PATTERNS OF LANDUSE AND SUCCESSION IN A LONGLEAF PINE FOREST

by

DARROC GOOLSBY

(Under the Direction of Michael Wimberly and Lindsay Boring)

ABSTRACT

This study quantified the changes in forest cover in the twentieth century in a *Pinus palustris* forest historically managed for bobwhite quail hunting. Many quail hunting sites in the southeast were historically characterized by annual burning and high amounts of forest fragmentation in the form of scattered wildlife food plots, agricultural fields, and homesites. Stand histories were constructed by examining series of historical aerial photographs and age class distributions of hardwoods and pines. Hardwood establishment occurred as components of interior forest succession but was more prevalent on field margins as old field succession. Longleaf pine establishment occurred during two periods, first, during a period of fire suppression in the 1930s, and second, during a period of selective timber removal in the 1950s. Hardwood establishment occurred during 1930s fire suppression as well as constantly through time as a result of annual low intensity burning which failed to kill aggressive oak regeneration.

INDEX WORDS: *Pinus palustris*, Land use history, Fire ecology, Forest succession, Bobwhite quail

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DEDICATION

To my parents.

To the memory of Robert W. Woodruff, Joseph W. Jones, and Herbert Stoddard.

Also, to Leon Neel.

Thank you all for caring about the piney woods.

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

Objectives and Approach

Land use has changed dramatically over the last century, and studies of land use legacies show that impacts left on a landscape are apparent for decades to centuries (Foster 1992; Foster et al. 1997). Past management practices in the southeastern coastal plain created a feedback loop which fundamentally altered the way fire interacted with the ecosystem by shifting species composition and the resulting fuels. Removal of conifers, oak-pine competition, and alteration of historic fire regimes all allowed hardwood trees with non-pyrogenic litter to increase in abundance. These activities caused further changes in fire regime and fundamental overstory shifts to relatively homogeneous hardwood and scrub forest by precluding longleaf pine (*Pinus palustris* Mill.) overstory dominance and allowing large amounts of hardwood establishment and overstory dominance (Monk 1968; Veno 1976; Gilliam and Platt 1999).

This study focuses on the spatial and temporal patterns of hardwood succession on landscapes historically managed for bobwhite quail hunting at the Joseph W. Jones Ecological Research Center at Ichauway. The creation of quail plantations in the early twentieth century conserved many patches of the now threatened longleaf pine ecosystem. Quail management historically included annual cool-season burning. Annual cool season burning was utilized to maintain an open understory for easy access by hunters and land managers as well as to provide a mosaic of burned and unburned vegetation, maximizing edge habitat valued by bobwhite quail (Stoddard 1931). Burning regimes of this type may result in low intensity fires that do not effectively kill hardwood saplings and thus encourage the growth of woody vegetation and hardwood stands (Robbins and Myers 1992; Brockway and Lewis 1997; Jacqmain et al. 1999). In addition, quail management often involves purposeful fragmentation of the landscape to maximize edge habitat valued by quail. These practices favor quail but may alter the spatial and temporal patterns of prescribed fire and encourage hardwood growth (Rebertus et al. 1993).

The main objective of this research is to explore the effects of historical land use legacies on the spatial and temporal patterns of hardwood succession in upland longleaf pine ecosystems. How has past land use affected the landscape as a whole through its influences upon fire and its subsequent long term affects on hardwood and longleaf stands? The spatial and temporal patterns of hardwood succession were documented with a combination of historical aerial photo interpretation and collection of tree age data. Interpretation of historical aerial photographs was used to quantify forest overstory structure and change. Field sampling was used to systematically sample longleaf pine and hardwood ages to construct age class distributions. The changes in overstory composition indicated by the aerial photographs and periods of tree establishment indicated by age class distributions were qualitatively related to known land management events described in historical land management records. Alternative hypotheses were used to drive this study. Use of these multiple working hypotheses provides testable scenarios against which patterns that are found can be compared. The hypothetical models presented below are not mutually exclusive.

The spatial patterns of hardwood succession were addressed using alternative hypotheses:

1) *Annual cool season burning*

Annual cool season burning resulted in low fuel accumulations and decreased fire intensity. Decreased fire intensity allowed hardwood seedlings and saplings to grow to sizes where they were immune to more intense fires and further affected fire behavior with non-pyric litterfall (Robbins and Myers 1992; Jacqmain et al.1999). Shifts to hardwood cover occurred across all covertypes, regardless of spatial location.

2) *Landscape fragmentation*

Hardwood and shrub growth along non-forested edges was encouraged as part of management for bobwhite quail, and this vegetation did not burn with intensity and continuity needed to ensure longleaf pine recruitment (McGuire et al. 2001; Boring et al. 2004). Shifts to hardwoods occurred closer to non-forested edges and less at greater distances from non-forested edges.

3) *Land use change*

Succession on old-field sites favored hardwood establishment and excluded longleaf pine dominance in the overstory (Landers et al. 1995). Shifts to hardwoods occurred primarily on non-forested areas where agricultural abandonment took place.

The temporal patterns of hardwood succession were addressed using alternative hypotheses:

1) *Hardwood encroachment was a continuous, gradual process related to long-term land use practices such as annual burning and selective logging.*

Land use practices across broad scales and in large forested tracts could have allowed continuous, gradual hardwood encroachment across the landscape. This pattern of hardwood recruitment would be reflected by flat age class distributions with fairly even numbers of hardwoods in each age class. These processes would have been particularly evident in less fragmented and disturbed longleaf pine woodlands.

2) *Hardwood encroachment was "event punctuated," associated with specific land use events such as old field abandonment, the creation of hedgerows, and changes in fire regime.*

The addition of hedgerows, changes in shape and placement of agricultural fields, timber removal and culling of previously turpentined trees, and changes in dominant land use schemes in discrete time periods would create distinct periods of change in forest structure. Hardwood age class distributions would be peaked and narrow in temporal range, indicating distinct periods of hardwood establishment.

This thesis has been written in manuscript format. Chapter one contains an introduction and literature review. Chapter two is a manuscript to be submitted to the journal *Landscape Ecology*. Chapter three is a manuscript to be submitted to the journal

Forest Ecology and Management. Chapter four is a concluding chapter that ties together the major results of this study.

Literature Review

Longleaf pine and its decline

Longleaf pine woodlands are savanna-like ecosystems characterized by an open overstory of longleaf pine interspersed with midstory oaks. Longleaf pine woodlands tend to be dominated by a matrix of older, widely spaced trees with even aged patches of regeneration and oak thickets (Myers 1990). The ground cover is species rich and dominated by perennial grasses and forbes. More than 40 species/m^2 have been observed in many longleaf pine communities (Peet and Allard 1993). Wiregrass, *Aristida stricta* (Michx.), is the dominant perennial grass and is pyric in nature. It forms thick mats of fine fuel and only flowers after growing season burns. Low intensity fires every 2 to 5 years remove fuel accumulation, retard hardwood growth, and provide bare mineral soil needed for longleaf pine seeds to germinate. In today's fragmented landscape, large lightning caused fires are rare and most ignitions are anthropogenic (Robbins and Myers 1992).

In the absence of fire, longleaf pine woodlands have been shown to succeed to southern hardwood forests (*Quercus laevis* (Walter), *Q. incana* (Bartram), *Q. nigra* (L.), *Q. virginiana* (Mill.), *Q. stellata* (Wangenh.), *Q. falcata* (Michx.), *Prunus serotina* (Ehrh.), *Sassafras albidum* (Nutt.), *Carya tomentosa* (L.), *C. pallida* (Ashe)) (Monk 1968; Veno 1976). As existing midstory hardwoods increase in importance and hardwoods from neighboring upland communities invade, fuel types become less pyrogenic and fire becomes less frequent and more spatially heterogeneous. Hardwood litter contains fewer volatile organic compounds than longleaf pine litter and retains moisture better, and thus does not burn as well. The combination of longleaf pine needles and understory grasses provide a layer of fine fuel that facilitate the ignition and spread of fire (Williamson and Black 1981). Longleaf pine is shade intolerant and will generally not regenerate under hardwood canopies due to lack of sunlight and exposed soil. It is thought that hardwood succession can start in small patches and invade longleaf woodlands through time especially when fires become less frequent. This ecosystem shift is further exacerbated as hardwood trees become mature and resistant to fire, allowing further expansion of less pyrogenic fuels and seed sources for hardwoods (Gilliam and Platt 1999; Greenberg and Simons 1999).

Guerin (1993) studied the dynamics of oaks in longleaf pine woodlands. After frequent fire was reintroduced into the study area after 20 years of suppression, oak domes >2m tall were able to persist, while those <2 m tall remained in smaller size classes. In general, oaks with height <2 m were susceptible to burning, and were completely burned to their root collars, while oaks >2 m had a high probability of survival. Oaks >4 m were found to be almost completely resistant to fire. Suppression of the natural fire regime has been found to increase the rate of sand pine thicket encroachment in longleaf pine forests on Eglin Air Force Base (McCay 2000) and may operate on the same principles as hardwoods on Ichauway. Fire is recognized as the predominant management tool for longleaf pine woodlands but the fire resistance of large hardwoods to low intensity ground fires means that after a certain amount of succession, other management options such as mechanical treatment or herbicides must be considered (Landers et al. 1995).

Longleaf pine woodlands once dominated the coastal plain from eastern Texas to Virginia but now occupy approximately 3% of their former range and .00014% of their former range now stands as old growth (many large pines > 50cm dbh; see Varner and Kush 2004). The main cause of longleaf pine woodland decreases was failed regeneration after extensive logging in the late 1800s and early 1900s, and conversion of former longleaf pine woodlands to agricultural sites and pine plantations (Wahlenberg 1946; Frost 1993). The vast majority of old growth longleaf pine was cut by 1920 and the subsequent period of fire suppression that dominated forestry in the United States stopped regeneration on most sites and accelerated succession to southern hardwood forests (Wahlenberg 1946; Pyne 1982; Frost 1993). Several authors have also asserted that feral hogs destroyed much of the regenerating *Pinus palustris* because of their affinity for the delicate new growth and starchy root stalks (Wahlenberg 1946; Frost 1993).

Turpentining likely caused a significant decline in longleaf pine spatial extent and regeneration. Turpentine operations involved cutting into the bole of the tree and draining the resins out to distill for a variety of products. This weakened the tree and made it susceptible to disease and insect outbreaks. Additionally, turpentine woods were burned annually to maintain an open understory allowing easy access. This yearly burning can prevent longleaf pine regeneration as the seedlings are highly sensitive to fire in the first year of growth and during bud elongation in older seedlings (Wahlenberg 1946; Pyne 1982; Robbins and Myers 1992).

Cultural features such as homesites, fencerows, field margins, pastures, and wildlife food plots are often associated with hardwoods. The physical barriers of these cultural features as well as the non-pyrogenic fuels from hardwoods create prolific “fire shadows.” Fire shadows are areas protected from fire by topographic features or non-pyrogenic vegetation and fuels. These areas serve as footholds for invading hardwoods by extending the spatial extent of fire shadows through changes in litter types and decreased fire frequency. Hardwood successional areas then increase in spatial extant through time by extending the unburned portion of the landscape and thus providing more microsites for hardwood establishment. Mitchell et al. (1999) constructed age class distributions of longleaf pines and hardwoods on the least fragmented sites on Ichauway, the site for this study, and found very few hardwood trees.

Land use history of southwest Georgia and the role of quail plantations

Quail hunting plantations provide a valuable but complex venue in which to study longleaf pine. Many of the remaining old growth and high quality longleaf pine stands occupy former and current quail management sites (Varner and Kush 2004) that followed quail management principles outlined by Stoddard (1931). The historical use of fire on quail plantations to maintain habitat and open the woodlands for easy access likely helped prevent these ecosystems from completely succeeding into mixed or southern hardwood forests. However, the common practice of annual burning also precluded effective longleaf pine regeneration. Due to the use of complex fire prescriptions for longleaf pine regeneration, many sites are just now beginning to return to the diverse age structure described by Wahlenberg (1946). Quail management lands also historically hosted a diverse suite of land use legacies besides game management including timber harvest, turpentining operations, agriculture, and livestock production. Consequently, most have a complex history of groundcover disturbance, invasion by successional tree species, and fragmentation of stand and landscape scale fuel continuity. Alteration of the landscape through fragmentation by agricultural fields, development of home sites, and road construction has served as a catalyst in the alteration of natural fire regimes, creation of fire shadows, and resultant growth of hardwood thickets (Glitzenstein et al. 1995).

Quail management historically included annual cool-season burning and studies have demonstrated that burning regimes of this type may encourage the growth of woody vegetation and hardwood stands (Robbins and Myers 1992; Brockway and Lewis 1997; Jacqmain et al. 1999). Conversely, Glitzenstein et al. (1995) found through controlled field experiments that season of fire had no effect on longleaf pine population dynamics, and asserted that spatial variability in fire behavior was the overriding factor controlling species distribution. Annual cool season fires were generally not hot enough to kill hardwood seedlings and sprouts due to low fuel loading, and likely did not burn homogeneously across the landscape. This spatial variability in burning allowed many young pine and hardwood seedlings to survive each year. Hardwoods grow faster than longleaf at younger ages and increase in dominance more rapidly than longleaf pines (Platt et al. 1988; Glitzenstein et al. 1995; Palik and Pederson 1996; Greenberg and Simon 1999; Bechtold 2003). In addition, quail management often involves purposeful fragmentation of the landscape to maximize the edges valued by quail. This fragmentation is achieved by utilizing numerous small planted food plots throughout forest stands and plowing "birdrings" around trees, shrubs, wetlands, and depressions which may or may not be planted with grain crops (Stoddard 1931). It is thought that fragmentation features help to accelerate the successional process by providing refugia for woody and hardwood vegetation and influencing fire behavior. Successful invasion of adjacent longleaf pine sites is then possible when fires fail to burn homogenously for control of invading hardwood growth.

