitat. Generally speaking, the distribution of this community with respect to soils was similar to the pine dominated community (see Appendix C, table C.1). With respect to continuous independents, the mixed pine-oak community is clearly located in drier habitats compared to the hardwood and bay communities. Although clearly xeric in nature compared to the hardwood and bay communities, odds ratio estimates indicate that the mixed pine-oak is a slightly less xeric community compared to the pine dominated community. In comparison to the pine dominated community, the odds of locating the mixed pine-oak community is reduced with greater distance from water, but increased given greater slope. Despite this information, the question remains-what does this information mean in terms of species composition and presettlement fire regime in the presettlement mixed pine-oak community?

First, because of the weak association between this community and Udult soils, and the inability to differentiate this community from the pine dominated community based on soils, one would expect the dominant pine species to remain longleaf pine (Grace et al. 2000). Despite this however, because of the other habitat characteristics like increased slope, one would expect other, slightly more fire sensitive species to be components of this community. In association with the dominant longleaf, it has been suggested that under "natural" or presettlement fire regimes, only a few xeric oak species would be able to invade the midstory (Grace et al. 2000, Rebertus et al. 1993). The list of component species in the mixed pine-oak forest points to this being the case in Covington and Escambia counties. This is especially convincing in light of the fact that the common name blackjack oak likely was used to refer to all xeric oak species (*Quercus marilandica*, *Q. incana*, and *Q. laevis*). Additionally, post oak was often grouped into this community and the odds ratio estimates coupled with other xeric associates indicate that this common name likely refers to the xeric sand post oak (*Q. margaretta)*.

It has been suggested that this mixed pine-oak community described here was likely maintained by the spatial and temporal variation of presettlement fire regimes.

Essentially, the prevailing theory is that slightly reduced fire frequency would allow the invasion of midstory xeric hardwoods into the formerly longleaf dominated community (Grace et al. 2000, Rebertus 1993). This greater interval in fire return would benefit the xeric oaks, because, although considered vigorous re-sprouters, they are not as fire tolerant as juveniles compared to longleaf pine (Grace et al. 2000). In addition, season of burn may also have been important in the maintenance of the mixed pine-oak community, as the xeric oaks compete poorly given a growing season burn (Glitzenstein et al. 1995).

In reference to our models produced in Chapter Three, the overall low probability of locating the mixed pine-oak community is supported by this idea of a patchwork community across the landscape-pyrogenic in nature but less so than the pure longleaf communities. Potential explanations for this habitat of slightly reduced fire frequency include a slight shift in available moisture (higher slope values were associated with mixed pine-oak compared to the pine dominated community) or the interaction between the environment and the vegetation. In other words, once the xeric hardwoods invade by chance, they perpetuate this higher fire return interval by producing a slightly less combustible habitat (Rebertus et al. 1993, Mutch 1970).

Additional information, beyond community environment relationships and community species composition, support the case that the pine dominated and mixed pine-oak communities were fire maintained assemblages. Surveyors working in Escambia and Covington counties sporadically included qualitative descriptions of the presettlement landscape (Appendix A, table A.1). The information regarding topography and soils simply provides an avenue for testing associations already explored using logistic regression. The vegetation or timber descriptions provide specific information pertaining to the discussion of presettlement fire regimes. Of particular interest is the question whether the fire attributed characteristic of open woods is more commonly associated with the pyrogenic pine dominated community and mixed pine-oak community.

Table 3.1. Association between surveyor qualitative descriptions and witness tree communities, Escambia and Covington counties, Alabama. Odds ratio estimates from contingency table analysis. Significance of associations was determined with.* indicates associations that are not significant, according to the likelihood ratio chi-square at $p < 0.05$. All others are significant at $p < 0.001$.

Witness Tree Community	**“Open” woods**	**Swampy/Swamp land**
Pine dominated	4.29	0.26
Hardwood	0.23	3.11
Mixed Pine-Oak	*0.94	*1.17
Bay Community	0.14	7.20

Odds ratios show the increase or decrease in odds of locating each community given the presence of surveyor qualitative descriptions. In terms of interpretation, an odds ratio less than 1 means that odds of locating the community are reduced given the surveyor description. Alternatively, a number greater than 1 shows an increase in odds of a community given the surveyor description. An odds ratio close to one implies a negligible or weak association.

Table 3.1 indicates that when a description was given, the terms “open” or “open pine woods” were positively associated with the pine dominated community derived with cluster analysis. This information reasonably supports earlier inferences that this pine dominated community is pyrogenic in nature. As stated earlier, an open longleaf pine community would be quickly be invaded by hardwoods and other pines without the influence of periodic fire. Unfortunately, odds ratio estimates regarding the description “open” showed no significant association with mixed pine-oak community. The lack of association could be a result of higher density woods, or unwillingness on the part of the surveyor to assign these terms to anything other than pure pine stands.

Additional odds ratio estimates simply confirm previously held notions of the derived witness tree communities. The hardwood and bay communities were both negatively associated with the surveyor description of “open.” This in conjunction with odds ratio estimates with respect to environmental variables indicates that each these communities were composed of denser vegetation and were likely protected from frequent fire. Not surprisingly, the description “swampy” was most positively associated with the bay community and the hardwood community.

The Kruskal-Wallis test was used to determine if there was a difference between bearing distance across the four witness tree communities. This non-parametric method was used because of the non-normal distribution and the presence of true outliers in the bearing distance data (Ramsey and Shafer 2002). The test yielded significant differences in bearing distance among the 4 communities ($p < 0.0001$). Kruskal-Wallis test was also used for pairwise comparisons among the four communities. Pairwise comparisons revealed that bearing distance within the pine dominated community was greater than that exhibited by the hardwood or bay communities ($p < 0.0001$). Differences between bearing distance among the pine dominated and mixed pine-oak communities were not significant ($p = 0.2865$). However, the mixed pine-oak community did exhibit significantly greater bearing distance compared to the hardwood and bay communities ($p < 0.0001$). Finally, bearing distance within the hardwood community was greater than the bearing distance of the bay community ($p < 0.0001$). These findings with respect to bearing distance further support the assertion that the pine dominated and mixed pine-oak communities are open in nature and have been impacted by an active presettlement fire regime.

Species composition of the four communities established by cluster analysis led to the inference that the presettlement pine dominated and mixed pine-oak communities were fire maintained. Further, odds ratio estimates reported from the logistic regression output also support this notion. First, community associations with environmental variables indicate probabilities of locating these two communities were increased given a xeric suite of environmental conditions. Xeric environmental conditions include increased distance from water and association with upland well-drained soils for the pine dominated community. The mixed pine-oak community did not exhibit clear soil suborder associations, although probabilities of locating this community were higher given greater distances from water. In addition, these dry site characteristics have allowed reasonable conclusions regarding the likely component pine species. The argument for the pyrogenic nature of the mixed-pine oak species was strengthened by the large component of xeric oaks within the community.

Finally, the prominent role of fire across the two county study area, was bolstered by the surveyor qualitative descriptions of an “open” landscape with respect to the pine dominated community. Additionally, differences in bearing distance were noted across the four communities, with emphasis on the higher values associated with the pyrogenic pine dominated and mixed pine-oak communities. In light of this powerful argument for significant presettlement open pine forest, and a likely role of fire in maintaining them, the goal of this paper shifts to understanding the controlling factors in establishing such forests. Before addressing the host of associated questions, it is important to first document the extent to which anthropogenic disturbance may have influenced the structure of presettlement forests.

