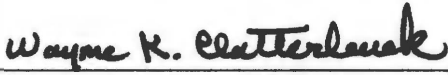


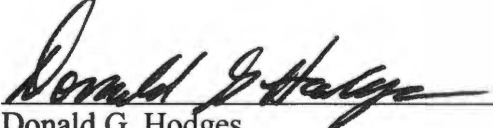
To the Graduate Council:

I am submitting herewith a dissertation written by Patrick Daniel Cassidy entitled "Dynamics and Development of Shortleaf Pine in East Tennessee." I have examined the final paper copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Natural Resources.


Wayne K. Clatterbuck, Major Advisor

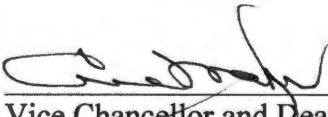
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Vice Chancellor and Dean of
Graduate Studies

“Dynamics and Development of Shortleaf Pine in East Tennessee”

**A Dissertation
Presented for the
Doctor of Philosophy
Degree
The University of Tennessee, Knoxville**

**Patrick Daniel Cassidy
December 2004**

DEDICATION

For Michael Isaac.

“True science discovers God waiting behind every door.”

**“That’s what Tigger’s do best.”
- Tigger**

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ABSTRACT

The shortleaf pine resource in the Ridge and Valley region of Tennessee is in peril of being eradicated. A study of the resource was conducted at the Oak Ridge Forestry Station and Chuck Swan State Forest to determine the historical development, current conditions, and future potential of the resource in this physiographic region. Where once shortleaf pine flourished as a major species in pure and mixed stands in the Ridge and Valley, conditions are now such that the species does not regenerate well and is slowly fading from the ecosystem.

Aerial photography, historical documentation, interviews with current managers and historians, stem analysis, and field data collection from homogeneous sites were used to construct a dendrochronological series tracing shortleaf pine development. Through varied and frequent disturbances such as southern pine beetle, wildfires, diseases, and various harvesting conditions, the species was able to reproduce and perpetuate. The growth of the individual shortleaf stem can be categorized as "space enduring"; continuing to stay a member of the forest without regards to the changing conditions around it.

Shortleaf pine remnants added an average of one inch of diameter every decade. This growth pattern was consistent, regardless of competition levels, topography, age, height, and live crown ratio. As mixed hardwood species asserted their dominance on the landscape, the shortleaf pine remnants were able to endure even with comparatively lower live crown ratios. Shortleaf pines' diameter and height were equal to or greater than the hardwoods that developed with them.

Stem analysis conducted discovered two separate cohorts intermixed in the Ridge and Valley. The younger of these two cohorts became established in the mid-1930's as disturbances such as fire and harvesting created ideal conditions for shortleaf pine regeneration. However, management changes, beginning with the Tennessee Division of Forestry's fire suppression program in 1950, have limited the disturbances that otherwise would have created favorable regeneration conditions. There has been no regeneration of the species since the early 1970's.

The current state of the resource is that of an overmaturing remnant collection that lacks the ability or conditions to regenerate. The study was conducted on publicly managed lands; however the state of the resource may be direr on private lands where economics is often the determining management criteria. Management practices such as plantation establishment, underplanting, and natural regeneration through gap promotion are suggested to perpetuate the ubiquitously growing species in the Ridge and Valley. If these practices are not implemented, the current remnant state will continue to succumb to the mixed hardwood forests.

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Introduction

“No problem of greater importance was ever presented to the American people than that of the preservation and reproduction of the forests of the country. The accelerating consumption of timber makes it a question of but a few years when the demand must be restricted or the supplies must be drawn from other countries than our own. At the present rate of consumption a quarter of a century will see all our grand forests denuded of their most valuable timbers. There are now more than \$500 million invested practically for the destruction of our forests, and not \$50,000 invested for their preservation and reproduction. This simple statement shows the grave responsibility resting upon the present generation” (Killebrew 1897).

The social state of forestry in Tennessee today mirrors that of 100 years ago when Dr. Killebrew spoke on the Centennial Grounds in Nashville. Our forests must meet increasing market and non-market demands as well as serve as areas of historic preservation. However, the current forest composition of east Tennessee is quite different compared to Killebrew’s forest just as the forests of the late Pleistocene and Holocene eras differs from anything man has seen in Tennessee (Delcourt & Delcourt 1979). Autogenic and allogenic disturbance regimes have molded the forest landscape over time. While the intensity and duration of these dynamic pressures from 18,000 years before present to the mid-19th century are not equal, their outcomes and changes demonstrated across the landscape are comparable.

This dissertation examines one specific species' changes in response to the dynamics surrounding it; shortleaf pine. The research has three objectives:

1. To construct the historical condition that surrounded the development of the shortleaf pine resource in the Ridge and Valley of east Tennessee;
2. To examine the current growing stock and condition of the resource; and,
3. To predict the future of shortleaf pine in the region and determine what changes may be employed to alter that future.

Silvicultural knowledge and dendrochronological techniques were employed to build a historical understanding of the development of shortleaf pine in the northern region of east Tennessee's Great Ridge and Valley province. With this understanding in place, management propositions are defined in order to maintain the diminishing species on our landscape. The history and future of the species, the land, and its people are examined in this dissertation.

SECTION 1

The Elements

To understand the life of a species one must first understand its being and its surroundings. Where does it exist? What influences its growth? How is it impacted by the world around it? Time, the environment, and man all define the future composition of a forested landscape. This section will examine the forest changes over time in the study area, man's impact upon the area, and the silvics of shortleaf pine (*Pinus echinata*).

The Forest in General

The earliest forests of Tennessee resembled the modern landscape of Canada's Ontario, Manitoba, and Saskatchewan provinces. Jack pine-spruce (*Pinus banksiana* and *Picea* sp.) mixtures dominated the boreal exposed land that escaped the southern push of the Laurentide ice sheet; a massive glacier 12,000 feet thick that nearly covered 5 million square miles of North America (Delcourt & Delcourt 1984). By 18,000 years before present, this jack pine-spruce forest pushed as far south as present day Atlanta, GA with temperate forest species expanding into what is currently the Gulf of Mexico (Figure 1) (Watts 1980). This jack pine-spruce forest existed on a cold, arid, savannah type landscape implying that the woody vegetation was concentrated in clumps along favorable microsites.

The next 8,000 years brought about dramatic alterations in forest composition. As the glaciers waxed and waned, this period became an "ecological restive" (Edwards & Merrill 1977) as assemblages of forest communities immigrated and emigrated with the

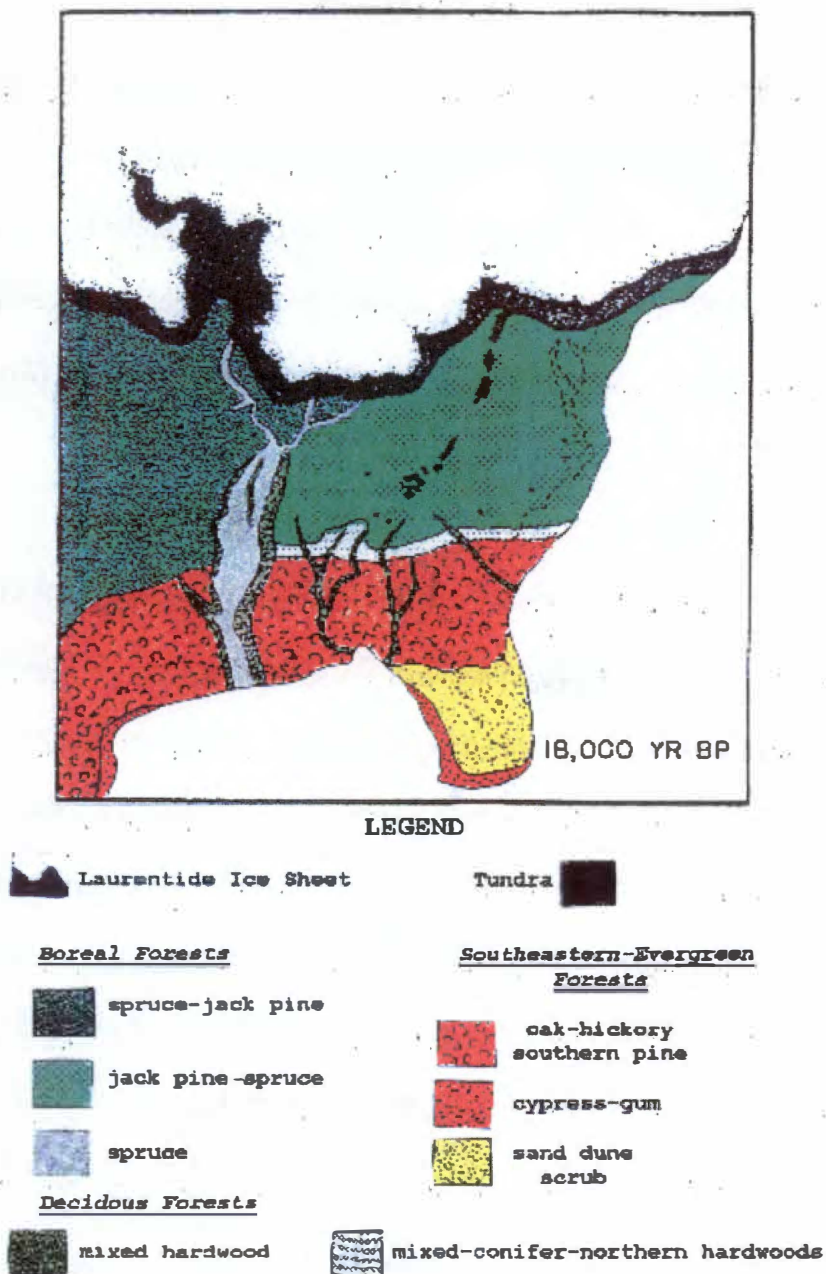


Figure 1. Forest community distribution, 18,000 years before present (Watts 1980).

shifts in precipitation and glacial movements. These north/south migrations resulted in a collection of species that has no modern analogue due to the rapid and dynamic shifts in species present. Boreal vegetation moved northward with the retreat of the glaciers and as ocean levels rised, deciduous species migrated away from the oceans and inward. Shade intolerant, ring porous, drought resistant oaks and hickories (*Quercus* sp. and *Carya* sp.) dominated the more xeric sites with mesic species such as American beech (*Fagus grandifolia*), ironwood (*Carpinus caroliniana*), elm (*Ulmus* sp.), and maple (*Acer* sp.) were relegated to the waterways (Jacobson et al. 1987). Paleo-Amerindians had moved into the southeastern United States by 9,500 years before present and brought about the changes that would define the forest until European settlers set foot on the continent (Anderson 1991).