Age class distributions in ecological study

Age class analysis can tell ecologists much about forest health and history. By comparing current age class distributions to theoretical expectations and supporting evidence, ecologists can make inferences about disturbance history and the successional trends that follow (Leak 1975; Lorimer 1984; Huff 1995). Pulses and gaps in age class distributions point to periods of release and suppression of regeneration (Tappeiner et al. 1997). The spatial pattern of age class distributions allows the identification of disturbance patches which may help unravel past management trends and future successional changes (Frelich and Lorimer 1991). Regeneration or lack of regeneration is indicated by the relative evenness of the age class distribution. Mortality or timber removal is indicated by lack of older age cohorts. Using tree ages is preferable to regression linked size-age equations because it allows for finer temporal resolution of data and eliminates the uncertainties associated with varying growth rates across site type and species. Age class distributions in natural, old-growth longleaf pine stands would be a negative exponential curve. Frequently, size and age class distributions are unimodal for second growth longleaf pine stands on plantation managed sites with the peak in the center of the graph reflecting the absence of older cohorts after logging activities and lack of regeneration (Myers and White 1987; Glitzenstein et al. 1995; Noel et al. 1998; Gilliam and Platt 1999).

Historical aerial photographs and the study of ecological change

Ecological studies utilizing historical aerial photographs to monitor land use and cover change are ubiquitous. Time series of aerial photographs provide the opportunity to look at change for long periods of time over large or small areas. When combined with field or historic data, aerial photos allow insights into past successional change, future successional trajectories, and plant invasion or movement. Archer (1989, 1990) was able to define specific processes of succession in Texas grasslands. Foster (1992) and Foster et al. (1997) combined historical photos, field data, and highly detailed land use records to describe land use history and its effect on forest succession in the northeast U.S.A. McCay (2000) combined field data with aerial photo series to describe the invasion of longleaf pine forests by sand pine. This invasion was linked directly with changes in fire regime caused by land use. Furthermore, McCay's research was able to explicitly describe site types that were favorable for sand pine invasion, thus allowing management decisions to be based on the relationships described in the 2000 study. Ward (2002) used aerial photos to show how privet invasion was influenced by land use legacies in a northern Georgia watershed. His study described land uses and associated geomorphology. Ward was able to conclude that specific land use events allowed punctuated privet invasion by providing large areas suitable for colonization.

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CHAPTER 2

SPATIAL PATTERNS OF LAND USE AND SUCCESSION IN A LONGLEAF PINE FOREST[1]

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[1] Goolsby, D., M. Wimberly, and L. Boring. To be submitted to *Landscape Ecology*.

ABSTRACT

This study quantified the changes in forest cover from 1953 to 1992 on 3500 ha in a longleaf pine (*Pinus palustris* L.) forest historically managed for northern bobwhite quail hunting. Many quail hunting sites in the southeastern U.S. were historically managed using numerous food plots, agricultural fields, and annual cool season burning. These land use activities ensured the regeneration of longleaf pine but allowed successional oaks to increase in extent. Forest cover was mapped on aerial photographs (1953 and 1992) and analyzed using a geographic information system. Succession occurred on two site types: 1) along field margins and on old fields and 2) in interior forests un-fragmented by large fields. About half of the landscape fell into each category, thus succession may occur on any area in the landscape.

Keywords: *Pinus palustris*, northern bobwhite quail, land use, succession, prescribed fire

INTRODUCTION

Land use practices have changed dramatically over the last century in North America, and studies of land use history show that impacts may be apparent for decades to centuries at all spatial scales (Foster et al. 1997). In forested areas, harvesting timber, changes in historic fire regimes, and fragmentation of forest stands can all accelerate successional processes (Archer 1990; Sharitz et al. 1992; Parshall et al. 2003). Understanding the spatial patterns of succession that these disturbances create is vital to ecosystem management and the management of multiple use forests. This is particularly true when managing ecosystems that are disturbance dependent and have early successional communities that may alter forest dynamics at long temporal scales.

Management practices during the twentieth century in the southeastern coastal plain of the United States created feedback mechanisms which have fundamentally altered the way fire interacts with longleaf pine (*Pinus palustris* Mill.) ecosystems by shifting species composition and the resulting fuels (Noss 1989; Ware et al. 1993). Removal of conifers decreased the amount of pyric litterfall, altered fire behavior, and led to heterogeneous burns. Fire frequency in the coastal plain plays an important role in stopping hardwood establishment and growth. Annual fires may decrease the amount of available fuel from litterfall and groundcover, and may not burn with sufficient intensity to kill hardwoods (Jacqmain et al. 1999; Boring et al. 2004). Infrequent fires allow hardwoods to grow to sizes where they are tolerant of the low intensity ground fires typically found in the southeast (Christensen 1981; Robbins and Myers 1992; Guerin 1993; Landers et al. 1995; Jacqmain et al. 1999). An intermediate fire frequency of 2 to 4 years is needed to maintain longleaf pine dominance. Once hardwoods have reached the overstory, they alter fuel accumulation through litterfall to less pyric fuels, thus altering fire behavior. These activities cause further changes in fire regime and fundamental overstory shifts to forests with large successional hardwood components (Wahlenberg 1946; Monk 1968; Veno 1976; Gilliam and Platt 1999).

The management of longleaf pine woodlands for northern bobwhite quail (*Colinus virginianus*) during the twentieth century has resulted in the conservation of isolated patches of this threatened ecosystem (Landers et al. 1995; Varner and Kush 2004). Quail plantations managed in the manner described by Herbert Stoddard (1931) maintained the use of prescribed fire and subsequently provided for large natural populations of bobwhite quail. These historical hunting plantations often regenerated and supported large amounts of high quality longleaf pine woodlands. Many of these woodlands have undergone varying successional changes characterized by the expansion of opportunistic hardwoods, especially *Quercus* species, including *Q. virginiana* (Mill.), *Q. nigra* (L.), *Q. falcata* (Michx.) and others (Jacqmain et al. 1999). In addition, these often dominant hardwoods are usually associated with anthropogenic features such as hedgerows, field margins, home sites, and roads. These oaks are not those typically associated with the oak mid-story of longleaf pine sandhill forests (Jacqmain et al. 1999).

Annual cool season burning was central to quail management in the twentieth century to open the understory, provide easy movement through the area by hunters, and create a mosaic of vegetation valued by quail. Historical quail management also included the fragmentation of the woodlands with numerous food plots and agricultural fields to provide large amounts of edge habitat (Stoddard 1931). Lands historically used for quail management have conserved isolated patches of this threatened longleaf pine ecosystem and maintained high quality multiple-use pine-grassland ecosystems. It is important to understand the successional mechanisms on these landscapes so these woodlands and diverse wildlife habitats may be managed sustainably, and where necessary, be restored (Landers et al. 1995).

The objective of this study was to quantify the spatial pattern of hardwood expansion in longleaf pine woodlands relative to historic land use. Forested and non-forested cover was mapped using historic aerial photographs and analyzed using a geographic information system (GIS) to answer questions about changes in hardwood abundance in relation to historical land use.

Expansion of hardwood cover was addressed using non-mutually exclusive alternative hypotheses:

1) Annual cool season burning

Annual cool season burning resulted in low fuel accumulations and decreased fire intensity. Decreased fire intensity allowed hardwood seedlings and saplings to grow to sizes where they were immune to more intense fires and further affected fire behavior with non-pyric litterfall (Robbins and Myers 1992; Jacqmain et al. 1999). These processes should result in shifts to hardwood cover across all covertypes, regardless of spatial location.

2) Landscape fragmentation

Hardwood and shrub growth along non-forested edges was encouraged as part of management for northern bobwhite quail, and this vegetation was not burned with the intensity and continuity needed to ensure longleaf pine recruitment (McGuire et al. 2001; Boring et al. 2004). These processes should result in shifts to hardwoods closer to non-forested edges and less at greater distances from non-forested edges.

3) Land use change

Succession on old-field sites favored hardwood establishment and excluded longleaf pine dominance in the overstory (Landers et al. 1995). These processes should result in shifts to hardwoods more frequently on non-forested areas where agricultural lands were abandoned than in continuously forested areas.

STUDY AREA DESCRIPTION

Our study area was the Joseph W. Jones Ecological Research Center at Ichauway (here after referred to as Ichauway) located in the Doughterty Plain of southwest Georgia, a subprovince of the Southeastern coastal plain. The 11 300 ha area currently contains approximately 7500 ha of longleaf pine dominated woodlands and approximately 1600 ha of old field complexes used for wildlife management, afforestation, and conservation of historic legacies. The area supports diverse forest and wildlife research as well as educational activities and demonstrations. Summer temperatures range from 21° C to 34° C and winter temperatures range from 5° C to 17° C. Most soils are characterized as well-drained loamy sand over sandy loam to sandy clay loam on gently rolling karst terraces. Elevations range from 27 to 61 m above sea level (Goebel et al. 1997).

Study Units

Three units on Ichauway were identified for analysis based on quality of historical aerial photographs, historical documentation, and variety of land use and land cover. Units with moderate to large amounts of human impacts and hardwood encroachment were chosen to interpret hardwood encroachment patterns under known quail management practices. These units represent the more disturbed areas on Ichauway, in contrast to more continuously forested units examined by Mitchell et al. (1999).

Study Unit 1 - Dubignon

Dubignon encompasses approximately 1300 ha of forested and non-forested landcover (Figure 2.1). The property was acquired by Robert W. Woodruff in 1940 or 1941, and was the last large acquisition completing the historic Ichauway plantation. Examination of historical aerial photographs from the 1930s and 1950s shows many dense stands of longleaf pine, mixed pine hardwood woodlands, large field complexes, and homesites. Most of Dubignon is classified as well drained upland terraces with some clayey depressions. The soils are mostly loamy sand over sandy loam to sandy clay loam (Goebel et al 1997). The overstory is dominated by *Pinus palustris*, *Quercus falcata*, and a variety of hardwoods. The Flint River and Ichawaynotchauway Creek border Dubignon, but bottomland areas were excluded from analysis because focus was on upland successional patterns and land use impacts.

Study Unit 2- Larkefield

Larkefield encompasses approximately 600 ha of field complexes, longleaf pine woodlands, mixed pine hardwood forests, and some bottomland hardwoods along the Ichawaynotchauway Creek (Figure 2.1). The area adjacent to the creek was analyzed in this study unit because the bluffs along the creek in Larkefield are high in elevation and remnant old longleaf pines exist along the bluff. Larkefield was acquired sometime in the late 1930s. Examination of historic aerial photographs shows Larkefield with some stands of trees persistent since the 1930s as well as much reforestation due to the shifting of the numerous agricultural complexes and addition of hedgerows. Non-forested and forested areas are highly interspersed in small patches (Figure 2.1). Upland soils in the sampling areas are mostly loamy sand over sandy loam to sandy clay loam (Goebel et al. 1997). The overstory is dominated by longleaf pine and successional hardwoods (*Quercus* spp.). Additionally, some loblolly pine (*Pinus taeda* L.) occur as successional components on some old-field sites and heavily disturbed forested areas.

Study Unit 3 – Sandy Desert

Sandy Desert was acquired in the 1920s with Robert W. Woodruff's original purchases to assemble Ichauway. It contains some of the oldest longleaf pine on the property. The area encompasses approximately 1600 ha of non-forested land, longleaf pine, and mixed pine-hardwood woodlands. The configuration of the landscape is less fragmented than that of Larkefield and similar to Dubignon, with non-forested and forested areas in large patches rather than interspersed. Soils are well drained upland terraces with loamy sand over sandy loam to sandy clay loam and somewhat excessively drained upland terraces with loamy sand to sandy loam (Goebel et al. 1997).

METHODS

Historical Records

Historical land use related documents were obtained from the Emory University Special Collection Archives in Atlanta, Georgia and from F and W Forestry Co. in Albany, Georgia. These documents contained potential general information on timber harvests from 1971 to 1984 as well as historical maps showing land acquisition by Robert W. Woodruff and anecdotal descriptions of the property during the mid twentieth century. More extensive land use records were not available for the property as a whole. Historical records housed at the Baker County courthouse were destroyed by fires and floods.

Aerial Photograph Processing

The period of analysis was chosen by examining the quality of historical aerial photographs for photo interpretation in relation to known management events. Dates before 1953 were not usable because photos lacked sufficient quality for photo interpretation. Dates after 1992 were excluded to minimize the effects of ongoing ecological restoration work conducted by the Jones Center.

Historical photographs covering the extent of the three study units for the years 1953 (1:24000) and 1992 (1:12000) were scanned to create digital images; 13 photographs for 1953 and 12 photographs for 1992. The scanned images were georectified to 1 foot resolution digital imagery from 2002 to an approximate accuracy of 5 m with a resulting grain size of approximately 0.5 m, well below the sizes of longleaf pine and successional hardwood crowns (Bechtold 2003).

Landcover maps were onscreen digitized using ArcGIS 9.1 (Environmental Systems Research Institute, Inc, 2005) to a minimum mapping unit of 0.5 ha to quantify the extent of pine and hardwood crown cover. Mixed forest covertypes were separated into two distinct classes, one pine dominated and one hardwood dominated in order to quantify mixed stands with more or less hardwood component. We hypothesized that pine cover with less hardwood cover components represented areas earlier in the successional process. Quantifying relative amounts of longleaf pine and hardwood crown cover increases our understanding of the dynamics involved in fuel accumulation. Coupling crown cover with the known prescribed burning regime of annual cool season fire allowed inferences to be made about the causes of tree establishment.

Landcover was classified as the following:

Non-forest: agricultural fields, home sites, un-forested depressions.

Hardwood: forested areas containing >90% hardwood cover.

Mixed hardwood: forested areas containing >50% hardwood cover with the remaining balance in pine cover.

Mixed pine: forested areas containing >50% pine cover, with remaining the balance in hardwood cover.

Pine: forested areas containing >90% pine cover, with few to no hardwoods.

Spatial Analysis

Digitized landcover maps were converted to 25 m (pixel size: 625 m^2) raster images. Twenty-five meter pixels were chosen because the grain size encompassed a majority of the small scattered food plots on the landscape, for ease of calculations, and to eliminate the artifacts of hand-drawn landcover polygons. Landcover was delineated more precisely on the 1992 photos because the aerial photos were of much higher quality than the 1953 photos. The use of raster maps in the analysis allowed us to compare the landcover data from the two dates at a similar level of precision.

Landcover was analyzed using FRAGSTATS (McGarigal et al. 2002) to quantify number of patches, total class area, mean patch area, and percentage of landscape on each unit at both time periods. Patches were defined using an 8-cell rule. Landcover change was analyzed by overlaying the 1953 and 1992 landcover maps. This change map was used to calculate the proportion of pixels of any covertype that changed to any other covertype or remained the same. These transition proportions were organized into change matrices for each unit and all units pooled.