Historical Context of GLO Surveys and Evidence of Native American Settlement

In addressing the impact of anthropogenic disturbance, the peoples responsible for land use impacts must first be identified. In covering the two county study area, field note data were recorded from 57 Townships. All surveys were conducted between 1820 and 1846, with over 98% of all witness tree points recorded between 1820 and 1826. Creek Indians did not officially surrender this land until 1814 (Ward 1991). It was not until 1819 that Alabama gained statehood and the Cahaba and Sparta land districts were established to begin surveying the area (Ward 1991). Land sales to white settlers were limited until the late 1830's and early 1840's (Ward 1991). In light of this timeline, the surveys are indeed representative of the forests prior to any substantial European land use.

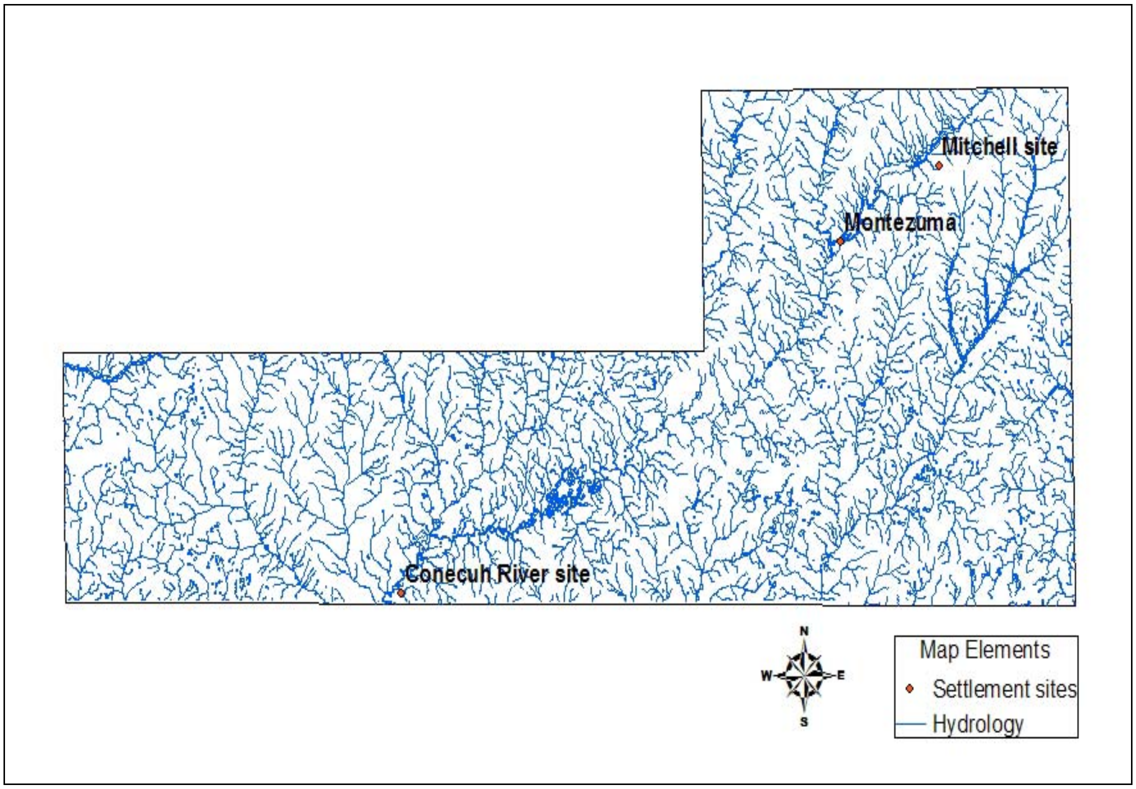
Therefore, Native Americans were the only group capable of influencing the landscape prior to the generation of General Land Office surveys. Potential land use impacts on the part of Native Americans are considerable. Potential land-use scenarios includes broad scale burning to increase wildlife browse and thus available game, burning as a hunting technique, burning of agricultural fields in preparation for planting, burning to improve ability to travel and visibility, and the collection of woody debris in proximity to settlement sites (Martin 1973, Hudson 1976, Foster 2001).

As a result of water availability and fertile soils, Native American settlements in the Southeast were generally located in flood plain areas of significant rivers, with agricultural fields located immediately adjacent to towns (Hudson 1976). Native American use of fire is clearly the most likely and most efficient way in which Native Americans may have imparted broad scale influence on vegetation (Wall Kimmmerer and Kanawha Lake 2001). With respect to burning, Hudson (1976) notes that “Indians actually modified the forest cover far out of proportion to their numbers.” Although while traveling through Florida, Bartram (1791) noted fires as a daily occurrence, most scholars have suggested that Southeastern Indians generally burn in the winter (Hudson 1976, Glitzenstein et al. 1995). There is also evidence that the practice of burning was entrenched in culture of Southeastern Indians, as lightning and fire were often associated with purity (Hudson 1976).

In order to address the role of Native American land use in Escambia and Covington counties, knowledge of their presence immediately prior to the public land surveys must be established. If these potential impacts are to be documented with witness trees, the size of the population in addition to the approximate date of abandonment is of primary importance. Population is especially important given the primary types of land use; large populations would be needed for agricultural practices to be noticeable, while only a small population would be needed for burning to have discernable impacts.

By all accounts, Creek Indians were the primary group controlling the land within modern Escambia and Covington counties immediately prior to European settlement (Hudson 1976). The following map shows all known Native American settlements located within the study area. Characteristics of each settlement and the source used to identify the settlement will be discussed individually.

Figure 3.1. Identified presettlement Native American settlement sites and hydrology for Escambia and Covington counties, Alabama.



As illustrated in figure 3.1, all Native American settlement sites identified are classic with respect to their location near significant water sources. Two of the settlement sites identified (Conecuh River site, Mitchell site) were abandoned at the latest by 1600 A.D (personal communication, Futato). Both settlements were of the Pensacola culture. The Conecuh River site was relatively small, 100 X 200 meters, with evidence suggesting that it was a seasonal hunting encampment (personal communication, Jenkins). Despite its seasonal nature, inhabitants would have likely established garden plots growing mainly corn, beans, and squash (personal communication, Jenkins). The Mitchell site was slightly larger (400 X 300 meters) and likely maintained a year round population (personal communication, Futato). Agricultural fields may have covered as much as 10 acres (personal communication, Futato).

The settlement site of Montezuma is mentioned in several historical sources concerning Covington County (Ward 1991, Harris 1977, Bryan and Bryan 1985). In 1826, Montezuma had Covington County's first Post Office and served as the County seat (Bryan and Bryan 1985). Prior to 1815, there were very few if any white settlers in Covington County, yet Montezuma had already been established (Bryan and Bryan 1985). The name suggests a Spanish influence, by way of Desoto's exploration of Mexico, yet aboriginal cemeteries along the Conecuh suggest the town may have its origins as a Native American settlement (Bryan and Bryan 1985). Further evidence of Native American origins is the location of Montezuma along the path of the Indian Ridge Trail which starts in Pensacola (Bryan and Bryan 1985). However, little can be said definitively about the origins of Montezuma and its location is only an estimate.

Other sites were mentioned in the historical literature, but the information regarding their location is vague. For example, in the *History of Escambia County, Alabama* a settlement was noted in military records that put the settlement in Escambia County, Alabama: "…20 miles East of Ft. Crawford in Escambia County, probably on the Blackwater Creek, stood a village [Native American] of considerable size (Waters 1983)." Because of the non-specific nature of information this settlement, as well as others, they could not be accurately mapped as needed for the purposes of this study.