Some of the largest collections of Paleo-Amerindian artifacts are found in immediate association with areas that were droughty, consisting of oak-hickory mixes with savannah grasslands. These people were hunter/gatherers and followed the migration of wild game throughout the seasons. The presence of ancient pottery remains indicates that it was not until 4,500 years before present that tribes started to settle into sustainable communities (Anderson 1991). At this same time a global cooling trend stabilized the ocean levels as well as limiting woody species to their present natural ranges. This stabilization of species movement established the currently accepted modern plant assemblages (Davis 1983).

As these cultures advanced, their populations increased and the demand for more food increased. A vital tool for the attraction and diversion of game was fire. Pollen cores indicate that fire was present for the production of charcoal, to promote early

successional woody vegetation, and to promote the annual growth of sunflowers, gourds, squash, and other important plants (Hudson 1976). The continued clearing of land promoted the practice of farming with maize as the key species. Human populations flourished as they learned to utilize everything the forests made available to them and by 1500, native populations in the southeast exceeded 2 million people (Dobyns 1983). Outside of the population centers however, where fire only touched the landscape through natural processes, the deep shade tolerant understory flourished and made travel nearly impossible. European settlers would comment that they smelled the lands along the coastal region before seeing them, implying that the native populations understood the management importance of fire (Croderoy 1983).

The arrival of European settlers shifted the entire ecosystem of the southeast. With them, Europeans brought a desire to explore as well as new diseases that ravaged native populations. With the decline of native people came a decline in ecosystem knowledge (Hartley 1977). As fire started to decrease in application and agricultural systems eroded, the appearance of the landscape changed. Fire-dependant ecosystems that had functioned for a thousand years disappeared and the dark forest encroached upon the new settlers. This forest is the “native forest” often discussed in heated conversations regarding preservation of our resources. The once savannah-like landscape of oaks and pinelands gradually became a mixture of oak-hickory forests where wildfire was limited. Extensive shortleaf, eastern white pine (*Pinus strobus*), and Virginia pine (*Pinus virginiana*) barrens existed only where fire still occurred with regularity.

By the time settlers moved into eastern Tennessee, the landscape was an intimidating force, a solemn, mysterious, and seemingly interminable forest. “To the

pioneers it must have been a dismal sight to find all the land shrouded in the deep gloom of the forest, to catch but seldom the cheering rays of the summer sun, to walk at midday through the dark and melancholy woods that stretched from mountain to valley, from plain to river, from state line to state line” (Sudworth 1897). The history of forestland in Tennessee is one marked by the dominance of oak-hickory-pine after the last glaciation. This has been a landscape marked by periods of drought associated with both natural and applied fire to produce forests dominated by shade-intolerant species. In the absence of such a historical disturbance, it is increasingly difficult to regenerate key oak and pine species (Abrams 1992; Brose & Van Lear 1998; Loftis & McGee 1993). Since 1953, the South has lost 16 million acres of southern yellow pine timberland due to fire suppression, pest and health concerns, and improper management (South & Buckner 2003). Since fire has been excluded from the region for a better part of the past century, the mature oak-pine forests are experiencing successional replacement by more shade tolerant species (Abrams & Downs 1990; Abrams et al. 1995; Little 1974; Mikan et al. 1994; Rose 1984). The current forests may be poised for another species shift; this time due to man’s inaction. The remainder of this study will examine the changes in the forest from European settlement in a limited portion of the Great Ridge and Valley to present day and its impact upon the shortleaf pine component.

Ridge and Valley Physiographic Province

Tennessee is comprised of nine physiographic regions, making it one of the most diverse states in the Union, ranging from the mountains in the east to the Mississippi River bottom in the west (Fenneman 1938). The Great Ridge and Valley, the region of

interest for this research, lies in the eastern portion of the state between the Unaka Mountains to the east of the ridge and valley and the Cumberland Plateau west of the region (Figure 2).

The Ridge and Valley Province reaches from the St. Lawrence Valley in New York to the Coastal Plain in Alabama. The province ranges in width from 100 miles in the north to 30 miles in the south (Fenneman 1938). This long narrow province is a result of the Folded Appalachian geosyncline. The folding and fracturing of the land during the late Paleozoic era created the northeast-southwest orientation of the region. The geologic events exposed areas of the Ordovician and Cambrian limestones, shales, sandstones, and Devonian and Mississippian limestone and chert in the northern regions making this the second highest area with karst topography in the state (Miller 1974). The Tennessee, Clinch, French Broad, and Holston rivers all follow the valleys but occasionally cut across the strike of the ridges contributing to large quantities of ground water reserves and well-water systems (Bailey & Lee 1991).

The forest types of this province vary from oak-pine mixtures along the ridge tops to yellow-poplar (*Liriodendron tulipifera*), American beech, and mixed mesophytic communities along the slopes and in the valleys (Braun 1950). This study was confined to the north-central region of the Ridge and Valley in Tennessee. Hence the findings should not be construed as a generalization across the species native range. Wide growth and development differences have been noted in other studies over short linear distances (Burton 1964; Graney 1991).

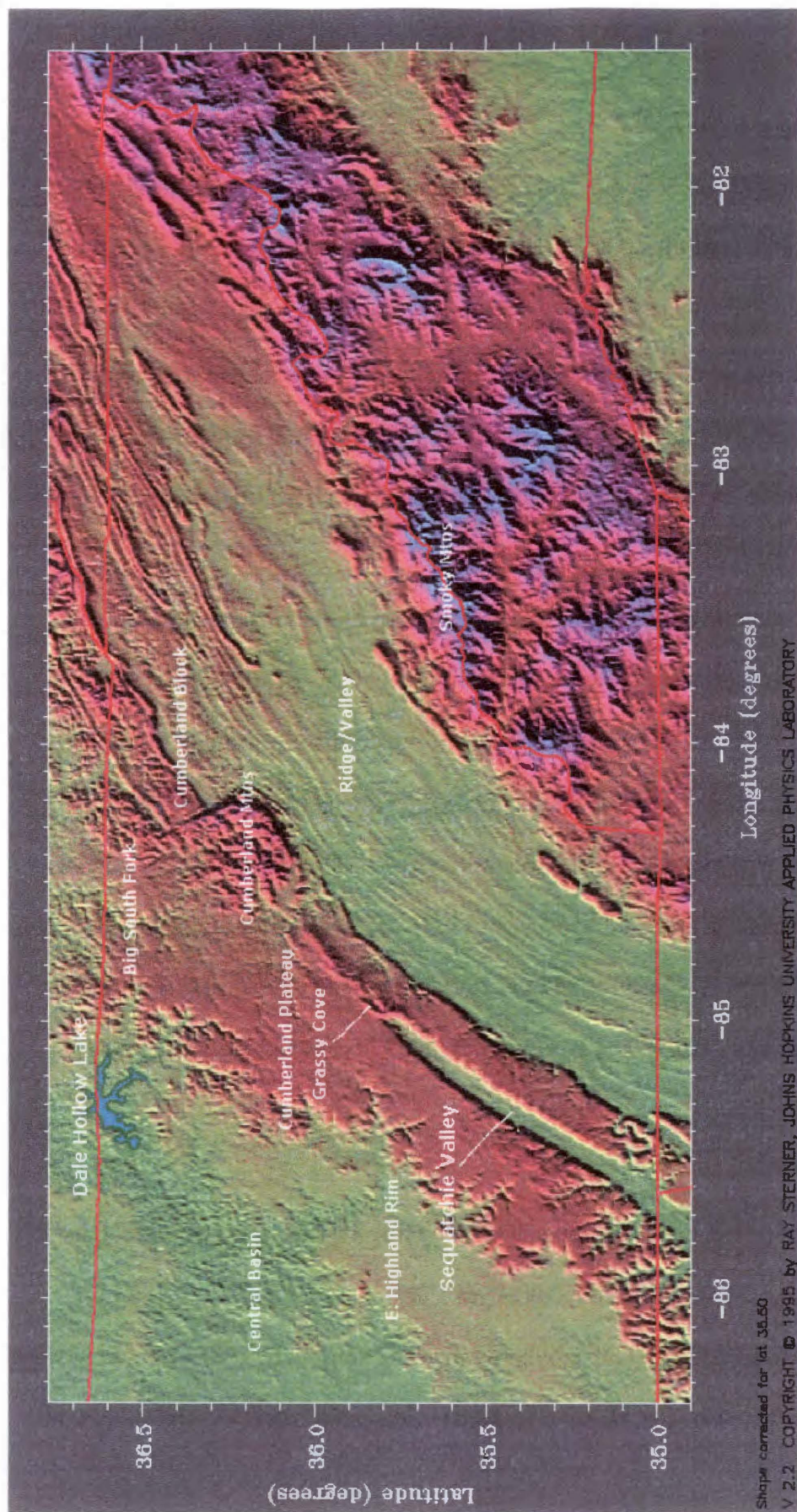


Figure 2. Physiography of east Tennessee. Image supplied by John Hopkins University, 1995.