To examine the effects of persistent non-forested patches and isolate areas that had undergone re-forestation, an existing landcover data set digitized from 1938 aerial photos was used to identify non-forested areas. These landcover data already existed at the Jones Center and included several forested cover types but did not quantify mixed cover types to the level of detail required for this study. Extent of non-forested patches in the 1938 landcover dataset was checked against 1938 aerial photographs and historical ownership maps to ensure accuracy. Only the non-forested patches from the 1938 landcover were used in analysis.

On the upland sites used for this study, covertypes with large hardwood components represented later successional woodlands. If hardwoods were expanding from non-forested edges, one would expect to see hardwood and mixed hardwood percent cover decrease with increasing distance from non-forested patches and pine and mixed pine percent cover increase with increasing distance from non-forested patches. The 1938 non-forest patches were overlayed on the 1953 and 1992 landcover maps to examine the amount of non-forested area that remained non-forested on the landscape as well as forested patches that were the result of old-field abandonment. A Euclidian distance calculation was used to isolate pixels from the 1953 and 1992 data sets at 50 m intervals extending out to 400 m from the edge of the 1938 non-forested patches. Percent cover of all cover types in 1953 and 1992 within the 1938 non-forested patches and in each 50 m distance class were calculated.

RESULTS

Historical Information

A generalized timeline of land use practices on Ichauway and southwest Georgia was developed (Table 2.1). Robert W. Woodruff began assembling Ichauway Plantation in 1929 and continued acquiring large parcels of land until the last large block was purchased in 1941. During this time the dominant land management shifted from subsistence farming to forest protection and quail management. Measures were taken to preserve the remaining forest and to encourage regeneration by excluding woodland grazing of livestock and fire suppression in the 1930s. This period marked a change in the land use of the property that is evident in a change in landcover. This transition period, including fire suppression in the 1930s, allowed regeneration of both longleaf pines and hardwoods (see Goolsby et al. in prep).

A second shift in land use leading to changes in landcover occurred during the 1950s and 1960s. Selective timber cutting of remnant turpentined trees and other damaged longleaf pines opened the overstory and allowed regeneration of both longleaf pine and successional hardwoods. This period of time included the addition of hedgerows to break up many fields on the property, with the effect of increasing the hardwood component of the overstory along forested-non-forested edges. Annual cool season burning remained the dominant fire regime until a shift in 1989 with the creation of the Joseph W. Jones Ecological Research Center.

Land cover characteristics

In 1953, the Ichauway landscape consisted of one-third non-forested areas, large patches of pine cover (17%), and mixed pine cover (23%), and mean patch sizes were similar (17 to 22.3 ha) (Table 2.2). Hardwood patches were numerous and small in size, with 51 patches covering 8% of the area. The most fragmented unit, Larkefield, contained relatively small amounts of pine cover in small patches (7%) and large areas of non-forested cover (42%). The largest unit, Sandy Desert, contained large amounts of mixed cover (31% of the sampled area for mixed pine and mixed hardwood combined) and large amounts of non-forested areas (39%). Pine cover in Dubignon occupied 22% of the landscape with the largest mean patch size (93.8 ha).

During the 39 year study period, mixed covertypes greatly increased (Table 2.2). Patch structure on the landscape increased in complexity across all units combined as landcover transitioned into a finer grained mosaic of smaller patches; mean patch area for all cover types decreased about 50% and the total number of patches almost doubled. Mean non-forest patch area decreased and mean pine patch area decreased. Hardwood patches slightly decreased in mean size but almost doubled in total number of patches. Mixed pine and mixed hardwood cover comprised the majority of area on all units in 1992 (34% and 28%, respectively).

On the Dubignon unit, pine cover decreased to only 3% in small patches while mean patch area of hardwoods and non-forest cover types was half of their 1953 values. Mixed pine and mixed hardwood cover types increased to 32% and 33% of the landscape, respectively. The Sandy Desert unit had 1992 values similar to those of Dubignon. In the Larkefield sampling area, pine cover increased to 10% of the sampled area; however, this reflected the increase in successional loblolly pines. Non-forested cover decreased to 30% of the sampled area and mean patch area decreased. Mixed cover types remained about the same in mean patch size and percent cover.

Transition analysis

Across all units, all cover types had a high probability of staying the same with the exception of pine (68%). Mixed pine changed to mixed hardwood (43%) across all sites (Table 2.3). Non-forested pixels generally transitioned to mixed hardwood (15%) or remained non-forested (66%). These general trends were consistent at both Dubignon and Sandy Desert. However, in Larkefield mixed pine had a lower proportion of transition to mixed hardwood (16%) and a higher proportion of pixels staying mixed pine, reflecting old-field succession of loblolly pine (42%) (Table 2.3). Hardwood cover transitioned to mixed hardwood and almost half of the mixed hardwood transitioned to mixed pine. This reflects the increase in abundance of loblolly pine in Larkefield and regeneration of longleaf pine in areas that underwent selective timber harvests (see Goolsby et al. in prep). Overall, Dubignon changed the most with large proportions of the change in pixels being from pine to mixed covertypes.

Old field reforestation

Most non-forested patches were persistent on the landscape through time but decreased in size, generally due to the fragmentation of larger fields with hedgerows and afforestation of field margins (Figure 2.1 and Table 2.2). Most of the area in non-forested patches in 1938 remained non-forested in 1953 and 1992 (Figure 2.2). By 1992, the percentage of the sample area covered by non-forest decreased to approximately 25%, reflecting a trend of decreased non-forest patch size and extent but persistent non-forested patches. Approximately 21% of the sample area remained non-forested from 1938 to 1992 (Figure 2.2).

In 1953, distribution of forest cover types on reforested and continuously forested areas was similar with the exception of hardwood cover, which occurred on a larger percentage of reforested areas than continuously forested areas (Table 2.4). Mixed cover types were similar between old-field and continuously forested areas; pine cover was similar on continuously forested sites than old-field sites. By 1992, there were distinct differences in the distribution of forested cover types between continuously forested and reforested areas. Continuously forested areas contained less hardwood cover than on re-forested areas, and more mixed pine cover than on reforested areas. Pine cover was similar (Table 2.4).

Edge effects from historical non-forested patches

Changes in proportions of each covertype across distance classes at each unit in 1953 and 1992 were determined (Figure 2.3). Non-forested areas decreased in extent with increasing distance from 1938 non-forested areas on all units in both 1953 and 1992. Percent non-forest cover was between 60% and 80% in areas non-forested in 1938, and dropped to below 20% at distances greater than 100 m. Hardwood percent cover remained below 20% across all distance classes in both 1953 and 1992 on all units. Mixed hardwood percent cover was low at Dubignon in 1953 in all distance classes (approximately 20%), and increased to over 40% in distance classes of 50 m and above in 1992. In Larkefield, mixed hardwood increased with increasing distance from 1938 non-forested patches in 1953; in 1992 mixed hardwood was between 15% and 20% in all classes less than 300 m, then increased to over 40% in the 400 m distance class. In the Sandy Desert unit, mixed hardwood percent cover stayed at approximately 20% across all classes 50 m and greater in 1953, and increased to between 30% and 40% across all distance classes in 1992. In general, pine cover was found to increase with distance from 1938 non-forested patches in Dubignon and Larkefield in 1953, but was very low at all distances in 1992.

Overall, covertypes containing pine increased with increasing distance from 1938 non-forested patches in 1953 and did not increase with increasing distance in 1992. The threshold of this effect is 100 m in 1953, the point at which mixed covertypes remained approximately even with increasing distance (Figure 2.3). This pattern is not clear in 1992 because broad scale hardwood establishment occurred across the entire forested landscape, regardless of the distance to historical 1938 non-forested patches. Combining the effects of afforestation in non-forested patches and edge-effects of these patches, these processes affected approximately 56.6% of the sampled landscape, while broad scale succession in interior, un-fragmented forested areas affected 43.3% of the landscape (Figure 2.2).

DISCUSSION

Influences of hardwood succession

Hardwoods have encroached upon many of the remaining longleaf pine forests of the southeastern U.S. (Frost 1993; Varner and Kush 2004). While most successional changes have been attributed to fire suppression (Veno 1976; Hartnett and Krofta 1989; Guerin 1993; Glitzenstein et al. 1995; Gilliam and Platt 1999), encroachment on Ichauway has been attributed to abundance of oak advanced regeneration and annual cool season burning associated with quail management (Jacqmain et al. 1999). Much forest fragmentation may exacerbate the relationship between annual burning and hardwood succession, especially when annual burns reduce adequate fuel accumulation for a hot, homogeneous burn to control invading hardwood growth (Jacqmain et al. 1999; McGuire 2001). Data in this study indicate that all three alternative hypotheses likely functioned together to accelerate hardwood succession. At the broadest scale, most pine cover changed over time into forests with large hardwood components, supporting hypothesis 1. At smaller scales, hardwood dominance was associated with the edges of non-forested features, but this pattern did not extend far out into the stands, supporting hypothesis 2. Furthermore, cleared areas in 1938 appeared to change over time to contain both longleaf pine and hardwood components, but with more hardwoods than in continually forested areas (hypothesis 3).

Forest cover on Ichauway was found to generally move from pine dominated to mixed forest cover, a broad-scale effect resulting from numerous land use practices, including quail plantation management. While some pure pine patches were persistent, they were small and isolated. Even units with large patches of un-fragmented forest at Sandy Desert and Dubignon showed extensive hardwood establishment. The increased complexity of land cover structure is primarily due to the change in agricultural field structure (few large to many small), but may also reflect an increase in possible accuracy of classification in the later aerial photos. There were also changes in forest cover from large patches of pine dominated forest to clusters of smaller hardwood dominated areas. The trends found in the transition analysis of pine to mixed pine and mixed pine to mixed hardwood support the hypothesis that the overall landscape matrix underwent gradual successional changes with increasing hardwood dominance.

Some increase in the hardwood component of contemporary forests can be attributed to old-field succession and human influenced reforestation of non-forested areas. The mixed hardwood cover type had a high probability of replacing non-forested areas in both 1938 and 1953, indicating both hardwood regeneration and hardwood succession (see Goolsby et al. in prep). A large component of the change of non-forest to forest is the addition of hedgerows to the landscape. These hardwood areas do not contribute to pyrogenic fuel buildup; thus fires in these areas would not reduce hardwood cover. Hedgerows provide opportunities for hardwood recruitment and regeneration by providing seed sources, sucker sprouts, and non-pyrogenic ground fuels. The effects from 1938 non-forested areas did not extend spatially very far into forested areas or is being obscured by the overall proliferation of hardwood regeneration.

This study documented hardwood encroachment on the most fragmented and disturbed sites on Ichauway. In contrast to our study, Mitchell et al. (1999) documented few successional oaks in the least disturbed longleaf pine woodlands on Ichauway, supporting our hypotheses that landscape fragmentation with numerous openings leads to shifts in forest overstory to oak successional species. Land use change from abandonment of non-forested areas used for agriculture and pasture lands also resulted in forest regrowth with large increases in hardwood successional species.

Larkefield was the most fragmented unit, yet it showed the least amount of change. This lack of change could be due to the early configuration of forest patches in the historically fragmented landscape, with these effects overriding the landscape-scale successional trends occurring in the other two units. The landcover data from Larkefield is also confounded by the occurrence of successional loblolly pine which was indistinguishable from longleaf pine in some areas of Larkefield on the historical aerial photographs. However, ground-truthing found that the influence of loblolly pine was restricted to the extreme southern and western portions of the unit, particularly on bluffs along the Ichawaynotchauway Creek and on old-field sites. Loblolly is a successional pine with fire intolerant seedlings that generally appears in lower, wetter areas as well as a successional component in old-field sites. The loblolly pine responses to fragmentation would be similar to hardwoods but seedlings are less tolerant of annual burning than oak species and longleaf pine.

The use of fire on quail plantations to maintain habitat and open the woodlands for easy access by hunting parties and for management helped maintain these ecosystems from completely succeeding into southern mixed hardwood-pine forests (Ware et al. 1993; Landers et al. 1995). However, the common practice of annually burning also encouraged successional oaks (Jacqmain et al. 1999; McGuire 2001; Goolsby in prep) to gain dominance over time due to their competitiveness in the understory and the tendency of annual burns to eliminate one year longleaf pine seedlings.

Stewardship Implications

Quail management lands were historically assembled from a diverse suite of land use legacies that preceded game management including timber harvest, turpentining operations, agriculture, livestock production, and human habitation. Consequently, most have a complex history of overstory removal, groundcover disturbance, invasion by successional tree species, and fragmentation of fuel continuity at the stand and landscape scale. The landscape was shaped by fragmentation due to agricultural fields, locations of home sites, and woodland roads. These were synergistic to the alteration of historic fire regimes, the creation of fire suppressed microsites (“fire shadows”), and the resultant rapid and extensive growth of hardwood thickets (Glitzenstein et al. 1995). Active management of private longleaf woodlands to discourage successional hardwood growth and dominance is vital to ensure that high quality longleaf pine woodlands remain on the landscape.

Several patterns of land use and overstory structure contributed to the conditions of current stands. First, hardwood encroachment was evident over a 41 year period on most of the forested landscape. Second, hardwood establishment occurred across all land cover types regardless of landscape configuration. Sites previously non-forested did not regenerate to longleaf pine dominated overstories although longleaf pine regeneration did occur. Once hardwoods reach the mid- and overstory they cannot be effectively removed by fire (Guerin 1993) and other removal techniques must be used. Management of longleaf pine woodlands uses prescribed fire with the objectives of controlling hardwood growth and capturing longleaf pine regeneration (Landers et al. 1995). Restoring longleaf pine overstory dominance then provides for continuity of high quality pyric fuels which are essential for the continued use of prescribed fire to suppress successional hardwoods and to and restore native groundcover.