The early abandonment dates coupled with the inexact information regarding settlement location inhibited the ability to proceed with any sort of catchment analysis of species, distance from settlement, or bearing distance (Foster et al. 2004). As a result the hypotheses regarding Native American land use could not be tested with the witness tree records. Important inferences regarding their influence on the landscape, however, can be outlined given an adequate understanding of the history of this region. Key elements of this history indicate that the 300 years leading up to the public land surveys was a period of transition for the lower Creeks in South Alabama.

This period of transition began with the explorations of Hernando De Soto in the late 1530’s and early 1540’s. De Soto explored much of the Southeast often violently attacking Indian villages in search of gold or other valuables. While De Soto and other early explorers inflicted hardship upon the Native Americans by attacking their villages, the Indians as a whole suffered most from their exposure to western diseases (Hudson 1976). A later expedition, led by Tristan de Luna in 1559, reported a dramatic reduction in Native American populations along the Alabama River near the Gulf Coast (Hudson 1976). In the 1730’s the Cherokees, the Creeks northern neighbors, experienced a smallpox epidemic which reportedly killed nearly half of the population (Hudson 1976). Given the experience of neighboring peoples, it is not unreasonable to think that the Creeks in South Alabama encountered similar severe losses due to exposure to new diseases.

The time period immediately preceding the General Land Office public land surveys was also a tumultuous period for the Creek Indians that controlled the land in current Escambia and Covington counties. Of particular importance in this region was the Creek Indian War of 1813-1814. The war was representative of a split among Creek Indian leadership as to how to face the pressures of American expansion. A faction called the Red Sticks, made up of mostly Upper Creeks, took a violent and aggressive anti-American approach, while the Lower Creeks maintained an air of neutrality (Sugden 1997). This neutrality soon changed however, as the aggressive actions by the Red Sticks encouraged white settlers and eventually the U.S. military to retaliate against all Southeastern Indians. Fearful of white retaliation, the previously neutral Lower Creeks now took up arms against the Red Sticks, essentially dividing the Creek Nation (Sugden 1997).

Important events in the Creek War took place in and near the Escambia and Covington counties study area. The Battle of Burnt Corn Creek took place in north, central Escambia County, in which the Red Sticks routed a portion of the Mississippi Territorial militia (Sugden 1997). Within 50 miles of our study site was the battle at Fort Mims on the Alabama River, in which the Red Sticks successfully raided and defeated U.S forces (Sugden 1997).

Despite appeals to the British and Spanish, the Red Sticks became increasingly isolated in their war against the Americans. This led to their eventual defeat at Horseshoe Bend in 1814 (Hudson 1976, Sugden 1996). Following this defeat, major tribes in the Southeast were able to maintain some lands, but they were isolated, and the floodgates were opened for American settlers. Modern day Escambia and Covington County lands were ceded to the U.S. in 1814 (Ward 1991). The Creeks strongly resisted removal, and even until 1838, they maintained a small presence in Alabama (Hudson 1976).

Given this history, some conclusions can be drawn about the likely impact of Native Americans on the forests of Escambia and Covington counties. First, it is extremely likely that the Native Americans had some impact on these lands prior to 1600, as our map indicates two Mississippian sites in the two counties. The Native American population in Escambia and Covington counties in the 300 years prior to the pubic land surveys however, was likely never large. Most major settlements in this period were located north along the fall-line, where both piedmont and coastal plain resources could be exploited (Hudson 1976). Populations were also denser along the coasts, presumably to take advantage of the abundance of fish and other resources (Hudson 1976). In fact, the area north of Pensacola was referred to as a hunting territory by Bartram, which was "a solitary, uninhabited wilderness (Waselkov and Braund 1995)." To summarize, immediately prior to the surveys, Creek Indians controlled and were present in the study area, but did not establish permanent settlements.

Discussion

This study has been successful in addressing many of the methodological weaknesses associated with previous attempts to characterize presettlement Native American land use. Rather than relying on anecdotal evidence of "open" landscapes, primary characterization of the presettlement landscape was derived from General Land Office public land surveys. Witness tree data supplied a strong case that two of the defined witness tree communities exhibit an open structure, fire tolerant species composition, and relationships with environmental variables which indicate pyrogenic communities.

Further, this study is distinguished from previous studies in that it has a tightly defined study area. A limited spatial extent has allowed exploration of the likelihood of Native American impacts, by locating known presettlement village sites. In addition, limiting the spatial scope of this study, allows the researcher to develop a clear history of the region as it pertains to Native American settlement. In general, a well-defined study site eases the integration of sources, and builds a stronger case from which to address the central question of this chapter-what disturbance maintained the presettlement structure of Escambia and Covington counties?

Given the low Native American population within the study site prior to the surveys, one can safely eliminate the first hypothesis regarding the maintenance of open pine dominated forests; that they were the result of abandonment of extensive agricultural fields. This leaves fire as the only logical disturbance which could have maintained this forest structure. At this juncture in the discussion, focus will shift to the source of presettlement fire.

In light of the evidence already presented, the Lower Creeks most likely used the land contained within this study site as hunting grounds. The literature indicates that fire use related to hunting could occur in two primary fashions; either as a means to capture prey or burning to stimulate the growth of browse for potential prey (Wall Kimmerer and Kanawha Lake 2001, Hammett 1992). Burning to stimulate wildlife populations is a fire use intrinsically connected to the production of heterogeneous landscapes and is well-documented Native American land use practice. Although a well-established use of fire, the question of interest here is whether hunting parties created a successional mosaic to exploit the resources of Escambia and Covington counties.

Given the literature and information on Native American settlement, burning to create a successional mosaic within the study area seems very unlikely. First, prescribed burning by Native Americans in the Southeast has been generally associated with communal hunts and large groups (Hammet 1992). It seems unlikely that this size gathering would take place at such significant distances from their permanent settlements located along the fall line (Hudson 1976). Along the same lines, exploiting the resources produced through burning would have required considerable travel. Burning without exploiting the positive results runs counter to the generally accepted characterization of Native Americans as practical managers of natural resources. Each of these facts makes Native American burning to create a patchwork landscape an implausible explanation for the open, fire maintained landscapes within the study area.

The second way in which hunting groups may have used fire is as a specific hunting technique. In general, fire was used as a means of driving wild game. This could mean forming a fire ring and driving game towards the middle, or driving game towards natural barriers, where they could be easily killed (Hammett 1992, Brown 2000). Although possible, the use of fire in this manner would also have been unlikely in South Alabama for one primary reason-this type of fire was also associated with large groups of Indians (Hammett 1992, Brown 2000). The use of fire ring or fire circle was a communal activity, reserved for special occasions, and often requiring 300-400 participants (Hammett 1992, Brown 2000). It seems very unlikely that this type of activity would occur at significant distances from permanent settlements. Finally, even if this fire use was common in South Alabama it would not result in an open structure to the extent described by the witness tree data. These fires would have been limited in spatial extent, and control over the fire would have been paramount to success (Hammett 1992).

In light of the lack of Creek settlement in the region, and the turmoil associated with period from 1800-1820's, I would argue that Creek Indians were likely only a minor and sporadic influence on the fire regime immediately prior to the public land surveys. Other less significant uses of fire by Native Americans have not been discussed extensively here, such as burning for ease of travel or unintended burning from negligence (Hammett 1992, Martin 1973). These types of fire use alone would not maintain the extent of open forests described by the witness tree data and also run counter to the modern concept of Native Americans as pragmatic, sophisticated manipulators of fire. Acceptance of this type of explanation would signal a return to early stereotypes of Native Americans as crude, negligent, pyromaniacs (Martin 1973).