Shortleaf Pine Characteristics

Of all the major southern pines, shortleaf pine is the most widely distributed occurring in 22 states, south from New Jersey to the Gulf Coast and west from the Atlantic Ocean to Oklahoma (Lawson 1986), covering 440,000 square miles (Figure 3). Across much of this region, shortleaf pine has been recently overlooked in favor of loblolly pine (*Pinus taeda*) mainly due to shortleaf's slower initial growth rate, difficulty in obtaining regeneration, and susceptibility to pathogens such as littleleaf disease and needle rust (Guldin 1986).

However, concern over these susceptibilities and limitations may conceal the inherent potential of the species. Stem and crown form of shortleaf pine are superior compared to other southern pines and occurs due to superior self-pruning. Shortleaf is less susceptible to damage from ice, snow, and cold temperatures than other southern yellow pines and has shown admirable drought resistance (Dorman 1976). A concise literature review has been authored by Haney (1962), the silvics investigated by Fowells (1965) and Lawson and Kitchens (1986), genetics by Dorman (1976), and common silvicultural systems by Walker and Wiant (1966) and Lawson and Kitchens (1983).

Natural Range

Shortleaf pine is a major component of three forest types; shortleaf pine, loblolly pine-shortleaf pine, and shortleaf pine-oak (Eyre 1980). It is also a component of 15 other cover types in association with southern pines and xerophytic oaks such as chestnut oak (*Quercus prinus*), post oak (*Quercus stellata*), and scarlet oak (*Quercus coccinea*).



Figure 3. Native range of shortleaf pine (Lawson 1986).

Of the southern pines, shortleaf pine occupies the broadest and most geographically varied habitats (Critchfield & Little 1966). It occurs in the Atlantic Coastal Plain, the Appalachian Mountains, the Great Ridge and Valley, and the Interior Plateau and Plains (Fenneman 1938). Superior growth and community dominance occurs in the Ouachita and Ozark Mountains of Arkansas, Missouri, and Oklahoma (Guldin 1986).

The southeastern United States is characterized by warm humid summers, mild winters, and prolific rainfall. Within the range of shortleaf pine, temperature and rainfall varies greatly (Wahlenberg & Ostrom 1956). Sites tend to be drier along the western and northern edges of its range with annual precipitation rates of 40 inches to the Gulf Coast where rainfall can accumulate to 64 inches. Snowfall varies almost as greatly with none occurring along the southern extremes to over 80 inches at high elevations in the Appalachian Mountains. Average annual temperatures vary from 45 to 75 degrees Fahrenheit with an isotherm of 50 degrees Fahrenheit paralleling the northern range limit (Lawson 1986). Shortleaf pine growth indices have shown a significant positive relationship between increased growth and increased precipitation levels and decreased temperatures (Grissino-Mayer & Butler 1993). According to Grissino-Mayer and Butler (1993), 38-46 percent of pine growth variance can be attributed to climatic factors. However, their model does not adequately work with growth after 1963, thus leading them to conclude that non-climatic factors such as management and land-use changes altered shortleaf growth and development.

As expected, the soils that support shortleaf vary greatly from dominant clay textures that are generally moist and deep to thin dry sandy soils along ridges. The best

development is on deep, well-drained sandy loam soils in the Coastal Plain uplands (Lawson & Kitchens 1983). Unfortunately, other species also grow very well on such sites, e.g. loblolly pine reaches its best development on such soils (Baker & Balmer 1983). In the mixed species uplands, shortleaf pine gives way to the succeeding oak-hickory climax type (White 1980). Topography also affects the development of shortleaf pine. In the Ozark Mountains, site quality improved as slopes changed from convex to concave, latitude decreased, and orientation shifted from the south to the north-northeast (Graney & Ferguson 1972). In the southern portions of its range, site quality increased with decreasing elevation and lower slope position (Ike & Huppuch 1968).

On good sites shortleaf is often out-competed by faster-growing loblolly pine. As sites become more extreme in topographic exposure, have thinner soils, and have harsher climatic conditions, shortleaf communities increase in prominence. The root system of shortleaf pines is typically more extensive than competing species on these lower quality sites (McQuilken 1935). Shortleaf pine has a lower demand for soil nutrients, and its greater tolerance of disturbance, particularly fire, allows its continuation across these landscapes (White 1980; Zak 1961). Thus the highest stand volumes of natural shortleaf pine occur in areas that are less favorable for loblolly pine as well as lands in which unfavorable physiographic conditions and disturbance regimes limit hardwood competition; specifically in the Ouachita Mountains (Sternitzke & Nelson 1970).

Life History

Shortleaf pine is monoecious and begins producing seed at age 20 (Fowells 1965). Flowering occurs from March to April with cones becoming mature in late October

through November of the second year. Relative to other southern pines, the cone and seed of shortleaf pine is smaller in size and abundance (Grayson 2000). Seed is produced annually with three-year cycles of seed production commonly reported in the western range of the species (Yocom & Lawson 1977) with six-to-ten year high quantity seed crop cycles elsewhere (Lawson 1986, Wittwer et al. 1997). The relationship between adequate precipitation during strobili primordial differentiation exhibits a positive correlation with seed production (Cain & Shelton 2000).

Seeds fall fairly close to the parent tree, with nearly half of them dispersing no further than 20 meters (Yocom 1968). On average, 70 percent of seeds fall within a month of maturity and cones may persist on the tree long after they are empty (Fowells 1965). Releasing seed trees from competition significantly increased seed quantity per tree but not always seeds per cone (Phares & Rodgers 1962).

Seed germination occurs in early spring and is most assured when the seed is on exposed mineral soil (Fowells 1965). Scarification of the soil, burning of logging debris, and hardwood control increases the probability of seedling establishment (Lawson 1986). Many seeds are devoured by birds and small mammals. Generally 100 sound seeds are required to develop a single seedling, depending upon seedbed conditions, yearly crop development, and environmental conditions (Yocom & Lawson 1977).

Within two to three months of germination, a characteristic 'j-crook' develops at the base of the seedling. This characteristic adaptation houses auxiliary buds that allow the pine to sprout should the stem be damaged or die (Chapman 1942). The ability to sprout enables the species to maintain itself in fire prone situations. As fire swept across the landscape in 3 to 5 year intervals (Hudson 1976), many seedlings and saplings would

have been killed due to crown scorching or stem damage. Shortleaf pines can sprout after such disturbances, even up to stem diameters of 8 inches at breast height, giving them a competitive advantage over competing pine species (Fowells 1965). Seedling height growth is slow compared to Virginia and loblolly pine, while the seedling develops a complex root system during the first two years after establishment (McQuilken 1935). Energies are invested in the formation of a massive taproot, historically also harvested for the pulp markets (McQuilken 1935). Shortleaf pine diameter growth is related to root development (Carlson & Harrington 1987). The taproot growth of shortleaf pine eventually results in better height growth and form than those species, such as Virginia pine, with shallow root systems (Harrington et al. 1987).

Shortleaf pine is shade intolerant (Eyre 1980). Because of slow initial height growth, seedlings quickly become overtopped by loblolly pines and competitive hardwoods. Once established, height growth ranges from one to three feet (Lawson 1986). The species has the ability to respond to releases at various ages. On the Cumberland Plateau, seedlings that were established under a canopy of hardwoods resumed good growth after overstory removal, but a year's height growth was lost for each year of suppression (Russell 1979). In northern Mississippi pole-sized trees responded to competition removal (Williston 1978). Due to its shade intolerance, shortleaf pine develops most commonly in even-aged stands. In the absence of disturbances, hardwood species develop in the understory and without allogenic influences could dominate (White 1980).

Littleleaf disease is the most damaging pathological threat to shortleaf pine (Walker and Wiant 1966). The disease is common in stands 30 to 50 years old and

growing on poorly drained soils (Lawson 1986). *Annosum* root rot, red heart, and brown spot (*Scirrhia acicola*) also impede stand and individual growth and development (Hepting 1971). The most damaging pest in the Ridge and Valley may be the southern pine beetle (*Dendroctonus frontalis*). Since 1998, over 390,000 acres of pine in Tennessee were devastated (TDF 2004). The Division of Forestry considers the most recent outbreak as the most destructive since 1976. The southern pine beetle was first recorded by early settlers in the region in 1760 (Price et al. 1992). Recorded histories from the Museum of Southern Appalachia make reference to the “red-top” disease killed pines in the mid-1800’s as well as outbreaks in the early 20th century. The beetles killed the less vigorous shortleaf trees, those that were in pure overstocked pine stands, and those that were over-mature.

As the beetle strikes, growth and productivity of the tree focuses on battling the beetle by producing resin and maintaining vital functions. Those trees that survive would be the most aggressively growing individuals or those that were already remnants in mixed hardwood stands. This is the situation in the Ridge and Valley.

Shortleaf pine is rarely managed to its biological capabilities. Individual trees can attain diameters over three feet, heights exceeding 110 feet, and ages of 150 years (Fowells 1965). The species is utilized primarily for lumber, plywood, and pulpwood. In east Tennessee, the species is prized by the log home building industry for its strength and durability. The species was once planted for erosion control, but since it did not produce as much litter as loblolly or Virginia pine, it became less desirable (Clark 1948; Grano 1949).