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TABLES AND FIGURES

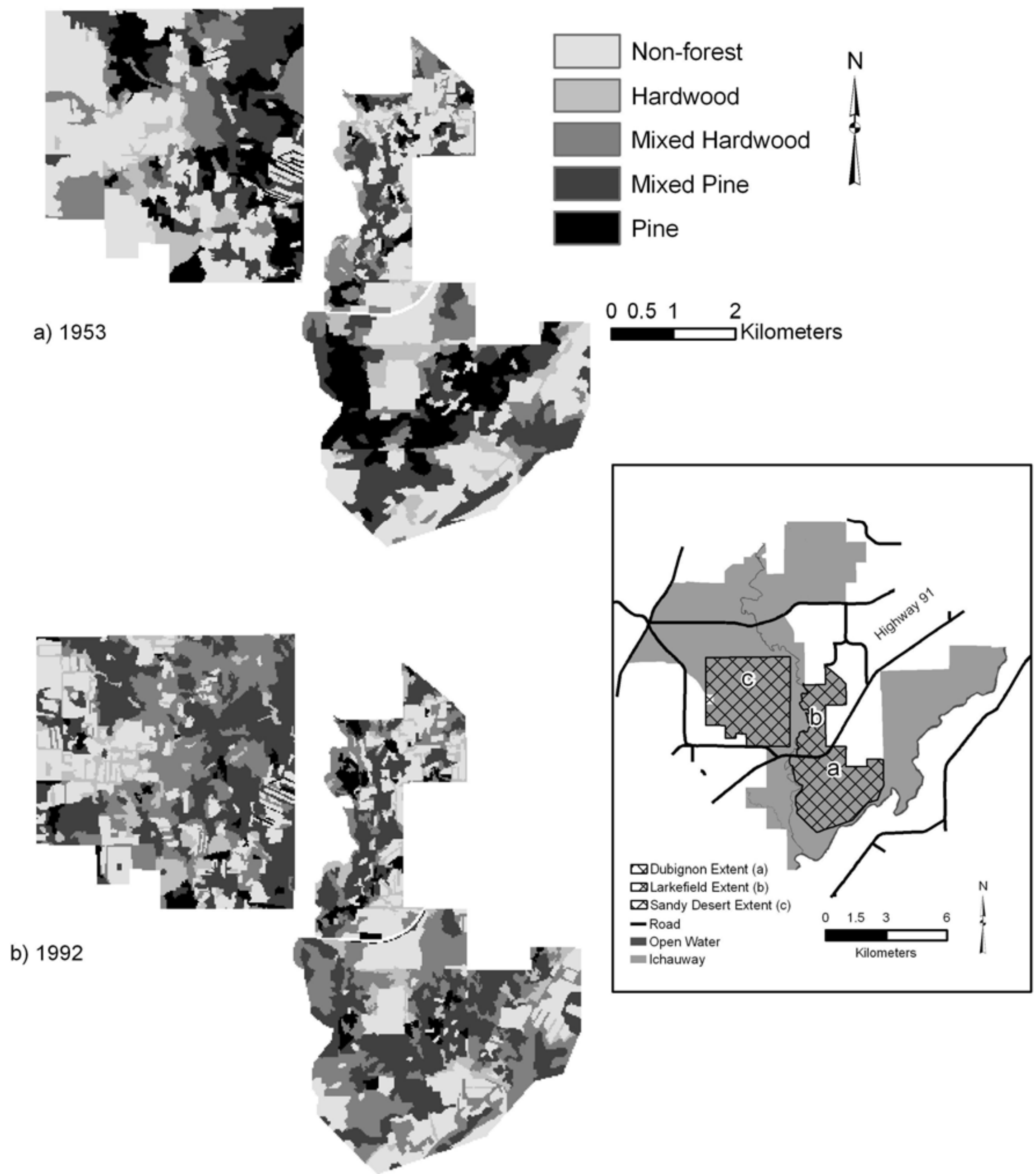

Figure 2.1. Land cover maps for 1953 and 1992 on 3500 ha of Ichauway, GA, U.S.A.. Inset shows sampling units on the entire property. Dubignon and Larkefield are separated by Highway 91.

Table 2.1. Generalized land use time line for Ichauway and southwest Georgia, from 1800s to late 1900s.

Time	Land Use
Mid to late 1800s	Widespread timber removal of old growth Widespread turpentining Some settlement and agriculture Livestock production on open range Frequent woods burning
~1900 through ~1929	Widespread timber removal of old growth Widespread turpentining Livestock production on open range Small sharecropper farming Frequent woods burning
~1929 through ~1940	Acquisition of properties to form Ichauway Plantation Quail management Selective timber harvest Continued turpentining Small sharecropper farming Planting of pines Fire suppression in the early 1930s
~1940 through ~1960	Quail management and increase of scattered food plots Selective timber harvest Turpentine tree removal Fenced livestock production Centralized agriculture
~1960 through ~1990	Quail management and scattered food plots Selective timber harvest Centralized agriculture Fenced livestock production Planting pines J.W. Jones Ecological Research Center created in 1991

Table 2.2. Covertype summary for 1953 and 1992 at all 3 sampled units at Ichauway, Georgia.

2a. All Units

	Total Class Area (ha)		Number of Patches (n)		Mean Patch Area (in ha) (+- 1 SE)				% of Landscape	
Cover Type	**1953**	**1992**	**1953**	**1992**	**1953**		**1992**		**1953**	**1992**
Non-forested	1314	901	59	144	22.3	(7)	6.3	(1)	37	25
Hardwood	276	314	51	98	5.4	(1)	3.2	(1)	8	9
Mixed Hardwood	522	992	59	98	8.8	(2)	10.1	(3)	15	28
Mixed Pine	824	1191	51	59	16.2	(4)	20.2	(7)	23	34
Pine	619	155	28	60	22.1	(10)	2.6	(1)	17	4
Total	3554	3554	248	459	14.3	(2)	7.7	(1)	100	100

2b. Dubignon

	Total Class Area (ha)		Number of Patches (n)		Mean Patch Area (in ha) (+- 1 SE)				% of Landscape	
Cover Type	**1953**	**1992**	**1953**	**1992**	**1953**		**1992**		**1953**	**1992**
Non-forested	422	337	21	35	20.1	(8)	9.6	(4)	32	26
Hardwood	108	83	13	21	8.3	(3)	4.0	(1)	8	6
Mixed Hardwood	154	430	18	26	8.5	(2)	16.5	(5)	12	33
Mixed Pine	337	418	18	15	18.7	(6)	27.9	(16)	26	32
Pine	282	34	3	15	93.8	(72)	2.3	(1)	22	3
Total	1302	1302	73	112	17.8	(5)	11.6	(3)	100	100

2c. Larkefield

	Total Class Area (ha)		Number of Patches (n)		Mean Patch Area (in ha) (+- 1 SE)				% of Landscape	
Cover Type	**1953**	**1992**	**1953**	**1992**	**1953**		**1992**		**1953**	**1992**
Non-forested	233	166	17	30	13.7	(8)	5.5	(2)	42	30
Hardwood	54	65	19	31	2.8	(1)	2.1	(1)	10	12
Mixed Hardwood	107	111	30	26	3.6	(1)	4.3	(1)	19	20
Mixed Pine	125	163	13	20	9.6	(6)	8.1	(4)	22	29
Pine	41	55	12	16	3.4	(1)	3.5	(1)	7	10
Total	559	559	91	123	6.1	(2)	4.5	(1)	100	100

2d. Sandy Desert

	Total Class Area (ha)		Number of Patches (n)		Mean Patch Area (in ha) (+- 1 SE)				% of Landscape	
Cover Type	**1953**	**1992**	**1953**	**1992**	**1953**		**1992**		**1953**	**1992**
Non-forested	659	398	21	79	31.4	(17)	5.0	(1)	39	24
Hardwood	114	166	19	46	6.0	(2)	3.6	(1)	7	10
Mixed Hardwood	261	452	11	46	23.7	(7)	9.8	(6)	15	27
Mixed Pine	362	611	20	24	18.1	(9)	25.5	(14)	21	36
Pine	297	66	13	29	22.8	(6)	2.3	(1)	18	4
Total	1692	1692	84	224	20.1	(5)	7.6	(2)	100	100

Table 2.3. Transition matrices for 1953 to 1992 of all cover types on 3 units on Ichauway, GA. Transition proportions are read as the proportion of pixels that changed from the classes listed in the rows to the classes in the columns. Diagonal values are retention percentages.

3a. All Units

	1994				
	Non-forest	Hardwood	Mixed Hardwood	Mixed Pine	Pine
1953					
Non-forest	0.66	0.09	0.15	0.10	0.01
Hardwood	0.02	0.45	0.43	0.10	0.00
Mixed Hardwood	0.02	0.07	0.42	0.45	0.05
Mixed Pine	0.02	0.04	0.43	0.46	0.06
Pine	0.01	0.01	0.18	0.68	0.11

3b.

DUBIGNON

	1994				
	Non-forest	Hardwood	Mixed Hardwood	Mixed Pine	Pine
1953					
Non-forest	0.76	0.04	0.11	0.07	0.01
Hardwood	0.03	0.37	0.46	0.13	0.00
Mixed Hardwood	0.02	0.03	0.57	0.38	0.00
Mixed Pine	0.02	0.05	0.51	0.41	0.02
Pine	0.01	0.01	0.27	0.62	0.09

3c.

LARKEFIELD

	1994				
	Non-forest	Hardwood	Mixed Hardwood	Mixed Pine	Pine
1953					
Non-forest	0.71	0.09	0.10	0.09	0.01
Hardwood	0.00	0.42	0.57	0.02	0.00
Mixed Hardwood	0.01	0.13	0.29	0.46	0.11
Mixed Pine	0.00	0.05	0.16	0.59	0.20
Pine	0.00	0.03	0.13	0.43	0.42

Table 2.3 continued.

3d.

SANDY DESERT			1994		
	Non-forest	Hardwood	Mixed Hardwood	Mixed Pine	Pine
1953					
Non-forest	0.57	0.11	0.18	0.12	0.02
Hardwood	0.02	0.53	0.33	0.11	0.00
Mixed Hardwood	0.02	0.06	0.39	0.48	0.05
Mixed Pine	0.03	0.03	0.44	0.45	0.05
Pine	0.02	0.01	0.10	0.78	0.09

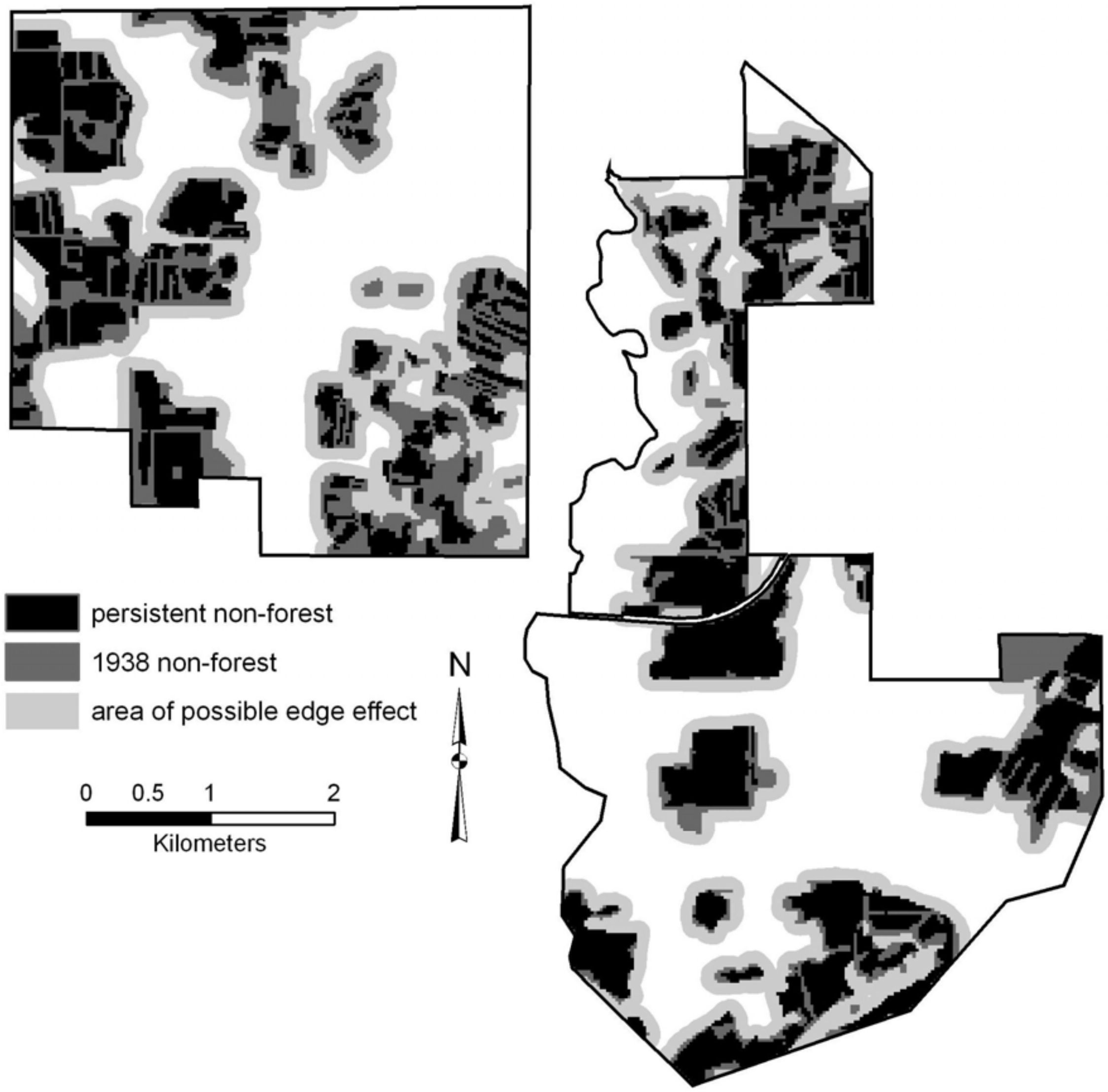

Figure 2.2 Non-forested patches persistent through time, 1938 non-forested patches, and area of possible edge effect on the three sampling units of Ichauway, GA. U.S.A.

Table 2.4. Percent cover of all forest cover types on areas reforested since 1938 and continuously forested areas on Ichauway, GA.