The general lack of evidence of a considerable Native American population is the strongest evidence against a strong role of Native American fire in presettlement Escambia and Covington counties. As Kretch (1999) states, "…there was most likely considerable variation linked to population size and density, with the greatest frequency of fires (and greatest ecological impact) found where the population was highest and the land most densely settled." Native American influence within the study area would have come primarily from a Lower Creek population, dramatically reduced in size due to disease, undergoing political turmoil, and operating at a considerable distance from permanent settlement (Foster 2001). These factors make a strong case against a significant component of Native American ignitions.

Another, more plausible source of ignition in South Alabama is lightning, generally associated with warm weather thunderstorms. According to data reported from NASA satellites, South Alabama falls into a region of the U.S. which experiences extremely high numbers of lightning flashes per year at approximately 40 flashes/square kilometer (Price et al. 2001). According to contemporary data from Florida, which exhibits similar weather patterns compared to South Alabama, lightning caused fires are minimal in April, highest in May and June, slightly less in July and August, and greatly reduced in September and October (Komarek 1964).

This information delineates an importance difference between potential sources of fire. Lightning ignitions are concentrated in the growing season, while Native American burning in the Southeast is historically considered a winter event. The season of burning by Native Americans is not entirely clear, however sources regarding the Southeast indicate fire as a means of clearing land generally took place in the winter, while fire ring hunts were autumn events (Brown 2000, Hudson 1976). Further, following modern perception of Indians as practical managers, burning would likely only occur when the forest was not susceptible to catastrophic fire (Williams 2000). Modern prescribed burning in the coastal plain generally takes place in the winter to avoid this scenario.

Information from the witness tree data and life history traits of component species indicate a study site marked by growing season, lightning ignited fires. The pine dominated community, comprising 54% of the total area of the study site, consists of 100% pine, most of which was likely longleaf pine. Such a huge area of only pine indicates that fire was likely active in restricting invasion by hardwood species. Interestingly, modern studies have shown that growing season fires produce topkill in hardwoods and are efficient in maintaining pure longleaf stands (Glitzenstein et al. 1995). In light of this information, presettlement lightning fires would have been efficient in maintaining this expansive pine dominated community.

Finally, this chapter is unique with respect to its conclusions regarding presettlement fire regimes. All evidence indicates that the open forest structure of presettlement Escambia and Covington counties, prior to the GLO surveys, was maintained with mainly lightning ignited fires. These results point to the need to address the role of Native Americans in shaping presettlement forests in a spatially explicit manner, and thus avoid wrongly attributing or exaggerating the extent of Native American impact on presettlement forests.

CONCLUSIONS AND IMPLICATIONS

Results presented in this thesis fall into three distinct categories including methodological guidelines in the use of witness tree data, detailed description of presettlement South Alabama, and increased understanding of the presettlement fire regime impacting forest communities. The findings presented have the potential to inform future management decisions within the region. Specifically, the relevance of this research to management or policy resides in the description of a baseline or reference ecological condition. The utility of understanding historical landscapes has been recognized by many including Aldo Leopold who stated (1941): "a science of land health needs, first of all, a base datum of normality, a picture of how healthy land maintains itself as an organism." The goal of this chapter is to review the three main contributions of this thesis and to discuss the implications of these findings for management.

Methods and Management Ramifications

In comparing the methods used in this study with those used in previous witness tree research, several important recommendations for future work with this data source were yielded. Recommendations for future witness tree work include early analysis of data flaws, incorporating an understanding of these flaws in subsequent analysis, consideration of scale problems involved with environmental sampling and community analysis, and providing an honest assessment of the assumptions underlying witness tree analysis. One of the challenges facing all research in historical ecology is the inherent flaws in the data (Swetnam et al. 1999). Common flaws plaguing historical data sources are summarized by Swetnam et al. (1999): "the most important limitation of historical ecology is that the record of the past is often brief, fragmentary, or simply unobtainable for the process or structure of interest." In light of these problems, researchers in historical ecology are in some ways at the mercy of their dataset. Instead of gathering data with the specific purpose of testing a hypothesis, the historical ecologist often needs to design their analysis around the inherent flaws in the data. This does not mean that researchers should abandon questions of interest, but rather that they should be flexible in terms of how they address problems, with a specific eye towards the inherent flaws of the data.

There are two examples of flaws or weaknesses in the witness tree data of Escambia and Covington counties that affected the methods chosen. First, the problem of common name inconsistency across surveyors witness tree shaped subsequent analysis. Specifically, the problem of shifting common names among surveyor groups made the formation of witness tree communities and subsequent analysis on a community basis logical. Analyzing the data on a community basis made results less susceptible to the inconsistencies or bias among surveyors.

A second challenge associated with the witness tree data was the lack of direct evidence regarding presettlement fire. In GLO surveys conducted in other regions, surveyors consistently noted disturbance, offering some hope that similar data would be available in South Alabama surveys (Canham and Loucks 1984). Without specific reference to fire, methods shifted to using the data available to construct an argument for open, fire maintained forests. This included analysis of bearing distance, qualitative surveyor descriptions, and the examination of forest community and environmental variable relations specific to fire. These two challenges associated with the witness tree data used in this study, inconsistency in the use of common names among surveyors and lack of direct fire evidence, point to the need for researchers to understand the flaws in their data and to exhibit flexibility in the face of these concerns.

Scale problems, or the inattention to potential scale problems, are a second reoccurring problem in witness tree analysis. The literature revealed scale problems present in two consistently used steps in analysis, including the geo-referencing of witness trees and the formation of witness tree samples. The methods used in geo-referencing witness trees are generally inconsistent and often ambiguous. In some cases bearing distance and compass bearing are incorporated in deriving witness tree location, while in some studies this information is not used. Additionally, some studies use the term “transcribe” to describe the process of locating witness trees from plat maps, while others used field note data within a GIS to locate witness trees. In identifying these discrepancies in geo-referencing methods, the most important point is that future studies should be clear regarding the method chosen and how this may affect further analysis.

The progression of witness tree analysis often includes the sampling of environmental variables within a GIS, or sampling in order to define witness tree communities. Generally, the sampling of environmental variables seemed reasonable, and researchers were consistently aware of scale related problems inherent in this portion of witness tree analysis. Weaknesses in the methods used to define witness tree communities, however were not as clear and logical. The most common weakness in this step of analysis was the use of broad scale samples. For example, in one study, samples were defined as all witness trees falling within a 1-km grid. These broad scale samples are problematic in that they may report associations between species that are not really present. More specifically, with the likelihood of habitat variability over a 1-km distance, trees located within a sample of this size may have no real association. This study recommends the use of spatially explicit samples, such as section corner and quarter corner samples, so that the species associations identified are more likely meaningful.

The last major finding, described in detail in Chapter One, was the overall lack of researcher acknowledgement regarding the assumptions underlying witness tree analysis. One of the most overlooked assumptions deals with defining relationships between modern GIS datasets and historic witness tree records. For example, although differences are likely subtle, modern GIS datasets of soils or topography have likely been altered by 200 years of land use, possibly weakening relationships with witness tree distribution. The assumptions underlying this study are discussed in detail in Chapter One.