Shortleaf pine is slowly disappearing in some areas. With the genetic improvements made to loblolly pine, and its faster growth and development, lands that once were dominated by shortleaf pine have been replaced with loblolly plantations. The improvement in cold hardiness has extended the planting range of loblolly northward into the native range of shortleaf. The exclusion of fire due to suppression programs and urban/wildland interfaces has also limited the natural regeneration of shortleaf pine. Only remnant stands and individual trees dot the landscape; especially in east Tennessee.

SECTION 2

Research Methodology

This research was conducted to examine three interlinking aspects of the natural shortleaf pine resource in the study area: the historic growth and development of the resource, the current state of the resource, and the future of the species with respect to potential regeneration mechanisms and economical impacts. It was not practical to follow a stand year after year as it developed considering that results would have taken decades. Considering the improvements in ecological understanding, past history was reconstructed using the tools of dendrochronology coupled with the understanding of forest species interactions and man's impact upon the land.

Dendrochronology relies upon stem analysis to establish past growth development patterns. A 'neighborhood' analysis of relationships between adjacent trees provides further insight into the development of the targeted individual tree. Building a chronological sequence of trees and neighborhoods provides similar results to that of continuous measurements of a single neighborhood over a period of years (Abrams et al. 1995; Abrams et al. 1997; Foster 1988; Savage 1991).

A neighborhood was a collection of trees surrounding the target shortleaf pine. An individual shortleaf pine served as the center of each neighborhood. Trees were considered part of the neighborhood if their crowns were either in direct competition with that of the shortleaf pine upon visual inspection or had influenced the development of the shortleaf pine in the past. These neighborhoods had no fixed radius distance but rarely exceeded a 40 foot radius. Crown classes that were considered to be in competition with

the shortleaf pine included all dominant and co-dominant individuals. For definitions of each crown class, see Kraft's Crown Classification (Oliver & Larson 1990).

Within each neighborhood, two additional plots were established. Overstory data were collected in a fixed radius, 0.1 acre plot while midstory data were collected in a 0.02 acre plot. Overstory trees were those whose crowns were interacting as part of the dominant canopy. Midstory trees were greater than one inch in diameter but not associated with the upper canopy level. The fixed radius plots for overstory and midstory catalogued species, diameter at breast height (DBH), and crown classification.

Stands with shortleaf pine components were identified in the north-central region of the Great Ridge and Valley of east Tennessee. The study was contained to one physiographic region to work with a homogenous landscape, consistent historical weather patterns, similar historical anthropogenic influences, and disturbance regimes. The history, weather, forest composition, and topography at Chuck Swan State Forest and the University of Tennessee's Forestry Experiment Station in Oak Ridge satisfied the requirement of homogeneity.

Pure, natural shortleaf pine stands were not found in the study area due to harvesting, southern pine beetle infestations, and a lack of effective regeneration; even though historical documentation indicates that shortleaf pine was a major component in the Ridge and Valley prior to 1950 (Killebrew 1897, Sudworth 1897, Schenck 1904). Remnant individuals or groups were identified and collected into study neighborhoods. These remnant pines were studied to construct their development and the changes in the forest that surrounded them.

A total of 66 neighborhoods were identified; 46 on the Oak Ridge site, 20 at Chuck Swan. Table 1 shows the number of neighborhoods sampled by age class and the number of neighborhoods where stem analysis was conducted. No trees were encountered younger than 36 years of age and the distribution was greatest between ages 50 and 90 years. Table 2 shows the distribution of neighborhoods with respect to aspect and topography. A 'bench' is a flat area along a slope prior to reaching the slope's crest.

Four 0.5 acre importance value plots were established in shortleaf pine areas at Oak Ridge and at Chuck Swan. Plots were established randomly at various topographic positions. These plots were used to determine whether the study areas were similar in species composition, abundance, and dominance. The importance value index was evaluated for each site using the methodology of Curtis and McIntosh (1951).

An importance value index rating is the summation of the relative density, relative dominance, and relative frequency for a specific species. Relative density refers to the number of individuals of one species compared to the total number of individuals of all species; relative dominance is a relationship of a species' basal area compared to the total basal area of all species; and relative frequency relates the number of plots a species occurs compared to the total number of occurrences of all species. The purpose of the importance value index is to compare the sites for homogeneity (Curtis & McIntosh 1951).

A competition index was constructed to compare the degree of competition within each topographic setting using Hegyi's methodology (1974). With three topographic positions; ridgetop, slope, and bench, and two acknowledged aspects; north and south, any differences in competition due to neighborhood placement was evaluated. The

Table 1. Total number of neighborhoods and the number of plots on which stem analysis was performed at each age interval for the shortleaf pine research at the Oak Ridge and Chuck Swan study locations, Tennessee.

Age Interval	Number of neighborhoods	Number of neighborhoods used for stem analysis
30-39	2	0
40-49	3	0
50-59	12	2
60-69	12	5
70-79	9	1
80-89	8	0
90-99	4	0
100-109	5	2
110-119	1	1
120-129	4	1
130-139	4	2
140-149	1	1
150-159	1	1
TOTAL	66	16

Table 2. Neighborhoods divided in topographic and aspect categories for the shortleaf pine development research at the Oak Ridge and Chuck Swan study locations, Tennessee.

Aspect and Topography	Number of neighborhoods
Northern Ridge	9
Northern Bench	6
Northern Slope	13
Southern Ridge	13
Southern Bench	6
Southern Slope	19
TOTAL	66

information also was used to examine the relationship between diameter of the subject shortleaf pine and the distance between competing trees. By examining the competitor size and inter-tree distances, a projection of competition levels can be ascertained (Lorimer 1983).

The competition index was calculated by:

$CI = \sum (D_j / D_i) / DIST_{ij}$ where

CI = competition index of subject tree i

D_i = diameter at breast height of subject tree i

D_j = diameter at breast height of competitor tree j

$DIST_{ij}$ = distance between subject tree i and competitor j (Daniels 1976, Hegyi 1974, Lorimer 1983).

Each individual shortleaf pine was flagged and its location recorded with global positioning satellite coordinates. The following data were recorded for each tree within the neighborhood:

1. species,
2. crown classification,
3. diameter outside bark at breast height,
4. total height,
5. height to base of live crown,
6. damage classification (lightening, split, disease, insect or wildlife damage),
7. azimuth and distance of interacting trees from the subject shortleaf pine.

Increment cores were taken from each tree in the neighborhood plot, as close to the base as possible but not to exceed a foot up the bole. If the pith was not encountered

after two tries, a pith estimator was utilized in the lab as needed (Appelquist 1958; Liu 1986). The collection of field data extended over a two-year period beginning in the summer of 2002. All ages are reported through the 2000 growing season.

Increment cores were removed and placed in plastic core holders until they could be transferred to the laboratory. Each core was allowed to dry for no less than three days. The core was glued into a grooved core holder and sanded flush. Three grades of sandpaper were used to prepare the cores for examination; 240, 320, and 400 grit. Measurements of age and ring distances were made twice for accuracy using a Fisher Scientific stereozoom microscope. Tree rings were marked on the core by decade and damage scars were highlighted as appropriate (Stokes & Smiley 1996).

Destructive sampling of selective shortleaf pine and hardwoods were completed on sixteen neighborhoods selected to represent the range of age classes for the shortleaf pine. The distribution of the destructive sampling was skewed towards the younger age classes since they comprised a majority of the neighborhoods sampled. Trees were felled and the stem sectioned beginning at 0.5 feet and removing a section at four-foot intervals up to the growing tip of the tree, following the central-most leader. A visual assessment of cone production was made on each shortleaf pine after it was felled and a subjective ranking was applied; low, normal, high with respect to number of cones in the crown.

In the laboratory each disk was given three clear sanded strips from pith to bark and growth rings were counted and measured along each strip to determine average radial growth. Where needed a magnifying glass or microscope was used to determine true/false rings as well as mark fire scars. False rings are bands of what appears to be latewood that formed due to stresses encountered during the growing season (Figure 4).

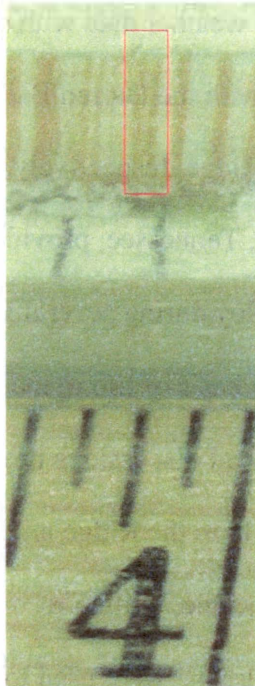


Figure 4. Increment core from a shortleaf pine taken from the shortleaf pine development research at Chuck Swan, Tennessee. The red box identifies a false ring followed by a true ring.

A climatic database was constructed from the National Oceanic and Atmospheric Administration at the Knoxville McGhee-Tyson Airport in Blount County, Tennessee. Daily high, low, and mean temperatures plus twenty-four hour precipitation and snowfall amounts were collected. This database extends back to January 1, 1910 and was added into the research to compare annual weather data with shortleaf pine growth.

Interviews were conducted with the Darren Bailey and Richard Evans, the current managers at Chuck Swan and Oak Ridge, respectively. John Rice Irwin, director of the Museum of Appalachia near Norris, Tennessee, provided historical documentation of settlement life in the Ridge and Valley during several visits to the museum. Historic Nashville, Inc. provided a historical basis of life in the region and the growth of Tennessee. These formal and informal discussions provided the much needed background and understanding of life in the Ridge and Valley of east Tennessee from settlement to the present. When possible, written records of life, forest inventories and harvests, and changes upon the landscape were used to collaborate these interviews. Much of this information was provided by the Tennessee Division of Forestry and TVA. Aerial photographs from 1935, 1970, 1984, and 1995 were utilized to confirm the dendrochronological data.