Cover type	1953 Old field	1953 Continuously forested	1992 Old field	1992 Continuously forested
Hardwood	20.2	12.3	26.3	11.8
Mixed Hardwood	23.3	23.3	36.9	37.4
Mixed Pine	32.1	36.8	30.3	44.9
Pine	24.4	27.6	6.5	5.8

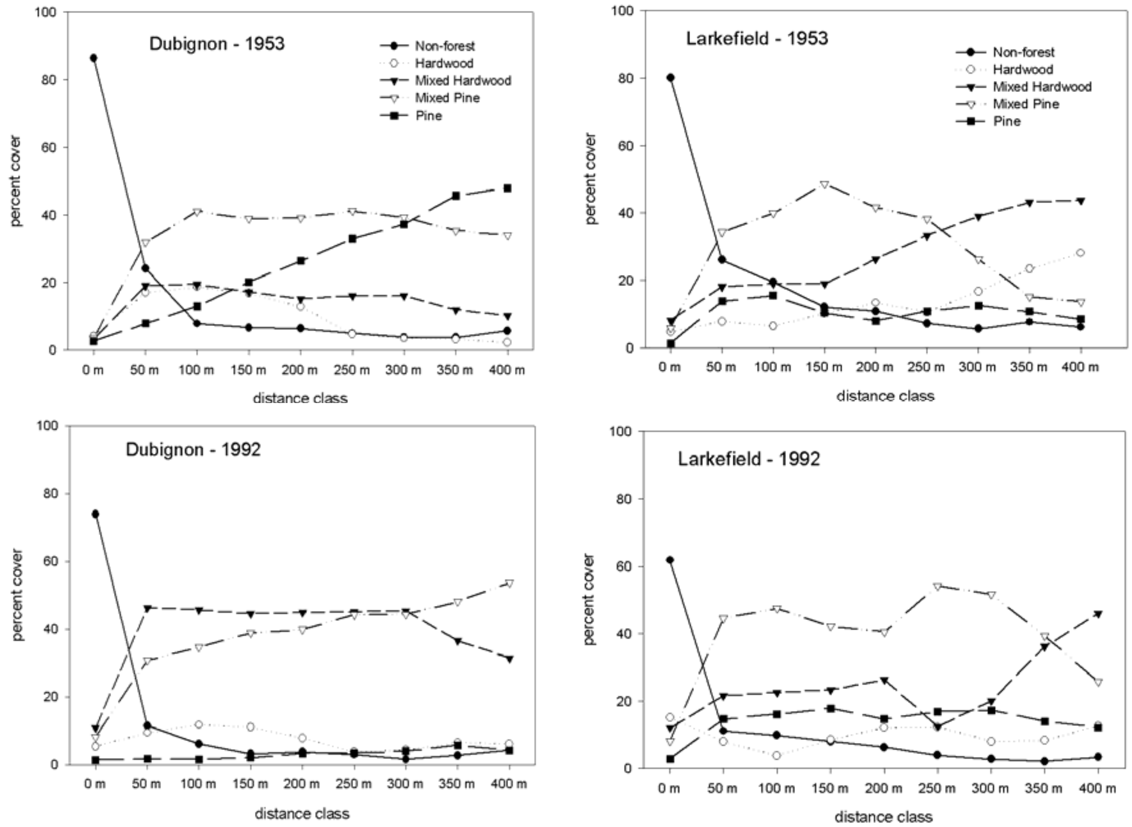

Figure 2.3. Percent cover of all cover types at 50 m intervals from the edge of 1938 non-forested patches. The 0 m distance class represents cover inside patches non-forested in 1938. The 50 m class contains all pixels < 50 m from the edge of 1938 non-forested patches, the 100 m class contains all pixels < 100 m and > 50 m from 1938 non-forested patches, continuing to 400 m. From Ichauway, GA.

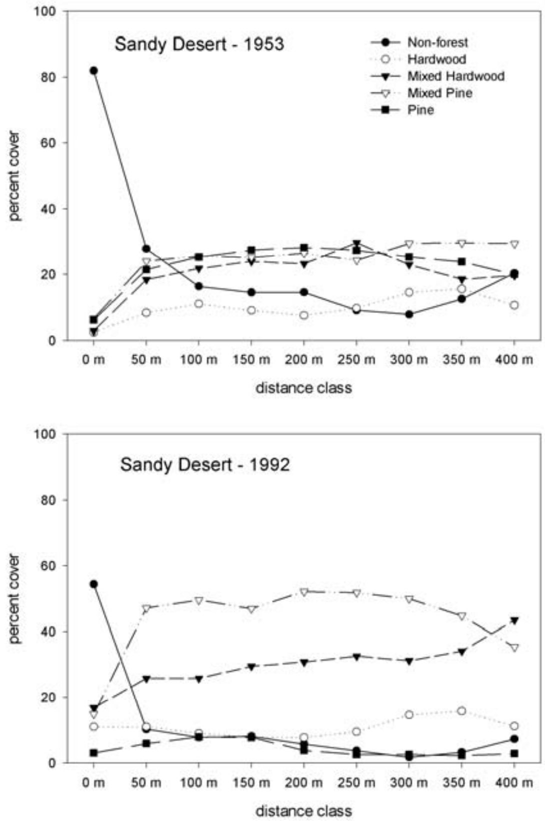

Figure 2.3 continued.

CHAPTER 3

LAND USE AND SUCCESSION IN LONGLEAF PINE WOODLANDS[1]

[1] Goolsby, D., L. Boring, and M. Wimberly. To be submitted to *Forest Ecology and Management*.

ABSTRACT

During the twentieth century longleaf pine (*Pinus palustris* L.) forests decreased to approximately three percent of their former range as a result of logging, failed regeneration, and conversion to intensively managed pine. During this time northern bobwhite quail hunting plantations conserved isolated patches of longleaf pine forests, although often with great amounts of successional trees as a result of annual low intensity fires and forest fragmentation. This study documented the patterns of oak and pine establishment on lands historically managed for bobwhite quail by examining age class distributions of hardwoods and longleaf pines. Oak age class distributions were created by counting rings on stumps left during hardwood removal for ecosystem restoration and longleaf pine age class distributions were created by increment boring standing trees. Age class distributions were qualitatively linked to historical records to identify management events that correlated with establishment periods, as well as position on the landscape. Oak establishment was found to occur in two temporal patterns: constant through time and pulsed establishment. In areas relatively un-fragmented by fields and food plots, oak establishment was constant through time with even numbers of oaks in each age class. In more fragmented areas, oak age class distributions were peaked, indicating a pulse of establishment in the 1960s associated with decreasing population of residents and resulting afforestation of old fields. Longleaf pine establishment was pulsed at all sites and through time as a result of heavy overstory removals and burning patterns.

Keywords: *Pinus palustris*, northern bobwhite quail, land use, succession, prescribed fire, oak establishment

INTRODUCTION

Longleaf pine (*Pinus palustris* Mill.) forests once dominated the coastal plain of the southeastern United States, although they now comprise only a small portion of their former range (Frost 1993; Varner and Kush 2004). Longleaf pine woodlands are maintained through frequent, low intensity prescribed fires that provide bare mineral soil needed for longleaf pine regeneration and prevent aggressive hardwood succession. The main causes of longleaf pine woodland decreases were regeneration failure after extensive logging in the late 1800s and early 1900s and conversion of former longleaf pine woodlands to agriculture and intensively managed pine plantations (Wahlenberg 1946; Frost 1993; Landers et al. 1995). Most old growth longleaf pine was cut by 1920, and the subsequent period of fire suppression that dominated forestry in the United States limited longleaf pine regeneration on most sites and accelerated succession to mixed pine and southern hardwood forests (Wahlenberg 1946; Pyne 1982; Frost 1993).

Longleaf pine forests are typically open savannah grasslands with hardwood mid-stories and diverse herbaceous groundcover. Hardwoods are natural components of longleaf pine woodlands and are limited by frequent, low intensity fires. Periodic fires kill hardwood saplings and sprouts, reduce competition for light and nutrients with longleaf pine, and expose bare mineral soil needed for natural longleaf pine regeneration (Myers 1990). However, hardwood "encroachment" (aggressive successional changes in longleaf pine forests to mixed oak-pine with a dense midstory of oaks) changes litter and fuel accumulation and significantly alters fire behavior. Much attention has been given to patterns of forest succession in longleaf pine communities resulting from fire suppression (Wahlenberg 1946; Monk 1968; Veno 1976; Myers and White 1987; Hartnett and Krofta

1989; Gilliam and Platt 1999; Greenburg and Simons 1999) but issues relating to historic anthropogenic burning and the complexities that other land uses play in structuring longleaf pine woodlands have not been examined either temporally or at broad spatial scales.

Management for northern bobwhite quail (*Colinus virginianus*) historically included annual cool-season burning. Annual cool season burning was utilized to maintain an open understory for easy access by hunters and land managers as well as to provide a mosaic of burned and unburned vegetation, maximizing edge habitat valued by bobwhite quail (Stoddard 1931). Burning regimes of this type may encourage the growth of woody vegetation and hardwood stands (Robbins and Myers 1992; Brockway and Lewis 1997; Jacqmain et al. 1999). In addition, quail management often involves purposeful fragmentation of the landscape to maximize edge habitat valued by quail. Historically, this fragmentation has been achieved by creating small planted food plots throughout forest stands (Stoddard 1931). The creation of edge habitat favor quail but may alter the spatial and temporal patterns of prescribed fire and encourage hardwood growth (Rebertus et al. 1993). Some historic removal of hardwood thickets occurred with the harvest of hardwood poles as well as periodic mechanical removals and chemical treatments to favor pine woodlands on some properties.

The southeastern United States has a rich cultural legacy of prescribed fire use in woodland management. Changing economic and land use patterns after intensive logging and failed longleaf pine regeneration in the 1920s resulted in widespread fire suppression across the South starting in the 1930s (Wahlenberg 1946; Pyne 1982; Frost 1993), resulting in the degradation of many of the remaining longleaf pine woodlands. One venue in which frequent fire remained an important management tool throughout the twentieth century was the management of the northern bobwhite quail (*Colinus virginianus*). This frequent burning has served to maintain tracts of longleaf pine and a rich array of biological diversity associated with their conservation (Kirkman et al. 2001), although sometimes in a degraded or heavily succeeded state. Longleaf pine must have a fire frequency of 2-5 years to maintain it's overstory dominance. On many historic quail lands, annual burning resulted in low fine fuel accumulations, poor conditions for successful longleaf pine regeneration, patchy burning, and decreased effectiveness of fire to slow the encroachment of successional hardwoods and other invasive species (Brockway and Lewis 1997; Jacqmain et al. 1999; Robbins and Myers 1992).

The objective of this study was to describe the temporal patterns of hardwood succession based on non-mutually exclusive multiple working hypotheses and to link hardwood and longleaf pine establishment to historical events on three representative land units historically managed for bobwhite quail. Hardwood and longleaf pine establishment was characterized by aging stumps of hardwoods left by mechanical hardwood removal for ecosystem restoration, as well as by examining increment cores from longleaf pine trees on the same sites. Distributions of establishment through time were qualitatively correlated to known land use events.

Our alternative hypotheses were:

a. *Hardwood encroachment was a continuous, gradual process related to long-term land use practices such as annual burning and selective logging.*

Land use practices across broad scales and in large forested tracts could have allowed continuous, gradual hardwood encroachment across the landscape. This pattern of hardwood recruitment would be reflected by flat age class distributions with fairly even numbers of hardwoods in each age class. These processes would have been particularly evident in less fragmented and disturbed longleaf pine woodlands.

b. *Hardwood encroachment was "event punctuated," associated with specific land use events such as old field abandonment, the creation of hedgerows, and changes in fire regime, resulting in pulsed successional oak establishment and dominance.*

The addition of hedgerows, changes in shape and placement of agricultural fields, timber removal and culling of previously turpentined trees, and changes in dominant land use schemes in discrete time periods would create distinct periods of change in forest structure. Oak age class distributions would have temporal pulses of regeneration, indicating distinct periods seedling release and overstory establishment.

SITE DESCRIPTION

The site for our study was the Joseph W. Jones Ecological Research Center at Ichauway (here after referred to as Ichauway) located in the Doughterty Plain of southwest Georgia in Baker Co., a subprovince of the southeastern coastal plain. The 11300 ha site currently contains about 7500 ha of longleaf dominated woodlands and approximately 1600 ha of field complexes used for wildlife management, afforestation, and conservation of historic legacies. The site supports diverse forest and wildlife research as well as educational activities and demonstrations. Summer temperatures range from 21° C to 34° C and winter temperatures range from 5° C to 17° C. The majority of soils are characterized as well-drained loamy sand over sandy loam to sandy clay loam on gently rolling karst terraces. Elevations range from 27 to 61 m above sea level (Goebel et al. 1997).

General Site History

The area that would become Ichauway Plantation was likely inhabited by humans at least 5000 years ago. The Woodland and Mississippian cultures influenced landcover with the use of fire to improve game browse, improve gathering and agricultural lands, maintain an open understory for easy travel, and control fuel accumulation near settlements (Wahlenberg 1946; Range 1954; Frost 1993). Europeans began settling the region in the mid 1800s, starting with turpentining settlements, livestock production and agriculture restricted to river corridors, followed by logging operations in the late nineteenth century (Forbes 1923; Range 1954; Frost 1993). Fire remained a dominant force in shaping forest structure well into the twentieth century as Europeans continued to use fire for many of the same purposes as prehistoric peoples. However, alteration of the landscape through fragmentation by agricultural fields, home sites, road construction, and fire breaks changed historic fire regimes and encouraged growth of hardwood thickets and increases in invasive species (Glitzenstein et al. 1995). Logging began to affect the landscape in the late nineteenth century and by the 1920s most of the old growth longleaf pine woodlands in the region had been cut (Frost 1993). During the early twentieth century, dry-land agriculture and livestock production in the form of sharecropping and tenant farming became prevalent on formerly forested sites.

We constructed a generalized timeline of land use practices in the Ichauway region (Table 3.1). Robert W. Woodruff began assembling Ichauway Plantation in 1929 and continued acquiring large parcels of land until the last large block was purchased in 1941. During this time the dominant land management shifted from subsistence farming to forest protection and quail management. Measures were taken to conserve the remaining forest and to encourage regeneration such as excluding woodland grazing of livestock and a brief period of fire suppression in the 1930s.