Many of the methodological criticisms discussed in Chapter One may be a result of the format in which they are presented. Put simply, the often truncated publication format is short on methods while emphasizing results. In my view, this can cripple the validity of findings, especially with witness tree studies and other types of historical ecology, where assumptions are abundant in any analysis. The lack of extensive discussions of methodology could have serious repercussions for the impact of this research in management or policy. With the most discerning readers, a lack of information on methods could lead to the discounting of valuable information.

Conversely, other managers, without an understanding of the methods required in analysis may simply accept the findings of a given study or extend findings beyond there intended scope. The worst case scenario, from a scientific perspective, is that managers and policy makers, unable to consult an objective methods section or discussion of underlying assumptions, will choose to use information gained in historical ecology based on the degree to which it supports their management agenda or perspective.

Presettlement Forests and their Management Implications

In describing the presettlement forests of Escambia and Covington counties, the following information was presented including: (1) common name abundances and the likely corresponding species, (2) witness tree classification into four communities, (3) relationships between selected environmental variables and witness tree communities, (4) map products, and (5) community area estimates. Species abundances and community area estimates provide unique, specific information regarding the presettlement forests of Escambia and Covington counties. The species composition within the derived witness tree communities and the relationships between these communities and environmental variables, however, generally validate previous notions of the presettlement forests of the Southeast Coastal Plain. Results regarding the presettlement forests of Escambia and Covington counties will be briefly reviewed by witness tree community.

Pine was the most commonly listed witness tree in the survey comprising over 83 % of the total witness tree sample. Unfortunately, there was no attempt by surveyors to speciate pines, with the exception of one surveyor who listed “long leaved pine” in his timber descriptions. Cluster analysis defined a pine dominated community (100 % pine), which according to my model would have covered approximately 54 % of the presettlement study area. In the attempt to determine the likely pine species composing this community, modern perceptions of the habitat preferences of southeastern pines were consulted. Specifically, these perceptions of habitat preferences were discussed in conjunction with witness tree community-environmental variable associations as defined by the logistic regression model. The association of the pine dominated community with low fertility, typically upland, Udult soils and high distances from water, point to this community being composed mainly of longleaf pine.

The mixed-pine oak community, although far less abundant across the study site, was similar to the pine dominated community with respect to its distribution across the landscape. This community, as expected, was located at greater distance from water compared to the bay and hardwood communities. According to odds ratio estimates, the mixed pine oak community was located at reduced distances from water, but increased slope when compared to the pine dominated community. Despite these distinctions however, the mixed pine-oak community and the pine dominated community, compared to the bay and hardwood communities, generally exhibited similar distributions across the landscape with respect to selected environmental variables. This combined with species composition led to our preliminary conclusion that this is predominately a xeric, upland habitat. According to the model, this community would have covered approximately 10 % of the presettlement study area.

The bay and hardwood communities both exhibit differing relationships to selected environmental variables compared to the mixed pine-oak and pine dominated communities. The odds of locating the bay or hardwood community compared to the pine dominated or mixed pine-oak community were diminished given greater distance from water. The primary distinction between these two communities was in relation to slope. Specifically, the bay community was located in the flattest locations compared to all other communities. In contrast, the odds of locating the hardwood community were increased with greater slope compared to the other communities. Further, the hardwood community exhibited the greatest diversity of common names listed compared to other derived communities. In contrast, the bay community was far less diverse, with over 73 % of this community being comprised of the common name bay. Model results indicated that the hardwood community would have comprised approximately 31 % of the presettlement study region, while the bay community would have accounted for only 4 % of the land cover.

From a management and policy perspective, the descriptions of presettlement forests have some potential applications. Much of the information regarding the species composition of derived communities and the relationship between the communities and the chosen environmental variables is validated in the literature. This information is still valuable, however, because it supports previous notions of presettlement forest with an alternative data source. In this sense, the information could serve as additional support for groups interested in a restoration agenda. These findings are especially relevant to the conservation of longleaf pine ecosystems, which have experienced dramatic declines since presettlement times (Frost 1993).

Other information provided in the description of presettlement forests extends beyond the simple validation of widely held notions of presettlement vegetation. For example, Conecuh National Forest located in Covington County may have an interest in the area estimates for the derived witness tree communities. The Revised Land and Resource Management Plan for the National Forests of Alabama specifically addresses the need for restoration of Coastal Plain longleaf forests. In addition this document indicates that future short term changes should result from prescribed burning, natural disturbance, and restoration to native communities (USDA Forest Service 2004). In light of these goals, the Forest Service is likely in need of information regarding the distribution and relative abundance of native communities.

The work presented in this study provides valuable information on reference conditions. The finding of this study are applicable to management and policy, but must be approached with caution. In addition to the underlying assumptions in analysis, the information is only a fleeting description of presettlement forests. In the context of the non-equilibrium paradigm, this information is only snapshot of a landscape in a state of constant flux (Swetnam et al. 1999). Therefore, this information combined with other sources may be most helpful in defining a historical range of variability (Swetnam et al. 1999).

Results Regarding Presettlement Fire and their Management Implications

Chapter Three integrates a variety of information to address the role of presettlement fire and its likely ignition source. The results of this chapter can be separated into two categories including information supporting an open, fire maintained presettlement forest, and information used to delineate the likely cause of chronic presettlement fire. The argument for open, fire maintained presettlement forests was initiated with a discussion of derived witness trees communities and their association with selected environmental variables. This information, already discussed in Chapter Three, was reframed with specific interest in fire. Although no definitive conclusions were drawn from these data, inferences were made as a result of species composition and community relationships with environmental variables. In examining this information in the context of fire, it was inferred that the habitats of the pine dominated and mixed pine-oak communities were xeric in nature and susceptible to frequent fires.

This preliminary conclusion was further supported using mean bearing distance data and surveyor qualitative descriptions. Specifically, results indicated higher mean bearing distances within the pine dominated and mixed pine-oak communities as compared to the bay and hardwood communities. This data supports the idea that these communities exhibited a more open structure that the bay or hardwood communities, with an active fire regime being the only plausible disturbance capable of maintaining this structure across the landscape. Finally, surveyor qualitative descriptions were tested for association with witness tree communities using contingency table analysis. The most significant result of this analysis was the association of the pine dominated community with the surveyor description "open." Although this study lacked any direct evidence of fire, the analysis summarized above built a strong argument for an open, fire maintained forest structure, especially within the pine dominated and mixed-pine oak communities.

After providing evidence of an open, fire maintained landscape the focus of this study shifted to delineating the likely source of ignition for this active fire regime. In addressing this question, archaeological evidence of Native American settlement prior to the witness tree surveys was presented in conjunction with a brief history of the region. This information was discussed in the context of frequent lightning in South Alabama and information regarding season of burn. The history of turmoil for Native Americans in and around Escambia and Covington counties prior to the 1820’s coupled with the lack of significant settlement within the region led to the conclusion that Native American fire was not a major force is shaping the presettlement forest described by witness tree data. A review of literature regarding Native American use of fire overwhelmingly supports the notion that Native Americans did mold a cultural landscape in the Southeast. A tightly defined study site coupled with a narrow temporal scale however, showed that this influence was minimal immediately prior to the GLO surveys. A more viable hypothesis of the region was adopted; that growing season lightning ignitions were likely most important in maintaining open forest structure.