SECTION 3

Study Area Description

This study was conducted in the north-central region of the Great Ridge and Valley of east Tennessee. In cooperation with the University of Tennessee and the Tennessee Division of Forestry, plots were established on the Chuck Swan State Forest near Sharp's Chapel in Union and Campbell Counties (N 36° 22', W 83° 53') and on the University of Tennessee's Forestry Experiment Station near Oak Ridge, Anderson County (N 36° 01', W 84° 26'). Forests at both are typical southern Appalachian mixed hardwood-pine stands and comprised of various age classes (TDF 2004).

General History of the Ridge and Valley

These lands were first settled in the late 18th century when British Lieutenant Henry Timberlake made an official visit to the Cherokee tribes of the Appalachian Mountains (Darnell 2003). Much of the information prior to the Civil War comes from oral histories and the few remaining diaries of early settlers. These historical documents¹ depicted a landscape filled with "a shadowy canopy of arboreal growth, in which the deadly reptile lay concealed and the savage enemy (native people) lurked" (Sudworth 1897). These mixed hardwood-pine forests dominated the landscape with the exception of rock-outcrops and the narrow, winding stream bottoms. Tennessee forests were where the largest of the eastern timber species grew large and the smallest of trees grew largest; species that would be classified as bushes elsewhere were characterized as trees due to

¹ Oral histories provided by the Museum of Appalachia, Norris, TN. and John Rice Irwin over several discussions from January 2002 to December 2003; mainly during the Tennessee Fall Homecoming celebrations, the second weekend of October.

the large size (Sudworth 1897). Homesteads were literally carved out of the timber in order to establish a life for these new people.

Fire was the most effective tool used by the early settlements and the key element used by the native people. The lands were set ablaze to clear them for agricultural uses, cattle grazing, and herbaceous vegetation production. With no range laws in place until the early 20th century, cattle roamed the landscape. After harsh winters, cattle farmers would initiate fires to promote early spring herbaceous forage. These fires went uncontrolled across the ridges and slopes (DeVivo 1991).

However, one of the most overlooked purposes of using fire was to ensure protection. Man's primal need to defend itself from the unknown and the unseen was a vital driving force in the utilization of fire on the landscape. By clearing the great timbers from the land and igniting the brambles and thickets of blackberry and green-briar, early settlers could provide a level of protection from raiding native people as well as the rampaging bear and panther in the region (Roszak et. al 1995). The fires that swept across the landscape, coupled with the removal of any timbers usable for home building, fence posts, and firewood produced bare mineral ground. These fires controlled initial vegetative competition while pyric species seedlings and pioneer species established themselves (Frost 1998).

The land took a harsh beating over the next 150 years in response to the agricultural practices utilized at the time. Settlers grew their subsistence crops wherever they could; stream valleys, hillsides, benches, or ridgetops often orienting their rows for ease of access with horse and wagon. Forest resources were pillaged for all possible uses with little thought being given to their regeneration. Land was vast and seemingly

infinite. The soils were susceptible to erosion and gulley formation, and as fields were abandoned due to poor production, natural succession oversaw reforestation (NDN 2003). The results of these disturbances are still present in the early 20th century when Associated Press journalist Lorena Hickock visited the region. In a letter dated June 6, 1934 to her editor, Henry Hopkins, Hickock noted the “great bald patches” of rock on the slopes of the ridges. Her report went on to describe a farmer whose traditional practices, handed down from generation after generation, was to get as much out of the land as he could and move on; usually five years is all one could count on and even then the corn planted in the region was only a third as tall as that of Iowa. “They work the land for a few years and then move on” (Hickock 1934). What this practice produced was a patchy landscape of abandoned agricultural fields that would seed in with wind-blown, light seeded species such as shortleaf pine, Virginia pine, and yellow-poplar.

The post-Civil War era saw a change in how Tennesseans viewed their forest resources. Forest landowners in the region, circa 1850, began considering how best to operate within their forestlands not for the production of lumber but for fire-wood. During this period there was very little coal being used in the state; blacksmiths utilized charcoal for fuel as did nearly every iron furnace in the state (Sudworth 1897). Nearly all the hotels, steamboats, private dwellings, and what railroads were available relied more on charcoal than stone-coal. Farmer’s attentions turned for a brief time from their croplands to the harvest of any and all firewood they could utilize until the coal mining industry successfully moved into production. Coal replaced wood as the fuel supply for metropolitan areas of the South such as Nashville, Memphis, and Birmingham (Sudworth 1897).

This spike in 'forest management' however continued to pay dividends to landowners as a new beast moved into the Ridge and Valley region, the steam locomotive. Two railways moved into the region during the mid-1800's, bringing with them the opportunity for forest landowners to profit even more from their clearing of lands for agriculture. The Nashville, Chattanooga, and St. Louis line was chartered in 1845, while the Louisville-Nashville line moved into the Ridge and Valley in 1881 (Castner 1995, Castner et al. 1996). Railroads affected the forest resource in three ways. First, rail lines, especially railroad trestles, in the South had been destroyed by the Federal Army during the Civil War. Trees were felled in great amounts to replace and expand the railways. Second, the introduction of the railway increased the number of forest fires. Sparks from the engines and dumping of spent coals added to the already common practice of forest burning. These events contributed to an ever increasing area for regeneration of pioneer species as well as suppression of competition in forested stands.

The third and greatest impact that the railways had was the opening of large timber markets and organized logging operations in the Ridge and Valley in the late 19th century. Up until this time, timber resources had been utilized only in the local areas and mainly for subsistence purposes. The railroads made the shipment of timber products to other regions of the country as well as Europe a possibility and a chance for landowners to improve their financial standing.

The growth of the rail system was a boom for towns west of the Ridge and Valley, especially the state's capital in Nashville. As the city's population increased so did the variety of industries looking to utilize the riverboats as well as the rail system.

Lumber companies quickly made Nashville one of the largest hardwood lumber centers in the nation, still to this day known as the U.S. hardwood flooring center (Norvell & Wallace 2004).

One such lumber company was founded by William Norvell and William Wallace in 1880. Norvell and Wallace had taken note of how decimated middle-Tennessee's hardwood forests had become due to intense logging, agricultural clearing, and the Civil War. With Reconstruction Era work occurring across the state, Norvell and Wallace understood the need for high quality and quantities of timber. When the Louisville-Nashville rail line moved into the Ridge and Valley, Norvell and Wallace joined the expansion and began harvesting the southern yellow pines in this region as well as from lands in Alabama and Georgia. Up until this time, southern yellow pine was virtually unknown as a construction component in the area but was quickly accepted by both the construction and commercial industries. Specifically, shortleaf pine became a high demand commodity due to its dense wood and strong capacity to support the weight of structures. To this day, some of Norvell and Wallace's first shortleaf pine supports can still be found in downtown Nashville warehouses and businesses (Norvell & Wallace 2004).

The practice of forestry was unorganized on the Tennessee landscape in the late 1800's-early 1900's; and compared to our modern understanding of forest dynamics, there was little that resembled modern analogues. Logging increased in the region as the growing urban centers needed lumber, rural communities needed fuel wood and a commodity to market, and the rail system grew. In 1907, the legislature passed the General Forestry Law, in response to the awakening that Tennessee's forests were in peril

due to logging practices and the lack of effective regeneration across the landscape; much of the lack of regeneration blamed on the massive and intense fires that crossed the landscape. A state forester was appointed in 1914 and by 1922 a spirited effort was started under the his leadership to suppress forest fires (Burkitt 1996).

Life in the Ridge and Valley hinged mainly on agriculture and making the most of the lands available. This depended greatly upon weather, markets, and man-power. The early part of the 1900's saw much of America's young men join the Great War in Europe only to return to the United States and face the harshest economic climate the country had ever faced in the Great Depression. The Great Depression and Dust Bowl conditions of the mid-west sent many native Tennesseans back to their home state during the first five years of the 1930's (Darnell 2003). Lorena Hickock's journey through the Ridge and Valley during this time identified nearly 70,000 families in east Tennessee as living on subsistence farming and what little government relief that was provided (Hickock 1934). These were the farmers who worked the lands to their breaking point and then moved on. In Hickock's opinion this area was in desperate need of some form of federal assistance and in 1933 it was provided with the creation of the Tennessee Valley Authority (TVA).

Post-war America was much different than before. The industrial giant had awoken and with it came bulldozers and other land moving machines that would reshape our landscapes. Along with these tools came applied knowledge brought back from Europe. The 20th Engineer Regiment of the American Expeditionary Force dedicated their lives and skills to the construction of needed materials in France during the war; harvesting and milling the forests of eastern Europe. During the nineteen months the United States had troops in Europe, the regiment constructed 17 new ship berths,

established over 1,500 miles of rail line, and completed 831 construction projects. The new hospital capacity of France increased to twice as much as the new capacity in the United States. Construction projects in the United States approached \$800 million; twice the cost of the Panama Canal (Harberd 1936). The A.E.F. engineering regiments drew their resources from all over Europe and the United States coming to a new understanding of how to construct roads and implement efficient harvest practices. The use of heavy machinery cleared forested lands much more efficiently than ever before. Clearcutting started to gain in popularity compared to the past practices of selective harvesting. As forest industries turned their attention to the southeast, clearcutting became the standard harvesting method.

Chuck Swan State Forest

The Chuck Swan State Forest and Wildlife Management Area is situated on a peninsula surrounded by Norris Lake, formed by the congruence of the Powell and Clinch Rivers and part of the TVA reservoir system. Several intermittent and smaller perennial streams feed the reservoir moving across the sloping and gently rolling topography. The clayey to sandy loam soils were derived from dolomite, limestone, and sandstone. Soils are thin along the ridges and increase in depth down the slopes towards the river's edge.