Study Unit Criteria

Units with significant human impacts and hardwood establishment were chosen to see successional patterns clearly under known quail management practices as well as units with dominance of upland soils and absence of wetland complexes. Units were chosen for study based on quality and quantity of historic sources, variety of land use and land cover, and amount of area able to be sampled. Three units were chosen as representative of the most disturbed and hardwood encroached sites on Ichauway as well as having a diverse suite of historic land use practices. Many units with high amounts of hardwood encroachment have undergone mechanical removal of hardwoods since 2002 under a program of ecosystem restoration. These areas of hardwood removal were chosen as the primary sampling areas to use remnant stumps for hardwood age-class inquiry. These hardwood removal areas represented areas on Ichauway with the most amount of hardwoods and remnant longleaf conservation value.

Dubignon

The area called Dubignon encompassed approximately 1300 ha of forest, field complexes, and homesites (Figure 3.1). The property was acquired by R. W. Woodruff in

1940 or 1941, and was the last large acquisition completing Ichauway plantation. Examination of historic aerial photographs from the 1930s and 1950s found many dense stands of longleaf pine, mixed pine hardwood woodlands, as well as large field complexes and homesites. Most of Dubignon was classified as well drained upland terraces with some clayey depressions. The soils are mostly loamy sand over sandy loam to sandy clay loam (Goebel et al. 1997).

A report from Herbert Stoddard to Robert Woodruff in 1940 described the condition of the property and its value as quail management lands. Stoddard described the property as having many young loblolly pines, longleaf pines, and red oaks (*Quercus falcata* Michx.) with older longleaf already cut. The forest was described as being kept open by occasional burning. Stoddard mentioned numerous homesites and pasturelands as well as the practice of year-round woodland grazing. Stoddard stated the land was largely in poor condition for quail management but had high potential for being conditioned to good quail management land in 1 to 4 years once livestock was fenced and contained.

Larkefield

Larkefield encompassed approximately 600 ha of field complexes, longleaf pine woodlands, mixed pine hardwood forests, as well as bottom land hardwoods along the Ichawaynotchauway Creek (bottomlands were not examined in this project). Larkefield was acquired sometime in the late 1930s. Examination of historic aerial photographs found that Larkefield had some stands of trees persistent since the 1930s as well as much reforestation due to the shifting of the numerous agricultural complexes and addition of hedgerows. Non-forested (fields and homesites) and forested areas were highly interspersed in small patches (Figure 3.1). Upland soils in the sampling areas were mostly loamy sand over sandy loam to sandy clay loam (Goebel et al. 1997).

Sandy Desert

Sandy Desert was acquired in the early 1920s with Robert Woodruff's original purchases to assemble Ichauway. It contained some of the oldest longleaf pine on the property. The area encompassed approximately 600 ha of non-forested, longleaf pine, and mixed pine hardwood woodlands. The configuration of the landscape was less fragmented than that of Larkefield and more like that of Dubignon, with non-forested and forested areas in large patches rather than interspersed. Soils were well drained upland terraces with loamy sand over sandy loam to sandy clay loam and somewhat excessively drained upland terraces with loamy sand to sandy loam (Goebel et al. 1997).

METHODS

Historic Sources

Historical land use related documents were obtained from the Emory University Special Collection Archives, Atlanta, Georgia and from F and W Forestry Co., Albany, Georgia. These documents contained potential general information on timber harvests in from 1971 to 1984 as well as historic maps showing land acquisition by Robert W. Woodruff and anecdotal descriptions of the property during the mid twentieth century. More extensive land use records were generally not available for the property as a whole.

Historic records housed at the county courthouse were destroyed by past fires and floods. Historical aerial photographs were consulted to verify land use information from historic documents and characterize landcover and land use (Goolsby et al. in prep).

Sampling in Hardwood Removal Areas

For each unit, historical landcover was characterized from 1994 from aerial photographs within the area undergoing hardwood removal (Goolsby et al. in prep). Ninety-one 6 m x 50 m plots (30 at Larkefield and Sandy Desert, 31 at Dubignon) were randomly located using a random point generator in a geographic information system. Plots were stratified based on the percentage of landcover in each of 4 classes, hardwood dominated, mixed pine-hardwood with more than 50% hardwood, mixed pine-hardwood with more than 50% pine, and pine dominated. Plots were stratified so the proportion of plots in each landcover class equaled the proportion of the landscape the landcover class occupied.

Hardwood stump largest diameter, diameter perpendicular to largest diameter, and number of rings were recorded. On stumps with significant damage or rot, number of rings was not recorded. Diameters were averaged to get a single diameter for each stump. Stumps were generally between 6 and 20 cm tall. To count rings on hardwood stumps, chisels and sandpaper were used to make 1 to 2 grooves from the center of the stump to the edge. On stumps where 2 grooves were possible, the 2 ring counts were averaged. On stumps where only one groove was possible due to rot, damage, or poor condition, rings in the groove were counted twice and averaged. In each plot up to five longleaf pine trees were measured at breast height and increment bored at breast height

(1.4 m). If there were more than five longleaf trees on a plot, five were chosen at random to be increment bored.

Because pines were cored at breast height, the ages reported are conservative estimates and ignore the time longleaf may have stayed in the grass stage. The grass stage is a phase early in longleaf pine development before stem growth. Longleaf pines can stay in the grass stage for 2 to many years (Wahlenberg 1946). Longleaf pine ages reported therefore represent age since the tree was recruited into the overstory. All cores were mounted in the field, then dried and sanded to three-hundred grit. Rings were counted under a dissecting microscope (Maeglin 1979). The hardwoods documented in our study are prolific sprouters. A hardwood root collar may survive many fires and repeatedly re-sprout. Therefore, the caveats associated with the longleaf pine ages in this study also apply to hardwood ages. All longleaf pine and hardwood ages were put into 10 year classes for analysis and comparison. Age – class distributions were analyzed qualitatively by comparing the shapes of the distributions, as well as identifying gaps or peaks which may correlate with land use activities. Peaks were associated with periods of establishment or recruitment, gaps were associated with periods of little to no establishment, and flat or rounded distributions were identified as constant establishment through time. Constant recruitment through time is often associated with a negative exponential curve, however because we excluded individuals in the smallest size classes, this patterns was not expected.

Species Composition and Age Class of Reference Plots

During the hardwood removal from which hardwood ages were sampled, many hardwoods in smaller size classes (usually basal diameter <30 cm) were pushed over by machinery or destroyed beyond the ability to read the rings. To asses potential biases arising from these un-sampled trees, reference plots in intact areas adjacent to hardwood removal areas were chosen with comparable land use history and overstory composition. Twelve 6 m x 50 m plots were randomly located with a random point generator in a geographic information system. We used these plots to examine species composition and age-size relationship of smaller diameter hardwoods and characterize the species composition of areas with large amounts of hardwood encroachment. Species and diameter at breast height were recorded and all pines were increment bored as well as all hardwoods below 45 cm dbh not showing exterior evidence of interior rot. Additionally, existing data from a timber cruise conducted in 2003 by the Jones Center staff on the Dubignon unit were acquired to compare species composition and community structure with the reference and hardwood removal plots. This cruise combined many non-commercial hardwood species and so was not an explicit description of community structure but did give a general picture of the community structure on the Dubignon unit.

Age – Size Analysis

Linear regressions were conducted on data collected from hardwood removal areas as well as the intact reference stands to model age – size relationships for pines and hardwoods. Analysis of covariance (ANCOVA) was used in the PROC MIXED procedure of SAS (SAS Institute 2004) to detect significant goodness of fit in the regressions as well as significant differences in slope and intercept of hardwood and longleaf pine age – size relationships in the two data sets. Significance level was set at 0.05.

RESULTS

Composition and Structure on Reference Plots

Species composition of the reference plots indicated a mixed pine-hardwood forest with significant successional hardwood components (Table 3.2). *Pinus palustris* (longleaf pine) comprised approximately one third of the total basal 14.9 m^2/ha area and one quarter of the total number of stems. *Quercus margaretta* (Ashe ex Small), *Q. virginiana* (Mill.), and *Q. hemisphaerica* (Michx.) comprised half of the total basal area on the plots, while *Q. nigra* (L.), *Q. falcata*, and *Prunus serotina* (Ehrh.) comprised the remaining hardwood basal area. Based on the timber cruise conducted in 2003in Dubignon, *Quercus falcata* dominated the site with 23.9 stems per hectare and a basal area of 2.84 m^2 per ha (Table 3.3). Longleaf pine followed with 24.1 stems per ha and a basal area of 2.63 m^2 per ha. These data show the dominance of hardwoods in the stand and corroborate the dominance of hardwoods found in the reference plots.

Significant goodness of fit for linear regressions was detected for analyses of reference age size data (Table 3.4 and Figure 3.2). The longleaf pine age size regression equation had an r^2 of 0.60, and the hardwood regression equation has an r^2 of 0.48. Neither slopes nor intercepts were significantly different from each other which was likely due to the relatively small sample size of the reference stands. There is also some bias in this data set because many larger hardwoods were not able to be aged with increment cores due to hollow trees, whereas all longleaf pines were cored and aged. Hardwoods in smaller size classes (10 to 30 cm dbh) had a similar age size relationship as longleaf pines in larger size classes (30 to 50 cm dbh).

Composition and Structure on Hardwood Removal Plots

Basal area on hardwood removal plots was dominated by hardwoods (Table 3.5). Stem density of hardwoods was higher than density of longleaf pine at all sites except Dubignon, where longleaf pine stem density was slightly higher than hardwood stem density (84 stems per ha and 71 stems per ha, respectively). Both Larkefield and Sandy Desert contained approximately five times as much hardwood basal area as longleaf pine basal area, illustrating the dominance of hardwood overstory at these sites.

The age to size analysis of trees on hardwood removal plots shows the broader range of ages and sizes of hardwoods than pines. Intercepts were significantly different but slopes were not significantly different in the removal plot age-size regressions (Table 3.6 and Figure 3.3) indicating the overall larger size of hardwoods than longleaf pines in each age class. The longleaf pine regression equation has an r^2 of 0.41, and the hardwood regression equation has an r^2 of 0.12. Some effects in this regression may be an artifact of sampling method and of different tree species morphologies and taper of trunks. Longleaf pines tend to swell little at their bases in comparison to hardwoods which tend to add more buttressing. Figure 4 shows the basal diameter size distribution for all hardwoods in the removal plots as well as the distribution of all hardwoods which were capable of being aged. The large proportion of hardwoods unable to be aged in the smaller and larger size classes explains some of the weaknesses in the age size relationship and may explain why the generally accepted pattern of faster growth rates of hardwoods over longleaf pines in younger age classes was not empirically demonstrated.

Temporal Dynamics of Tree Establishment

The age class distributions showed two distinct periods of longleaf pine establishment, the first in the 50 to 69 year range and the second in the 70 to 89 year range. Hardwood age class distributions were generally peaked with gradually descending tails, indicating pulses of establishment occurring over several decades (Figure 3.5). Dubignon hardwood age class distributions, the least fragmented sampling site, showed a pattern of fairly constant hardwood recruitment through time. Conversely, hardwood establishment in Sandy Desert and Larkefield, sites with high amounts of fragmentation from fields and food plots, was narrower in temporal range with no hardwoods older than 79 years.

Longleaf pine establishment in Larkefield peaked in the 40-49 year age class at 10 trees per ha and a smaller peak also occurred in the 80-89 year age class at 7 trees per ha. Hardwood establishment in Larkefield peaked in the 40-49 year age class at 13 trees per ha, concurrent with the larger peak in longleaf pine establishment. Hardwood establishment in Sandy Desert peaked at approximately 10 trees per ha in the 40-49 year age class and approximately 8 trees per ha in the 60-69 year age class. Longleaf pine establishment peaked at the 50-59 and 70-79 year age classes. Pooling age data from all sites resulted in age class distributions that encompass a wider range of variability in land use legacy and thus establishment patterns more representative of the landscape as a whole. Across all sites, hardwood establishment peaked in the 40-49 year age class at approximately 9 trees per ha and longleaf pine establishment peaked in the 50-59 and 80-89 year classes at approximately 10 trees per ha. Establishment of longleaf pines was low on all units in the 60-69 year age class.

DISCUSSION

Community Composition and the Interactions with Fire

The land management activities associated with historic quail management ensured the persistence of longleaf pine woodlands on the landscape. Although quail management and annual cool season burning failed to control encroaching hardwoods (Jacqmain et al. 1999), they ensured periodic longleaf pine regeneration during the twentieth century. Hardwoods outnumbered longleaf pine in both stem density and basal area. The community described in this study is longleaf pine and successional, opportunistic hardwoods rather than classic longleaf pine sandhill hardwoods. Hardwoods in this study are predominately those associated with more intense anthropogenic impacts. *Quercus virginiana* and *Q. falcata* were common as shade trees at homesites and on pasture lands and they provide valuable forage for game species (Stoddard 1931). *Quercus margaretta* is an opportunistic oak associated with both longleaf pine sandhills and historic human settlements. Without pine needle fuel loading and continuity of longleaf pine overstory, these open areas did not burn with sufficient intensity to control the spread and dominance of opportunistic hardwoods.

Land use, forest overstory, and fire behavior all interact in a feedback loop to shape the forest patterns observed on these sites. Longleaf pine overstory is needed to provide adequate fuels to maintain low intensity fires that encourage pine regeneration and dominance and to reduce successional hardwood encroachment. The legacy of annual burning on quail lands ensured that longleaf pines would reproduce, but some of that regeneration would have been killed in annual fires since longleaf are sensitive to fire in their first year of growth. Annual cool season fires were generally not hot enough to suppress hardwood seedlings and sprouts due to low fuel loading, and likely did not burn very homogeneously across the landscape. This spatial variability in burning allowed many young pine and hardwood seedlings to survive each year. Hardwoods grow faster than longleaf at younger ages, thus influencing overstory dominance more rapidly through time than longleaf (Platt et al. 1988; Glitzenstein et al. 1995; Palik and Pederson 1996; Greenberg and Simon 1999; Jacqmain et al. 1999; McGuire et al. 2001; Bechtold 2003).