In areas in which restoration is a goal, I believe the findings presented in Chapter Three have two contributions. First, the results show that a sizable portion of the two county study area was dominated by fire maintained communities (60 %). Second, this forest structure was maintained mostly by growing season, lightning ignited fires. These findings should be considered, but may be unreasonable goals for restoration. Restoring the presettlement expanse of open forests would require public acceptance of an increased use of fire. In addition, for safety reasons, shifting prescribed burning to the growing season may also be unreasonable. Another problem is that prescribed burning itself is dissimilar to a natural burn in many ways. Prescribed burns are often intentionally thorough, while a lightning ignited burn would leave a heterogeneous landscape reflecting its varying speed and intensity across the landscape (Slocum et al. 2003).

Extensions of Witness Tree Analysis in Historical Ecology

The majority of the management and policy discussion of these results has been in terms of presettlement forests as a reference condition. In this capacity, the results of this study have a great deal to offer. The relevancy of these findings as reference conditions is evident in the modern concept of ecosystem management. By 1996, 18 Federal agencies and numerous state and local land managers had committed to the concept of ecosystem management, yet in many respects the definition of this approach is still uncertain (Christensen et al. 1996). Attempts to define ecosystem management often include such ideas and phrases as restore, ecological potential, native ecosystem, the recognition of humans as ecosystem components, and biodiversity. At the heart of ecosystem management however, is the concept of sustainability (Christensen et al. 1996). In the context of ecosystem management in particular, baseline presettlement conditions can help address the following questions: What condition should be the aim of restoration? What processes have historically helped maintain a regions native ecosystem? And perhaps most importantly, what system is sustainable given a particular habitat?

As already briefly discussed, the utility of the specific findings of this thesis are subject to questions in relation to the disequilibrium paradigm. In other words, in recognition of the dynamic character of ecological systems, addressing the management questions listed above with only a snapshot of presettlement forests is inherently problematic. In addressing this critique, suggestions for extending the work of this thesis and witness tree studies in general are necessary.

In extending the applicability of this thesis, further work should be conducted in understanding the historic range of variability for the region (Swetnam et al. 1999). This would be best accomplished through the integration of multiple sources, with specific emphasis on extending the temporal scale of this study. Useful data sources in extending the temporal time frame could include fire scar data, fossil pollen data, charcoal particle data, aerial photography, and modern land cover classifications (Egan and Howell 2001). The integration of multiple data sources covering a vast time step is challenging given the varying resolution and scales of the different data sources. Although only extending the temporal scale slightly in addressing the role of Native American fire in the study area, this study illustrates the potential for integrating multiple data sources. Despite the relative success in addressing the role of Native American fire, there may be more effective ways of approaching this question and extending it over a broader spatial scale.

The Archaeological State Site files available in Alabama could serve as a valuable starting point for future studies of Native American land use. Specifically, research could be initiated around known settlement sites inhabited immediately prior to the GLO surveys. From the standpoint of known Native American settlement sites, the witness tree records could be used to answer a variety of questions regarding Native American land use. The Southeast as whole could also benefit from a study regarding traditional ecological knowledge concerning the use of fire. Valuable information may be gained from existent Native American populations and Southerners in general (Putz 2003).

In conclusion, there is a need to extend historical ecology to further understand the historic range of variability for ecological systems (Swetnam et al. 1999). Fundamental in defining the range of variability should be an understanding of the historic role of natural and anthropogenic disturbance. The results yielded from this type of research holds great potential for those incorporating the principles of ecosystem management into their management goals. Ultimately, these management decisions rest with publicly held values. Progressive management relies on a cultural understanding that “Nature has a range of ways to be, but there is a limit to those ways, and therefore, human changes must be within those limits (Pickett et al. 1992).” The value of historical ecology resides in its ability to help define these limits.

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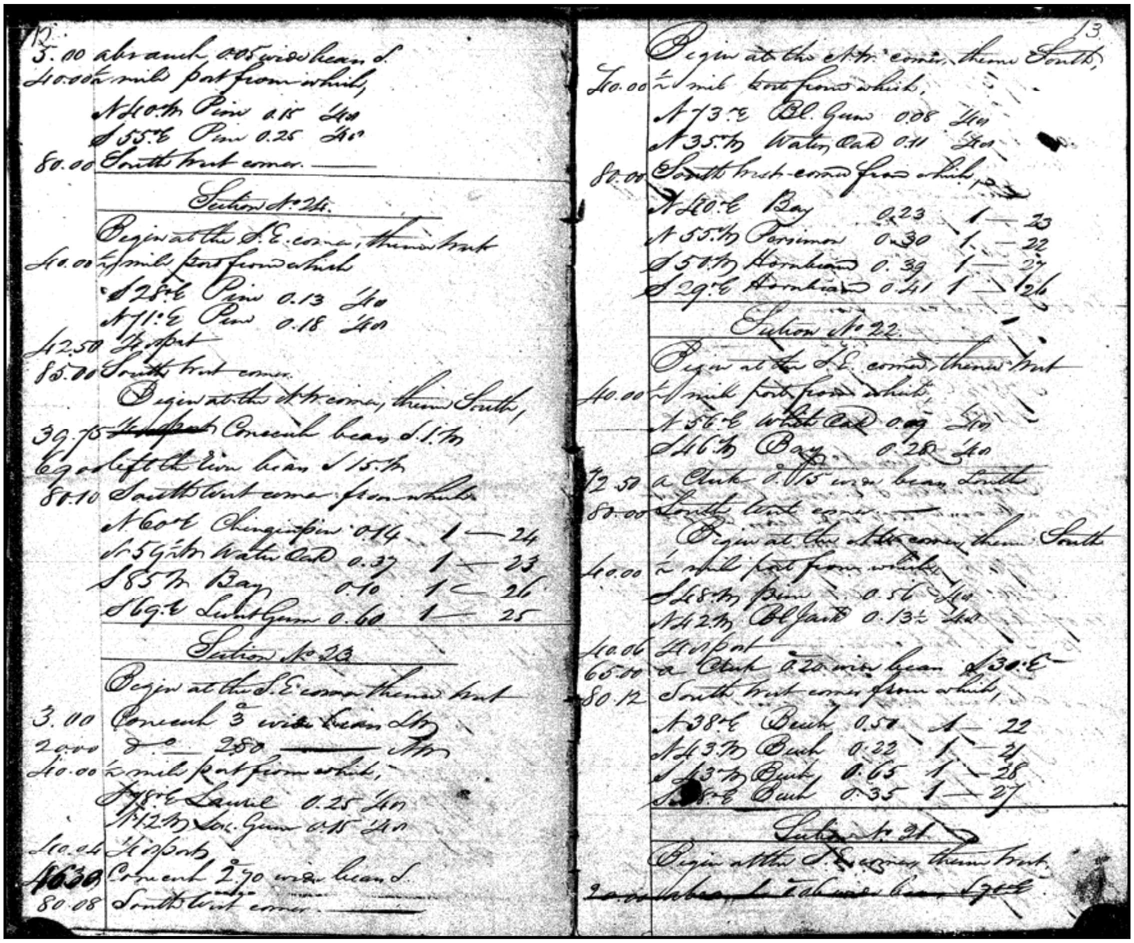
APPENDIX A

ADDITIONAL INFORMATION REGARDING PRESETTLEMENT GLO SURVEYS FOR ESCAMBIA AND COVINGTON COUNTIES, ALABAMA

Figure A.2. Sample surveyor field notes from Township 1N, 9E



12
3.00 a branch 0.05 wide bears S.
40.00 ½ mile post from which,
N 40° W Pine 0.15 40
S 55° E Pine 0.25 40
80.00 South West corner.

Section No 24.