The forest type is mainly mixed hardwood-pine interspersed with open grassland patches to promote wildlife habitat. The major hardwood species are white oak (*Quercus alba*), chestnut oak, mockernut hickory (*Carya tomentosa*), and yellow-poplar. Eastern white pine is the most frequently encountered pine. The drier ridgetops support

scarlet oak, white oak, southern red oak (*Quercus falcata* var. *falcata*), and northern red oak (*Quercus rubra*) with occasional shortleaf pines. Along slopes and benches, mockernut hickory, yellow-poplar, and eastern white pine become larger components of the forest. Most of the understory consists of black cherry (*Prunus serotina*), red maple (*Acer rubrum*), and persimmon (*Diospyros virginiana*). Regeneration is mainly red maple, various oaks, mockernut hickory, and eastern white pine. Where soils are deep and moist, yellow-poplar overtakes the area. There is an absence of shortleaf pine regeneration at Chuck Swan.

American chestnut (*Castanea dentata*) was abundant at Chuck Swan before succumbing to the chestnut blight in the early 1900's. Chestnut oak, northern red oak, and white oak seem to be occupying the niche vacated by American chestnut with a site index of 70 feet at base age 50 based on estimations and research on similar landscapes (Graney 1977). In comparison, Burton's work in the Norris watershed indicated planted shortleaf pine had a potential site index of 60 at base age 25 (Burton 1964).

Chuck Swan was originally settled by those that John Rice Irwin has called the diminishing 'mountain folk' of southern Appalachia. Numerous families established homesteads as early as the late 18th century, depending on agriculture for existence and utilizing the forest resources as needed. In 1933, President Franklin D. Roosevelt signed into law the TVA Act sponsored by Nebraskan Senator George Norris. The act intended to improve navigation, prevent flooding, and improve industrial development opportunities by bringing electricity to the Ridge and Valley. Within three years, Norris Dam was completed and Norris Lake was filled. The filling of the reservoir achieved TVA's goals but at the same time forced over 3,500 families to abandon their lands

(Darnell 2003). In an attempt to secure final income from their lands, the forests were felled and the timber and firewood sold. TVA reforested some of the harvested acres but mainly instigated fire suppression and allowed natural regeneration to take its course. Without periodic fire, the shortleaf pine communities were rapidly replaced by the oak-hickory forest type that currently comprises the forest. Fire suppression continued after Tennessee purchased the 25,000 acre property in 1952 and turned management over to the Division of Forestry.

Chuck Swan was not immune to the cycle of southern pine beetle outbreaks. The pine resource declined after beetle outbreaks in 1953, 1976, and 1998 leaving only remnant shortleaf pines in areas where the resource was young and could overcome such outbreaks. These pines had either been left as intermediate non-marketable individuals or had regenerated during the early years of state management when fires on the ridges were allowed to burn².

Oak Ridge Forestry Experiment Station

The University of Tennessee's Forestry Experiment Station at Oak Ridge is comprised of Pine and Chestnut Ridge and the intervening valley between them. Soils are formed from limestone on Chestnut Ridge, and shale on Pine Ridge. Cherty rock outcroppings and sinkholes are common. Intermittent streams create potential erosion problems with the sandy-loam to clay structured horizons. Study plots were established on a variety of topographic positions and aspects along these two ridges.

² According to interviews with Darren Bailey, TDF forester and Chuck Swan manager, conducted August 2002-December 2003.

The forest is similar in composition to that at Chuck Swan, typical southern Appalachian mixed hardwood-pine. The dominant hardwood overstory is comprised of white oak, chestnut oak, black oak (*Quercus velutina*), mockernut hickory, and post oak (*Quercus stellata*) and scarlet oak on the drier ridgetops (Hardaway 1962). Shortleaf pine has an estimated site index of 60 at base age 25 (Smalley and Bailey 1974). It occurs sporadically as a remnant component of the overstory with most of the pine overstory component comprised of Virginia pine and loblolly pine. The midstory is comprised of red maple, dogwood (*Cornus florida*), blackgum (*Nyssa sylvatica*), sourwood (*Oxydendrum arboreum*), and white ash (*Fraxinus americana*) along the better well drained soils. The understory is red maple, shade tolerant miscellaneous hardwoods such as dogwood and sourwood, mockernut hickory, and oaks species. Shortleaf pine regeneration was absent.

The Forestry Experiment Station property was first settled by early farmers. Aerial photographs taken in 1935 indicated that much of the property was farmed and pastured with the trees being utilized for building materials and firewood. As lands were abandoned, pioneer and fire adaptive species overtook the fields. In the early 1940's, the land was purchased by the federal government for the construction of Clinton Laboratories. This organization would evolve into the Oak Ridge National Lab; its purpose was the investigation of atomic energy. This quiet farming community quickly became the site of the Manhattan Project (ORNL 1994).

A boomtown was born with a house erected every 30 minutes during those first few years of growth (ORNL 1994). The population of Anderson County grew from 26,504 in 1940 to nearly 60,000 people in 1950 (Darnell 2003). The construction of the

lab itself required over 30,000 cubic yards of concrete, 4 million board feet of timber, and 20 percent more electricity annually than New York City (ORNL 1994). The city and labs expanded but it was still “America’s Secret City”; admittance onto the property was, and still is to a point, a product of national security. With new scientific breakthroughs resulting from lab work and the importance to the war effort, the entire area was protected by the military; with guard houses still standing empty in some areas of the city today.

Much of the timber used in constructing the labs came from the property. Fire was still used as a tool to clear land as well as the powerful land moving machines. This promoted one last regeneration event of shortleaf pine in the area, similar to the effects seen in the construction of Norris Dam. Like the Norris Dam project, fire suppression became a major emphasis in land management, altering the composition of the forest as it underwent succession.

In August of 1961, the University of Tennessee acquired 2,260 acres of forest in the area from the Department of Health, Education, and Welfare. The Oak Ridge plots in this research are located on these lands. A biologist with ORNL, Alexander Hollaneder described the lands in a University brochure. Prior to ORNL’s establishment the lands were a mixture of farms, shortleaf pine, and mixed hardwoods, but afterwards yellow-poplar, Virginia pine, and second-growth oak and hickory cover the landscape (Begun 1981).

Several disturbances have altered the forest composition. Tornadoes touched down across at the Oak Ridge Forestry Station in recent years promoting early successional growth and altering some older undisturbed sites. Infrequent wildfires have

burned the slopes of both ridges prior to University management promoting the growth of shortleaf pine. The most recent outbreak of southern pine beetle eliminated all but the most thrifty pines. The present shortleaf pine remnant is so small in frequency and dispersed thoroughly across the hardwood component, that the southern pine beetle did not impact these trees. However, certainly outbreaks in the mid 1970's and before did reduce the abundance of the shortleaf pine resource at the Forestry Station. Scattered timber harvesting has also occurred on the station for research purposes.

SECTION 4

Research Results

Site Similarities

The importance values, competition indices, and site index estimations all suggested that the two study sites were similar in productivity, composition, and structure (Table 3). Both locations were similar in species composition, occurrence, and tree size. Relative dominance of shortleaf pine was slightly higher in the Chuck Swan region while relative density was higher at Oak Ridge. Other observations in the importance value components include a higher relative dominance for white oak species and mockernut hickory at Oak Ridge and a higher relative frequency and dominance for yellow-poplar at Chuck Swan.

Hegyí's (1974) competition index was used to compare the degree of competition within each topographic setting (Figure 5). With three topographic regions, ridgetop, slope, and bench, and two acknowledged aspects, north and south, no significant differences associated were with topographic positions or aspect with respect to competition levels according to a comparison of means test.

The relationship between diameter of the subject shortleaf pine for each neighborhood and the distance in feet between competitor trees is shown in Figure 6. The coefficient of determination (R^2) is 0.38. This fairly weak relationship indicates that shortleaf pine diameter growth is positively impacted by increased spacing around the tree as it develops.

Table 3. Importance Value Indices for Chuck Swan and Oak Ridge neighborhoods for the shortleaf pine development research, Tennessee.

Chuck Swan					Oak Ridge				
Species	Relative Frequency	Relative Density	Relative Dominance	IV	Species	Relative Frequency	Relative Density	Relative Dominance	IV
Shortleaf Pine	20.83	8.64	29.24	58.71	Shortleaf Pine	20.66	11.91	20.66	53.23
White Oak ¹	12.50	8.12	12.54	34.16	White Oak	15.49	6.95	21.04	43.48
Red Oak ²	8.33	7.85	7.21	23.39	Red Oak	6.58	3.93	9.29	19.80
Red Maple	16.67	33.77	17.12	67.56	Red Maple	16.15	32.74	9.97	58.86
Mockernut Hickory	10.42	9.43	12.18	32.03	Mockernut Hickory	8.91	6.77	22.51	38.19
Yellow Poplar	8.33	4.45	10.69	23.47	Yellow Poplar	7.51	3.72	7.36	18.59
Virginia Pine	2.08	0.26	1.12	3.46	Virginia Pine	2.16	0.95	1.93	5.04
Misc. Hardwoods ₃	20.84	27.48	8.9	57.22	Misc. Hardwoods	22.54	33.03	7.24	62.81

¹ Species include White Oak, Chestnut Oak, and Post Oak

² Species include Southern Red Oak, Scarlet Oak, and Black Oak

³ Species include Flowering Dogwood, Blackgum, Sourwood, and other shade tolerant species.