The larger size of hardwood crowns than longleaf crowns means that fewer hardwoods are needed to alter forest overstory composition than the number of longleaf required to maintain it. Data from hardwood removal areas in Dubignon illustrate this pattern with longleaf pine occurring at 84 stems per ha and hardwoods occurring at 71 stems per ha, but hardwoods having more than twice the basal area per ha. Litterfall from hardwoods is less pyric than longleaf pine needles and thus prescribed fires do not burn as intensely or completely, thus protecting hardwood seedlings and failing to uncover bare mineral soil for longleaf pine regeneration (Wahlenberg 1946; Myers 1990). Young and mid-size hardwoods are generally aggressive resprouters, providing constant recruitment opportunity through time, and are only top-killed by prescribed fire (Jacqmain et al. 1999). Once hardwoods leave the seedling stage, they are generally not killed by these low intensity fires (Guerin 1993) and rapidly alter the forest overstory.

Temporal Dynamics of Oak Establishment

Two land use events correlate well with periods of tree establishment. Fire suppression was widespread throughout Georgia for a brief time, including on Ichauway, as a result of an initiative by the Georgia Forestry Commission. Historical documents from the Emory University Special Collections Archive verify that before 1930, the vast majority of the property was burned every year and that this pattern occurred on all adjacent lands. Fire suppression was initiated in 1930 with active patrols to put out fires and to create networks of fire breaks. Only 80 ha (200 acres) were burned on Ichauway in 1931. The documents do not say how long fire suppression was prevalent but later documents reflecting Herbert Stoddard's activities on the property in 1941 indicate that an active prescribed burning program was being utilized before that time.

Small peaks in hardwood establishment are seen in the 60 to 69 and 70 to 79 year age classes in Dubignon and Sandy Desert. Overall, the Dubignon age class distribution of hardwoods shows fairly constant recruitment through time. The lack of accelerated pulses in hardwood establishment found on the other unit may be the result of where sampling points were located. Hardwood removal and sampling in Dubignon occurred on a larger proportion of continuously forested areas whereas much of the hardwood removal on the other two units occurred close to field margins and in former hedgerows. Additionally, pulsed longleaf pine establishment is seen on all sites in this time period. It appears that the cessation of annual burning during this time may have allowed recruitment of all species of trees across woodlands, field margins, and hedgerows. Furthermore, the low levels of longleaf pine regeneration signified by a trough in the age class distribution in the 60-69 year age class may reflect either lack of successful longleaf pine germination or longleaf pine seedling and sapling mortality as a result of intense burning during the introduction of prescribed fire to Ichauway after the 1930s fire suppression. This was probably in the late 1930s, since by 1941 historical records indicate that Herbert Stoddard was providing consultation on land management at Ichauway to include the use of prescribed fire.

The second land use event evident in the age class distribution of tree establishment is associated with long term changes in longleaf pine woodland management. The 1940s and 1950s were a period of transition from land use dominated by subsistence agriculture to broad scale quail management. Robert Woodruff acquired the last piece of property comprising Ichauway in 1941. Anecdotal evidence from long term residents and land managers points to a period in the 1950s and early 1960s when broad scale selective timber harvests and salvage logging occurred. Many of the remnant turpentined trees with large “catfaces” as well as snags and crooked longleaf trees were removed by the 1950s to improve woodland aesthetics and wildlife browse potential of the forests for quail management. Large peaks in hardwood establishment are seen at all sites in the 50 to 59 year age class, as well as large peaks in establishment of longleaf pine. Mitchell et al. (1999) found peaks in longleaf pine and some oak recruitment during the same time period on less fragmented sites on Ichauway. It is likely that the removal of overstory trees using large openings resulted in the release of many suppressed longleaf pines and oaks (Boyer 1985; Grace and Platt 1995).

The late 1940s and 1950s were a period of widespread changes in the spatial structure of non-forested areas containing homesites and large field complexes (Goolsby et al. in prep). Subsistence farming peaked on Ichauway by the 1950s with approximately 400 people working the land on small farms scattered across the property. Many of the fields associated with these numerous farms had hedgerows added during this time, adding to the hardwood component of the woodlands. During the 1950s, advances in farming technology began to decrease the number of workers needed on the plantation (Range 1954) and allowed greater access to the interior of the stands and a greater ability to plow “birdrings” and create small wildlife food plots, but the numerous homesites and small fields left a lasting legacy. Many small fields were converted to food plots for game management. The increased use of tractors allowed small fields to be widely dispersed in forest stands. This also may have disrupted patterns of pyric fuel accumulation, thus increasing the spatial heterogeneity of fire, which is known to increase chances of hardwood encroachment (Glitzenstein et al. 1995), and increasing the ability of hardwoods to compete for light and nutrient resources (Gagnon et al. 2003). Examination of historic aerial photos shows the increase of hedgerows on field margins and old-field succession of former pasture and agricultural sites during this period (Goolsby et al. in prep).

Thus, a dichotomy between two types of hardwood establishment can be defined, event punctuated and even through time. Dubignon exhibits fairly continual hardwood recruitment in relatively un-fragmented stands, while the more fragmented and disturbed units have more distinct pulses of tree establishment linked with historic events, specifically the widespread appearance of hedgerows and old-field succession on former agricultural and pasture sites. When pooling age class data for all sites to look at broader spatial patterns, hardwood encroachment is peaked during the time of transition from agricultural dominated land use to quail dominated management. However, the peak is not distinct and has a tail into the older age classes, mainly due to older trees being found in Dubignon than in the other two units. The reason for the lack of older hardwoods in Sandy Desert and Larkefield is unknown. This may reflect the diverse suite of land use events encountered across larger spatial scales, specifically the interaction of widespread annual cool season burning, the creation and abandonment of large and small agricultural fields and food plots, and the dominance of hardwoods along field margins and homesites.

Relevance to Land Management

Quail hunting lands historically served as an important model in the larger realm of ecosystem conservation in the southeastern United States (Stoddard 1931). In increasingly fragmented and human dominated ecosystems, the need for increased management of pine woodlands for multiple use is important (Landers et al. 1995). This study underscores the need for integrated forest and wildlife management with particular emphasis on the complex relationship between life history traits of longleaf pines, successional oak species, and historic disturbance patterns of land use.

Decades to centuries of hardwood encroachment due to the disruption of historic fire regimes now necessitate more intensive ecosystem restoration efforts such as successional hardwood removal which created the opportunity and necessity for this research. It is imperative that longleaf pine overstory dominance be restored so that fuel types will be conducive to frequent, low intensity prescribed fires as a cost effective ecological management tool. Prescribed burning can then be effectively used to control hardwood encroachment, stimulate groundcover restoration (Robbins and Myers 1992; Glitzenstein et al. 2003) and capture natural longleaf pine regeneration. Private land owners who can effectively utilize prescribed fire and ecologically driven, single tree selective harvesting (Palik and Pederson 1996; Palik et al. 2002) to capture longleaf pine regeneration can manage land over the long term for economic opportunities emphasizing integrated timber and wildlife values (Landers et al. 1995; Van Lear et al. 2005).

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TABLES AND FIGURES

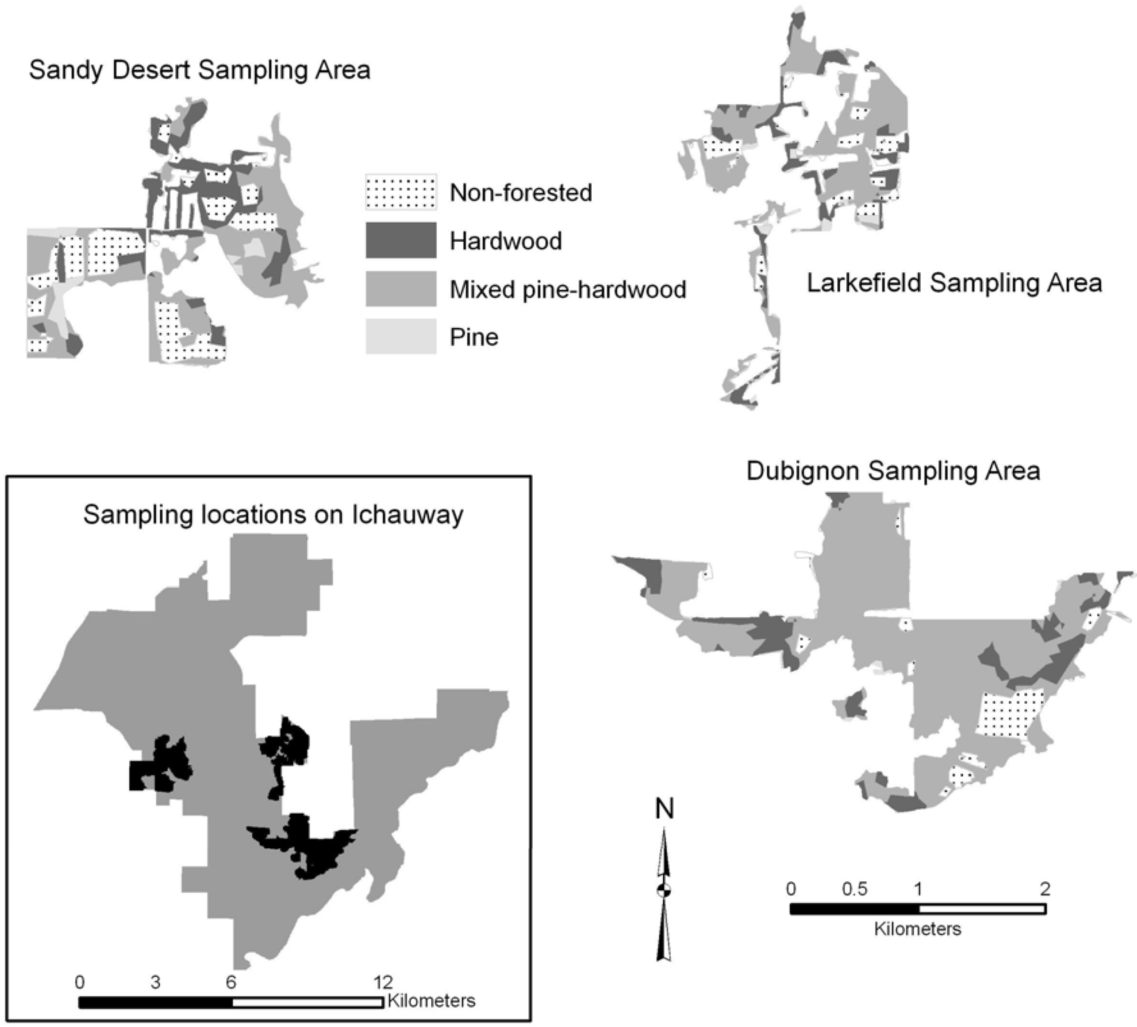


Figure 3.1. Map of study units on Ichauway, GA, U.S.A. Plots were stratified by covertype and randomly located on each unit. Mixed pine-hardwood classes have been combined for clarity.

Table 3.1. Generalized land use time line for Ichauway and southwest Georgia, from 1800s to late 1900s.

Time	Land Use
Mid to late 1800s	Widespread timber removal of old growth Widespread turpentining Some settlement and agriculture Livestock production on open range Frequent woods burning
~1900 through ~1929	Widespread timber removal of old growth Widespread turpentining Livestock production on open range Small sharecropper farming Frequent woods burning
~1929 through ~1940	Acquisition of properties to form Ichauway Plantation Quail management Selective timber harvest Continued turpentining Small sharecropper farming Planting of pines Fire suppression in the early 1930s
~1940 through ~1960	Quail management and increase of scattered food plots Selective timber harvest Turpentine tree removal Fenced livestock production Centralized agriculture
~1960 through ~1990	Quail management and scattered food plots Selective timber harvest Centralized agriculture Fenced livestock production Planting pines J.W. Jones Ecological Research Center created in 1991

Table 3.2. Species composition of 12 reference plots (4 in Dubignon, 8 in Sandy Desert) representing areas with high amounts of hardwood encroachment and smaller size classes of hardwoods. Data from Ichauway, GA, spring 2005.

Species	# of stems /ha	Basal area (m^2/ha)
Pinus palustris	47.2	5.43
Quercus margaretta	38.9	3.20
Quercus virginiana	33.3	2.66
Quercus hemisphaerica	36.1	1.89
Quercus nigra	13.9	0.95
Quercus falcata	22.2	0.73
Prunus serotina	2.8	0.07
Total	194.4	14.9

Table 3.3 Species composition summary for Dubignon from 2003 timber cruise of hardwood removal area, Ichauway, GA.

Species	# of stems /ha	basal area (m^2 /ha)
Quercus falcata	23.9	2.84
Pinus palustris	24.1	2.63
Other Oaks	13.3	0.74
Quercus virginiana	2.1	0.40
Pinus taeda	3.4	0.19
Pinus echinata	0.6	0.05
Other Hardwoods	2.3	0.05
Quercus nigra	0.4	0.03
Total	70.1	6.93

Table 3.4. Results from ANCOVA (Type 1 Test of fixed effects) analysis of age-size relationship for hardwoods and longleaf pines in reference plots. “*” indicates significance. Significance level set at 0.05.

Effect	Num DF	Den DF	F Value	Pr > f
Age	1	36	57.42	<.0001*
Species	1	36	3.20	0.0823
Age by Species	1	36	1.13	0.2950

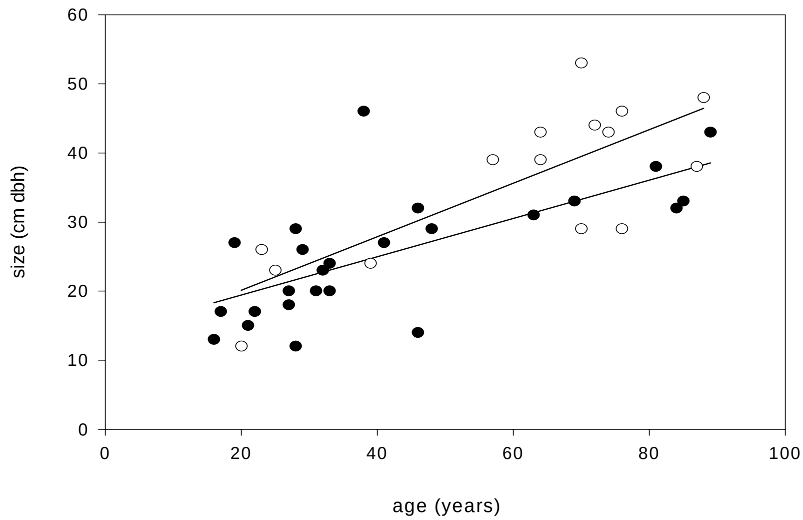


Figure 3.2. Age – Size Regression plot for longleaf pines and hardwoods on reference plots, Ichauway, GA, spring 2005. Closed circles are hardwoods. Open circles are longleaf pines. Longleaf regression equation is (size)=12.39+0.39(age). r^2=0.60. Hardwood regression equation is (size)=13.88+0.277(age). r^2=0.48.