Begin at the S.E. corner, thence West
40.00 ½ mile post from which
S 28° E Pine 0.13 40
N 71° E Pine 0.18 40
42.50 ½ post
85.00 South West corner.
Begin at the N.W. corner, thence South,
39.75 ~~½ post~~ Conecuh bears S 1° W
69.00 left the river bears S 15° W
80.10 South West corner from which
N 60° E Chinquapin 0.14 1—24
N 59½° W Water Oak 0.37 1—23
S 85° W Bay 0.10 1—26
S 69° E Sweet Gum 0.60 1—25

Section No 23

Begin at the S.E. corner thence West
3.00 Conecuh 3.00 wide bears SW
20.00 do 2.50 ——— NW
40.00 ½ mile post from which,
S 58° E Laurel 0.25 40
N 12° W Sw. Gum 0.15 40
40.04 ½ posts
46.30 Conecuh 2.70 wide bears S.
80.08 South West corner.

13
Begin at the N.W. corner, thence South,
40.00 ½ mile post from which,
N 73° E Bl. Gum 0.08 40
N 35° W Water Oak 0.11 40
80.00 South West corner from which,
N 40° E Bay 0.23 1—23
N 55° W Persimmon 0.30 1—22
S 50° W Hornbeam 0.39 1—27
S 29° E Hornbeam 0.41 1—26

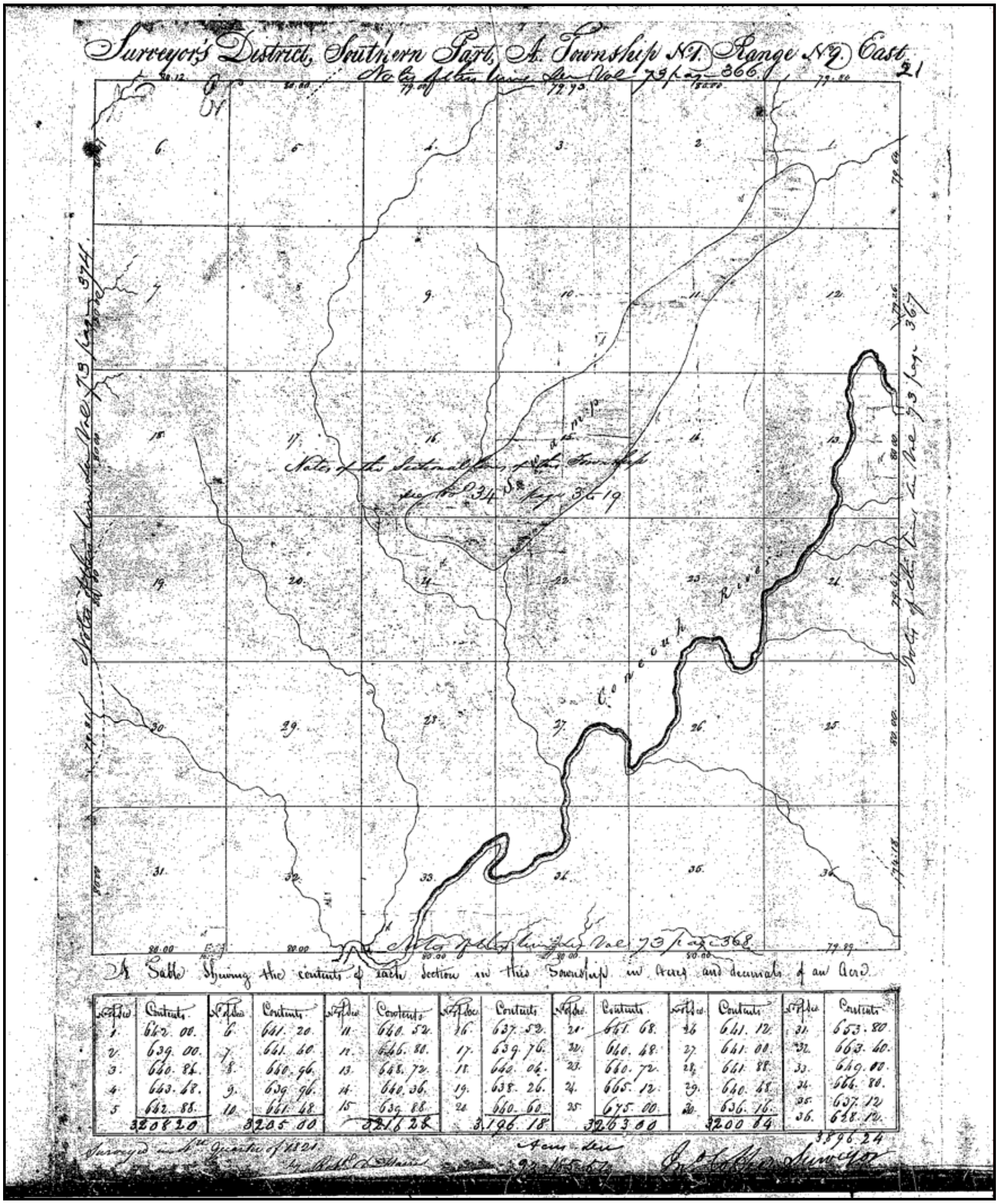
Section No 22.

Begin at the S.E. corner, thence West
40.00 ½ mile post from which,
N 56° E White Oak 0.09 40
S 46° W Bay 0.28 40
72.50 a Creek 0.15 wide bears South
80.00 South West corner
Begin at the N.W. corner thence South
40.00 ½ mile post from which
S 48° W Pine 0.56 40
N 42° W Bl. Jack 0.13½ 40
40.06 ½ post
65.00 a Creek 0.20 wide bears S 30° E
80.12 South West corner from which,
N 38° E Beech 0.57 1—22
N 43° W Beech 0.22 1—21
S 43° W Beech 0.65 1—28
S [illegible]8° E Beech 0.35 1—27

Section No 21

Begin at the S.E. corner, thence West
~~20.00 [illegible] 0.70 wide bears S 70° E~~

Figure A.1. Sample Township Map (1N, 9E) from General Land Office public lands surveys



A Table Shewing the contents of each Section in this Township in Acres and decimals of an Acre.

No. of Sec.	Contents	No. of Sec.	Contents	No. of Sec.	Contents	No. of Sec.	Contents	No. of Sec.	Contents	No. of Sec.	Contents	No. of Sec.	Contents
1.	642.00.	6.	641.20.	11.	640.52.	16.	637.52.	21.	641.68.	26.	641.12.	31.	653.80.
2.	639.00.	7.	641.60.	12.	646.80.	17.	639.76.	22.	640.48.	27.	641.00.	32.	663.60.
3.	640.86.	8.	640.96.	13.	648.72.	18.	640.04.	23.	640.72.	28.	641.88.	33.	649.00.
4.	643.68.	9.	639.96.	14.	640.36.	19.	638.26.	24.	665.12.	29.	640.48.	34.	666.80.
5	642.88.	10.	641.48.	15	639.88.	20.	640.60.	25.	675.00.	30.	636.16.	35.	637.12
												36.	628.12.
	3208 20		3205 00		3216 28		3196.18		3263 00		3200 64		3896.24

Surveyed in 1st Quarter of 1821 by [illegible]

Acres dec
23,185.67

[illegible] Surveyor

Figure A.3. Sample coding system for each Township

____N, _____ E, top line prefix from TNR was assigned to each corner. So, if this was 1N, 5E, each corner number would be preceded by the numbers 15.