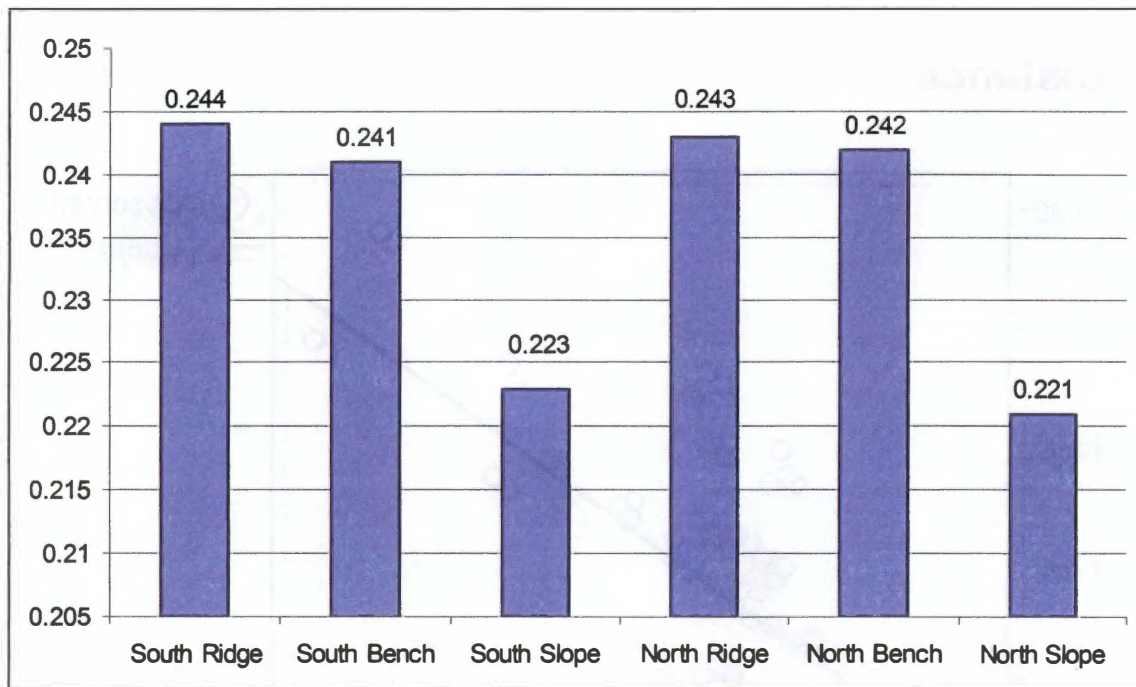


Figure 5. Competition indices with respect to topographic position and aspect based on Hegyi's formula for the shortleaf pine development research at the Oak Ridge and Chuck Swan study locations, Tennessee. Shortleaf pine cohorts were combined for this examination. No significant differences were discovered at $\alpha = 0.05$.

Distance

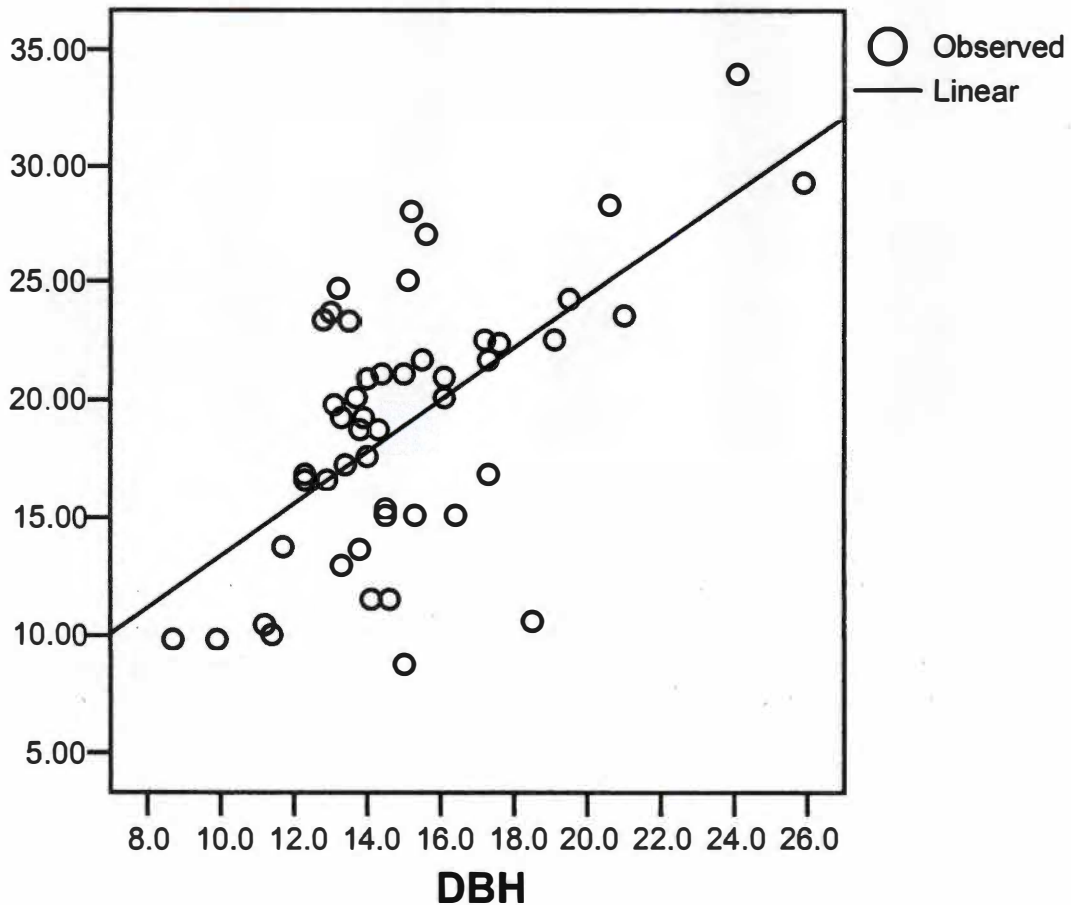


Figure 6. Shortleaf pine diameter-distance from competition trees relationship for the shortleaf pine development research at the Oak Ridge and Chuck Swan study locations, Tennessee. Distance is measured in feet and diameter in inches.

$$DBH = 0.347(\text{Distance}) + 8.474; R^2 \text{ equals } 0.384.$$

The overstory and midstory plots depict a complex forest in the Ridge and Valley area supporting the classification of this area as a mixed hardwood-pine forest type. Figure 7 shows the percentage of plots containing white and red oak species, yellow-poplar, Virginia pine, mockernut hickory, and red maple. Shade intolerant species such as yellow poplar and white and red oak species dominate the overstory while mockernut hickory and red maple are the most common species in the midstory. These two midstory species, both listed as shade tolerant to intolerant at times in their life cycle, can persist in the midstory for years and can respond to overstory releases (Trimble 1975). Both species are easily damaged or killed by fire due to their thin bark and poor insulating ability. The complete absence of shortleaf pine regeneration plus the overstory/midstory matrix indicates that fire has been absent for a quite some time.

Shortleaf Data and Relationships

Shortleaf pines were arranged into two-inch diameter classes, crown classifications, ten foot height classes, and live crown ratio categories. Tables 4 through 7 show the distribution of pines across these categories, respectively for both study locations, combined. Shortleaf pine was distributed across diameter classes ranging from 6 to 26 inches in a bell-shaped curve skewed to the smaller diameter classes with a peak occurring at the 14 inch class (Table 4). Eighty-seven percent of the individual stems were classified as being in the dominant or co-dominant (Table 5). Heights varied from the 60 foot class to over 120 feet in height with a bell curve distribution peaking in the 90-100 foot class (Table 6). Fifty-eight percent of the shortleaf pines had live crown percentages below 35 percent; 87 percent below the 45 percent live crown ratio level

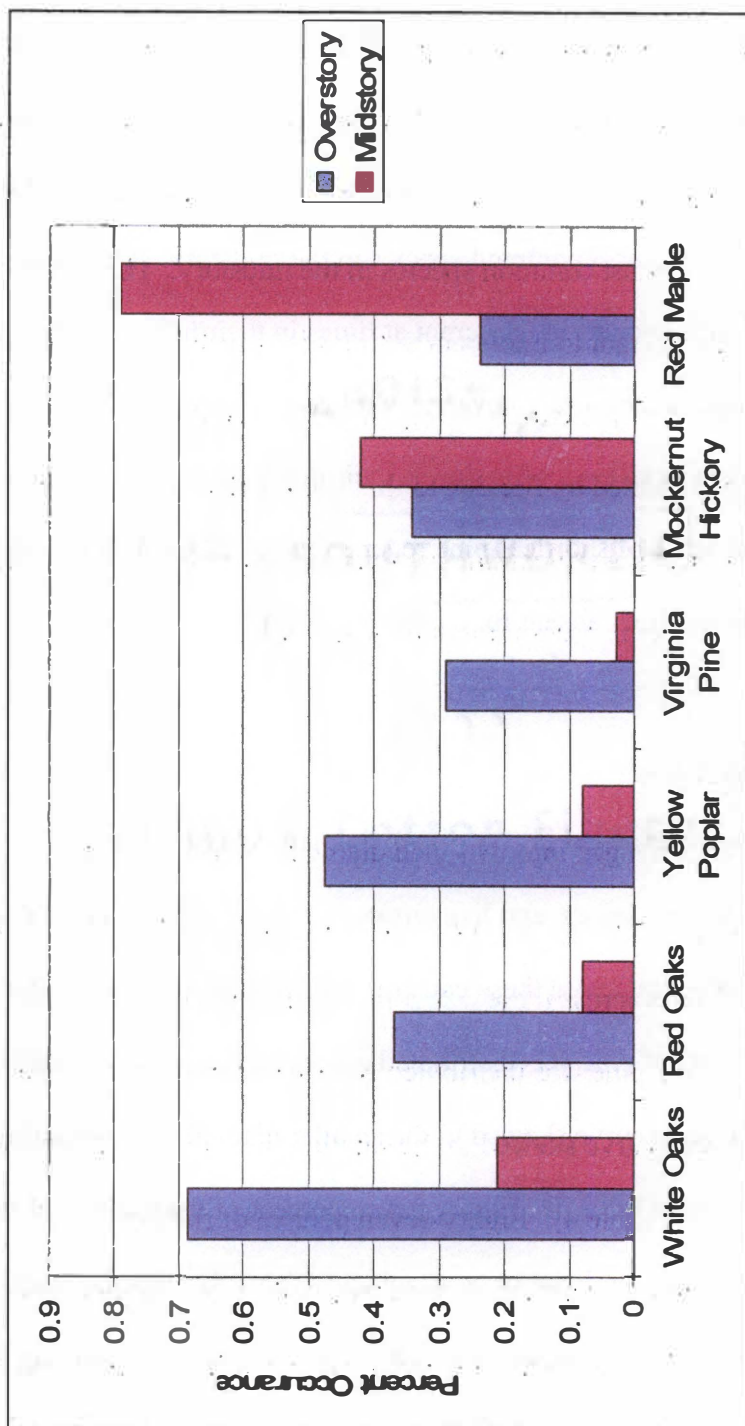


Figure 7. Overstory and midstory plot occurrence for selected species for the shortleaf pine development research at the Oak Ridge and Chuck Swan study locations, Tennessee. Figure represents the combined total from both study locations and cohort neighborhoods.