Table 3.5. Stems per hectare and basal area (ba in m^2) per hectare of longleaf pines and hardwoods at three sites from hardwood removal plots, Ichauway, GA, spring 2005.

	Longleaf Pines		Hardwoods	
Unit	stems/ha	ba m^2/ha	stems/ha	ba m^2/ha
Dubignon	84	7.8	71	18.6
Larkefield	66	7.2	87	35.3
Sandy Desert	61	5.9	94	24.6

Table 3.6. Results from ANCOVA (Type 1 Test of fixed effects) analysis of age-size relationship for hardwoods and longleaf pines in removal plots. “*” indicates significance. Significance level set at 0.05.

Effect	Num DF	Den DF	F Value	Pr > f
Age	1	229	44.78	<.0001*
Species	1	229	120.07	<.0001*
Age by Species	1	229	0.57	0.4491

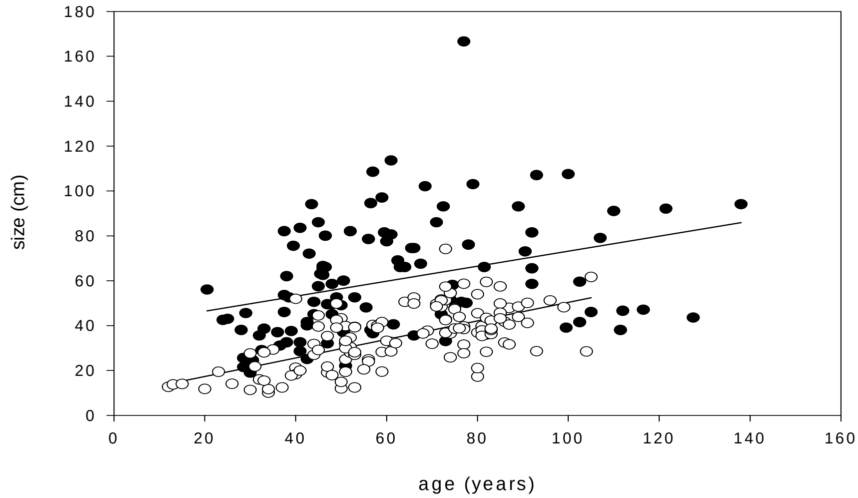


Figure 3.3. Age – Size Regression plot for longleaf pines and hardwoods on removal plots, Ichauway, GA, sampled spring 2005. Closed circles are hardwoods. Open circles are longleaf pines. Size reported is dbh in cm for pines and basal diameter in cm for hardwoods. Longleaf regression equation is (size)=9.04+0.41(age). r^2=0.41. Hardwood regression equation is (size)=39.68+0.33(age). r^2=0.12.

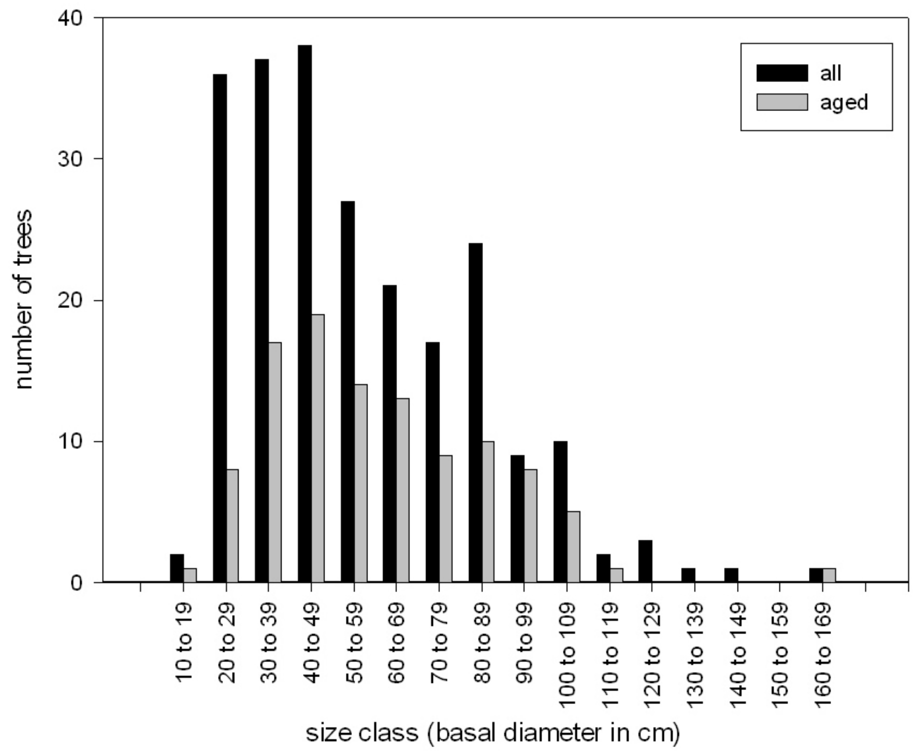
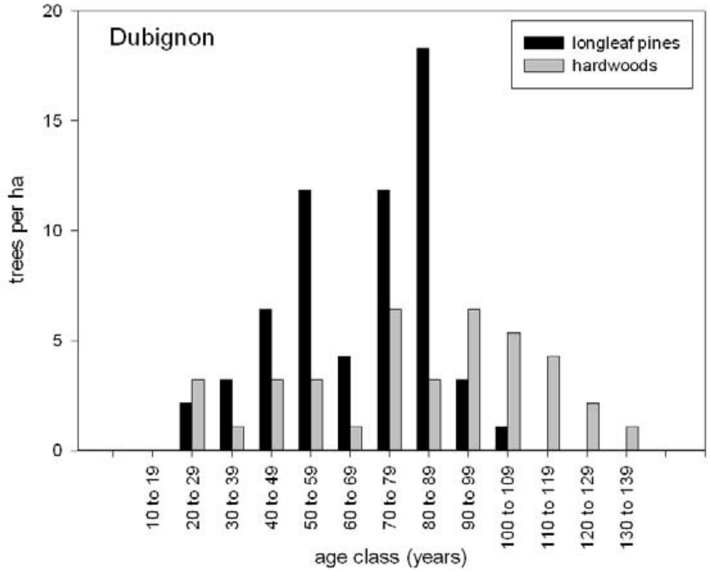


Figure 3.4. Size class distribution of intact hardwood stumps that could be aged versus all hardwoods on hardwoods including hollow or damaged stumps and standing hardwoods on hardwood removal plots, Ichauway, GA, sampled spring 2005.



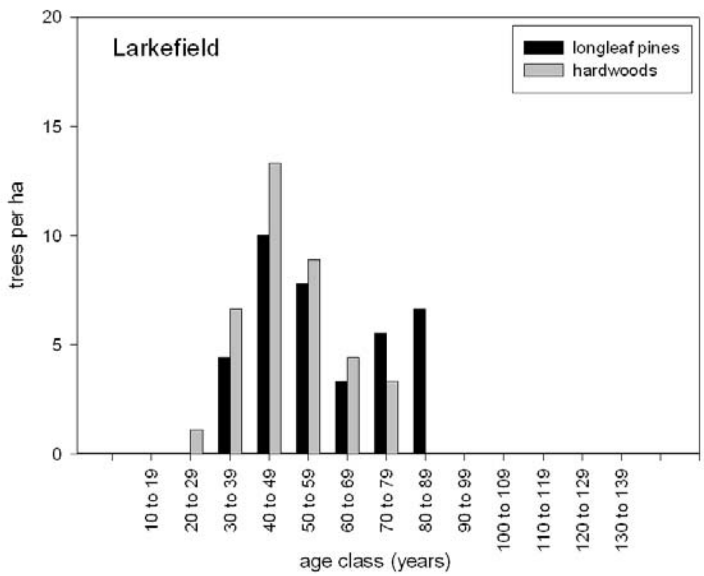
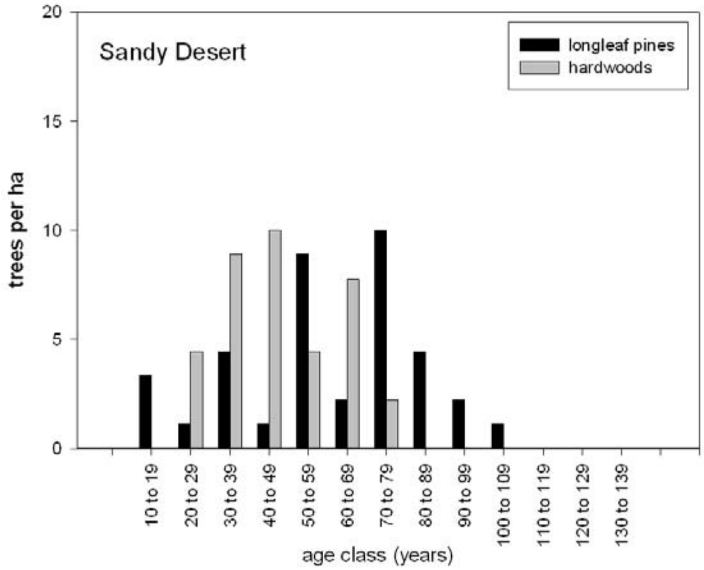


Figure 3.5. Longleaf pine and hardwood age-class distributions at Dubignon, Larkefield, Sandy Desert, and all three combined, Ichauway, GA, sampled spring 2005, based on data from hardwood removal plots.



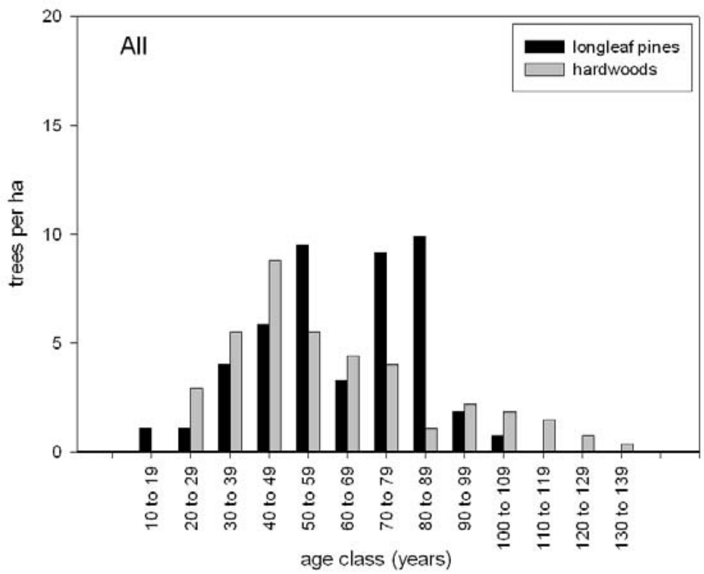


Figure 3.5 continued.

CHAPTER 4

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

Quail hunting lands serve as an important model in the larger realm of ecosystem conservation in the southeastern United States. In increasingly fragmented and human dominated ecosystems, the need for increased management of woodlands for multiple use is important (Landers et al. 1995). The use of fire on quail plantations to maintain habitat and open the woodlands for easy access likely helped maintain these longleaf pine ecosystems from completely succeeding into southern mixed hardwood-pine forests (Ware et al. 1993; Landers et al. 1995). However, the common practice of annually burning also often encouraged successional hardwood growth (Jacqmain et al. 1999).

This study focused on the most heavily human impacted areas on Ichauway. Conversely, Mitchell et al. (1999) constructed age class distributions of longleaf pine and hardwoods on the least disturbed sites on Ichauway. Periods of longleaf pine and hardwood establishment were coincident with the periods of longleaf pine and hardwood establishment found in this study, however, the amount of hardwoods found in the less disturbed and fragmented sites was significantly less. This suggests that the broad scale management events described here were integral in the conservation of longleaf pine woodlands but certain land management events such as the clearing of woodlands for agricultural and wildlife food plots as well as agricultural abandonment accelerated the successional process. This study underscores the need for integrated forest and wildlife management with particular emphasis on the complex relationship between life history traits of longleaf pines, hardwood species, and historic disturbance patterns of land use.

Spatial pattern conclusions

It is important to understand the patterns of land use and overstory structure that contributed to the conditions of current stands. First, hardwood encroachment was evident over a short 41 year period on a majority of the forested landscape. Second, hardwood establishment occurred across all land cover types regardless of landscape configuration. Approximately half of the landscape underwent succession associated with agricultural abandonment, afforestation, and forest-non-forest edge effects, and half underwent succession in relatively un-fragmented stands. Sites previously non-forested did not regenerate to longleaf pine dominated overstories although longleaf pine regeneration did occur. Therefore, it is important to manage longleaf pine woodlands using prescribed fire with the objectives of controlling hardwood growth and capturing longleaf pine regeneration (Landers et al. 1995). Once hardwoods reach a certain size they are not effectively removed by fire (Guerin 1993) and removal techniques must be used. Restoring longleaf pine overstory is an important step in overall ecosystem restoration, as this restores continuity of high quality pyrogenic fuels which are essential for the effective use of prescribed fire to suppress successional hardwoods and to and restore native groundcover.

Temporal Pattern Conclusions

A dichotomy between two types of hardwood establishment can be defined, event punctuated and constant through time. The least fragmented study unit exhibited fairly continual hardwood recruitment, while the more fragmented and disturbed units had more distinct peaks of tree establishment linked with historic events, specifically the widespread appearance of hedgerows and old-field succession on former agricultural and pasture sites. When pooling age class data for all sites to look at broader spatial patterns, hardwood encroachment was peaked during the time of transition from agricultural dominated land use to quail dominated management. However, the peak was not distinct and had a tail into the older age classes, mainly due to older trees being found in Dubignon than in the other two units, perhaps reflecting the diverse suite of land use events encountered across larger spatial scales, specifically the interaction of widespread annual cool season burning, the creation and abandonment of large and small agricultural fields and food plots, and the dominance of hardwoods along field margins and homesites.

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