70	732 **6**	733 **5**	734 **4**	735 **3**	736 **2**	70 **1**
20	28 **7**	29 **8**	210 **9**	211 **10**	212 **11**	20 **12**
30	317 **18**	316 **17**	315 **16**	314 **15**	313 **14**	30 **13**
40	420 **19**	421 **20**	422 **21**	423 **22**	424 **23**	40 **24**
50	529 **30**	528 **29**	527 **28**	526 **27**	525 **26**	50 **25**
60	632 **31**	633 **32**	634 **33**	635 **34**	636 **35**	60 **36**
70	732	733	734	735	736	70

Table A.1. Additional data tabulated from the surveyor field notes

Additional Data Acquired	Units/Description
Distance from section corner	Measured in Chains
Direction of surveyor movement	North, South, East or West
Bearing distance	Measured in Links
Bearing	Degrees
Direction X	1 or -1
Direction Y	1 or -1
Topography	Level, rolling, hilly, or broken
Vegetation description	Open, open pine woods, swampy, bottomland, marshy, brush woods, brushy
Soil rating	First, Second, or Third rate.
Surveyor group	Names of contributing surveyor
Date	Date of survey completion for each Township

APPENDIX B

REQUIRED CALCULATIONS FOR GEO-REFERENCING WITNESS TREES, PRODUCING RASTER DATA FOR WITNESS COMMUNITIES, AND PRODUCING AREA ESTIMATES FOR ESCAMBIA AND COVINGTON COUNTIES, ALABAMA

Equations B.1. Equations used to geo-reference witness tree data, Escambia and Covington counties, Alabama

Surveyor movement East:

Final X coordinate = section corner x coordinate + distance from corner + sin (compass bearing)*(bearing distance) * (direction x).

Final Y coordinate = section corner y coordinate + cos(compass bearing)*(bearing distance) * (direction y).

Surveyor movement West:

Final X coordinate = section corner x coordinate – distance from corner + sin (compass bearing)*(bearing distance) * (direction x).

Final Y coordinate = section corner y coordinate + cos(compass bearing)*(bearing distance) * (direction y).

Surveyor movement South:

Final X coordinate = section corner x coordinate + sin(compass bearing)* (bearing distance) * (direction x)

Final Y coordinate = section corner y coordinate – distance from corner + cos(compass bearing) *(bearing distance) * (direction y)

Surveyor movement North:

Final X coordinate = section corner x coordinate + sin(compass bearing)* (bearing distance) * (direction x)

Final Y coordinate = section corner y coordinate + distance from corner + cos(bearing distance) *(bearing distance) * (direction y)

Note: Direction x and y were coded as 1 or -1 from the surveys. For direction x: E = 1, W = -1 and for direction y: N = 1 and S = -1.

Equations B.2. Calculations for probability of the reference pine dominated community, Escambia and Covington counties, Alabama

The following equation is the standard equation for multinomial logistic regression. In this case the hardwood community is examined with the pine dominated community as the reference community.

$$\ln[prob(hardwood)/prob(pine)] = \beta_O + \beta_1 X_1 + \beta_2 X_2 + ...\beta_k X_k$$

The following equation simplifies the equations by referring to the logit in the following terms. This notation will be extended to the logit for the mixed pine-oak and bay communities.

$$g_H = \ln[prob(hardwood)/prob(pine)]$$

Then solve for the probability of the hardwood community. This step is also performed similarly for the mixed pine-oak and bay communities.

$$prob(hardwood) = \exp(g_H) * prob(pine)$$

All probabilities sum to one. So, solving for the probability of pine dominated community, the following equation is produced.

$$prob(pine) = 1 - prob(hardwood) - prob(bay) - prob(mixed)$$

Substituting from third equation provided, the following equation is produced.

$$prob(pine) = 1 - [\exp(g_H) * prob(pine)] - [\exp(g_B) * prob(pine)] - [\exp(g_M) * prob(pine)]$$

Solve for one and factor out the probability of the pine dominated community and the following equation is reached.

$$prob(pine)[1 + \exp(g_H) + \exp(g_B) + \exp(g_M)] = 1$$

Finally, solve for the probability of the pine dominated community and the following equation given in the chapter two is derived.

$$prob(pine) = 1/1 + \exp(g_H) + \exp(g_B) + \exp(g_M)$$

Equations B.3. Calculations in ArcGIS raster calculator to produce raster probability data for each witness tree community, Escambia and Covington counties, Alabama

In the following equations, suborder2 = Saprist soils, suborder3 = Ochrepts soils, and Suborder6 = Aquents soils. The continuous data set water_dist = distance from water.

Prob (hardwood community) / Prob (pine dominated community) = Exp(-0.4759 + [suborder2] * -0.5499 + [suborder3] * 0.5319 + [suborder6] * 1.9622 + [water_dist] * -0.00149 + [slope] * 0.1278)

Prob (mixed pine-oak community) / Prob (pine dominated community) = Exp(-1.7967 + [suborder2] * -0.1538 + [suborder3] * 0.2722 + [suborder6] * 0.4171 + [water_dist] * -0.00038 + [slope] * 0.0872)

Prob (bay community) / Prob (pine dominated community) = Exp(-0.9274 + [suborder2] * 0.00363 + [suborder3] * 0.0325 + [suborder6] * 1.3481 + [water_dist] * -0.00405 + [slope] * -0.2903)

Equations B.4. Equations and work required to produce witness tree community area estimates, Escambia and Covington counties, Alabama.

The first step in this process is to convert the probability raster data to percent per cell. Also, the integer function in raster calculator converts percentages to integers. The following equation was repeated for all four witness tree communities in the raster calculator.

Percent (hardwood) = int[prob(hardwood) *100]

After this step was performed for all four witness tree communities, the corresponding tables were exported to Excel. Attributes for each table include value and count. The values column was converted back to a decimal. So, a value of 2 now equals 0.02. Next a column called “area” was created, where area is equal to count * 900.00. 900.00 is the value for square meters of each cell. Finally, the total area for each decimal percentage was calculated by multiplying “area” by the decimal percentage. The values produced are summed to equal the total area for a given community in square meters.

APPENDIX C

ADDITIONAL TABLES DESCRIBING ASSOCIATION OF WITNESS TREE COMMUNITIES WITH ENVIRONMENTAL INDEPENDT VARIABLES

Table C.1. Odds ratio estimates which define relationships between witness tree communities and environmental independent variables, Escambia and Covington counties, Alabama. NS denotes odds ratios that are deemed not significant by the Wald statistic ($p < 0.05$). Odds ratios were calculated from slope or parameter estimates given in table 2.5.

	Pine community	Hardwood community	Mixed Pine-Oak community	Bay community	Model Effects
Pine community as the reference		4.032	1.465 NS	4.006 NS	Saprists vs. Udults
		11.895	2.243 NS	4.124 NS	Ochrepts vs. Udults
		49.721	2.592 NS	15.367	Aquents vs. Udults
		0.820	0.950	0.584	Distance from water (m)
		1.153	1.106	0.0725	Slope (degrees)
Hardwood community as the reference	Mixed Pine-Oak	Bay Community	**Mixed Pine-Oak as reference**	Bay Community	Model Effects
	0.363 NS	0.993		2.735 NS	Saprists vs. Udults
	0.189 NS	0.347		1.839 NS	Ochrepts vs. Udults
	0.052 NS	0.309 NS		5.938 NS	Aquents vs. Udults
	1.158	0.712		0.615	Distance from water (m)
	0.956	0.629		0.658	Slope (degrees)