Table 4. Diameter distribution of shortleaf pine for the shortleaf pine development research at the Oak Ridge and Chuck Swan study locations, Tennessee.

DBH (Inches)	Number of individuals sampled
6	1
8	3
10	3
12	11
14	21
16	15
18	5
20	3
22	2
24	1
26	1
TOTAL	66

Table 5. Crown classification of shortleaf pine for the shortleaf pine development research at the Oak Ridge and Chuck Swan study locations, Tennessee.

Crown Classification	Number of individuals sampled
Emergent	3
Dominant	20
Co-Dominant	37
Intermediate	6
TOTAL	66

Table 6. Ten foot height classes of shortleaf pine for the shortleaf pine development research at the Oak Ridge and Chuck Swan study locations, Tennessee.

Height Class (Feet)	Number of individuals sampled
60-70	2
70-80	8
80-90	11
90-100	31
100-110	11
110-120	2
120 +	1
TOTAL	66

Table 7. Live crown percentages of shortleaf pine for the shortleaf pine development research at the Oak Ridge and Chuck Swan study locations, Tennessee.

Live Crown Percentage Classes	Number of individuals sampled
15-25	11
25-35	27
35-45	19
45-55	9
TOTAL	66

(Table 7). The 'average shortleaf pine' was 83 years of age with a diameter of 14.5 inches, a total height of 92.5 feet, and a live crown percentage of 34 percent. By comparison, Table 8 displays the average yellow poplar, Virginia pine, white, and red oak individuals of dominant and co-dominant crown classes that occurred in the study neighborhoods.

Examining the forest from these averages of each species suggests that the age of the oak component is roughly the same as the shortleaf pine component; thus the study areas consist of a single aged or even-aged forest. However, when the pine component is isolated and age distribution is examined closer, two distinct age cohorts are apparent. The first cohort is composed of the remnant shortleaf that established late in the 19th century-early 20th century with the second cohort being younger; established in the late 1930's through the 1940's as offspring of this older cohort. Both cohorts appear at both study sites. Different cohort neighborhoods were often found close to each other. The number of individuals in the older cohort compared to the more recent cohort skew the average age so that it appears that the shortleaf pine resource is, on average, equal in age to the oak component. Most of the sampled neighborhoods are even-aged but there are a few two-aged stands in the Ridge and Valley comprised of mixed hardwood species (TDF 2004). The possibility of two-aged stands arises from the few neighborhoods sampled that contained both shortleaf pine age cohorts.

Figure 8 displays the time series of individual stem initiation for the 66 plots. Prior to the 1930 period, shortleaf pine regeneration was consistent and increased slightly over time while hardwood competition was limited mainly to red and white oaks, and was limited in number as well. An explosion in shortleaf pine recruitment occurred in the

Table 8. Average tree characteristics in study neighborhoods, dominant and co-dominant crown positions for the shortleaf pine development research on the Oak Ridge and Chuck Swan study locations, Tennessee.

Species	Diameter (inches)	Total Height (feet)	Age	Live Crown Percentage
Yellow Poplar	12.9	85	53	40
Virginia Pine	14.4	84	57	28
White Oak	19.5	91	81	53
Red Oak	18.2	87	81	48
Shortleaf Pine	14.5	92	83	34

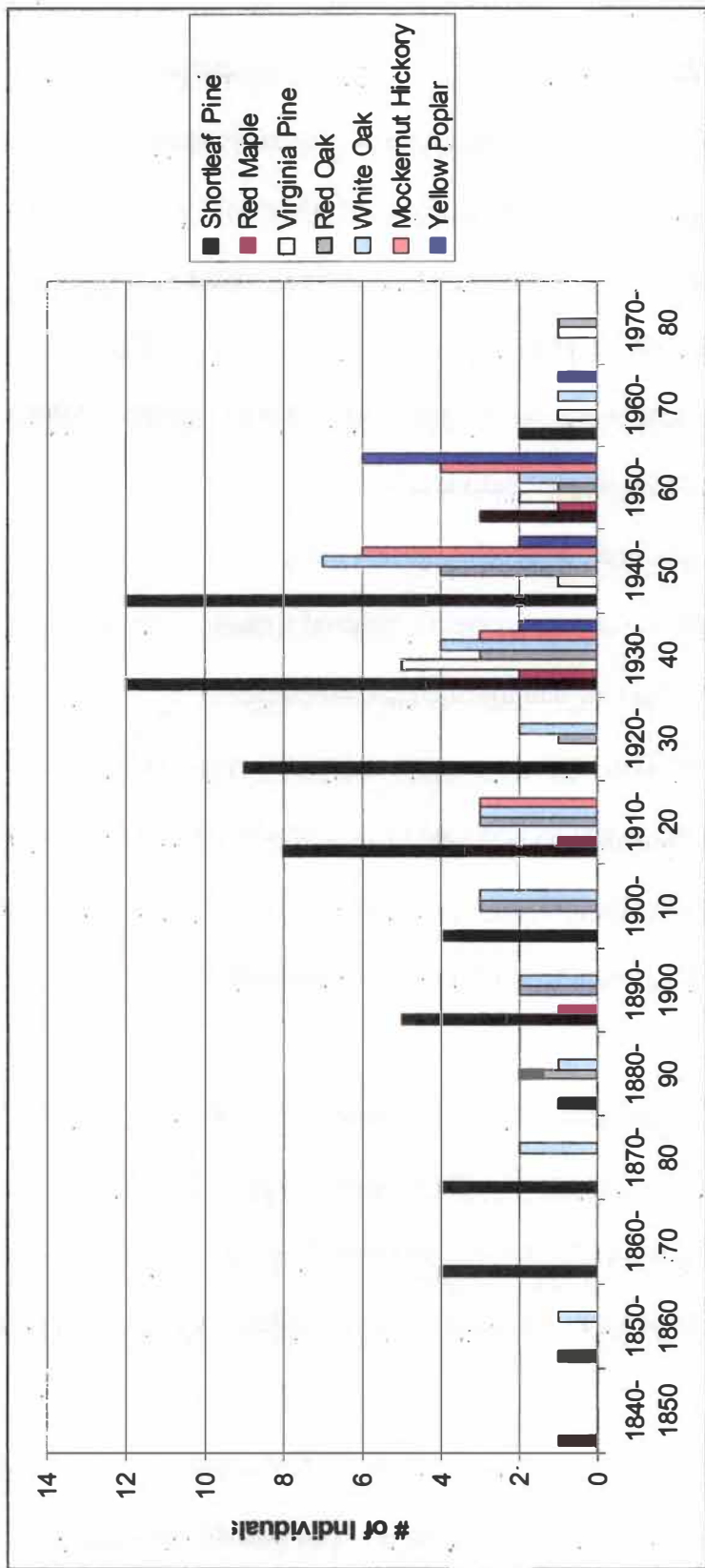


Figure 8. Initiation pattern of neighborhood species for the shortleaf pine development research at the Oak Ridge and Chuck Swan study locations, Tennessee.

1930's and 1940's with 24 individuals. This increase in regeneration coincides with the decline of the American chestnut, the arrival of TVA, and the construction of the Oak Ridge Labs. During those decades the introduction and increases in competitive hardwoods such as mockernut hickory, yellow-poplar, and white oaks also occurred. In the decades to follow, the forest conditions changed such that shortleaf pine regeneration declined until it ceased in the 1970's. The closed canopy conditions created by the overstory hardwoods and the suppression of fire, limited the area of suitable seedbeds, and thus hindered any future shortleaf pine individuals.

The recruitment data are based on species present today. Other trees may have initiated and died, leaving little evidence of remains, especially those in the late 1800's through the early 1900's. No decaying stumps or snags were observed on the study area as evidence of succumbed trees. However, American chestnut was known to populate the area prior to the chestnut blight and its loss could have impacted the neighborhood development. Some evidence of chestnut remains should still be present considering the slow decomposition rates of the resilient wood. However, these trees could have been easily removed.

Diameter-age relationships were examined for the shortleaf pine component. Diameter-age relationships were compared for the complete sampled population, populations of shortleaf pine at both Chuck Swan and Oak Ridge, and the populations within both the older cohort (Age Class A) and the younger cohort (Age Class B) (Figure 9).

Height-age relationships are explored in Figure 10. These relationships were also divided into components of age class and study location. Both the diameter-age and

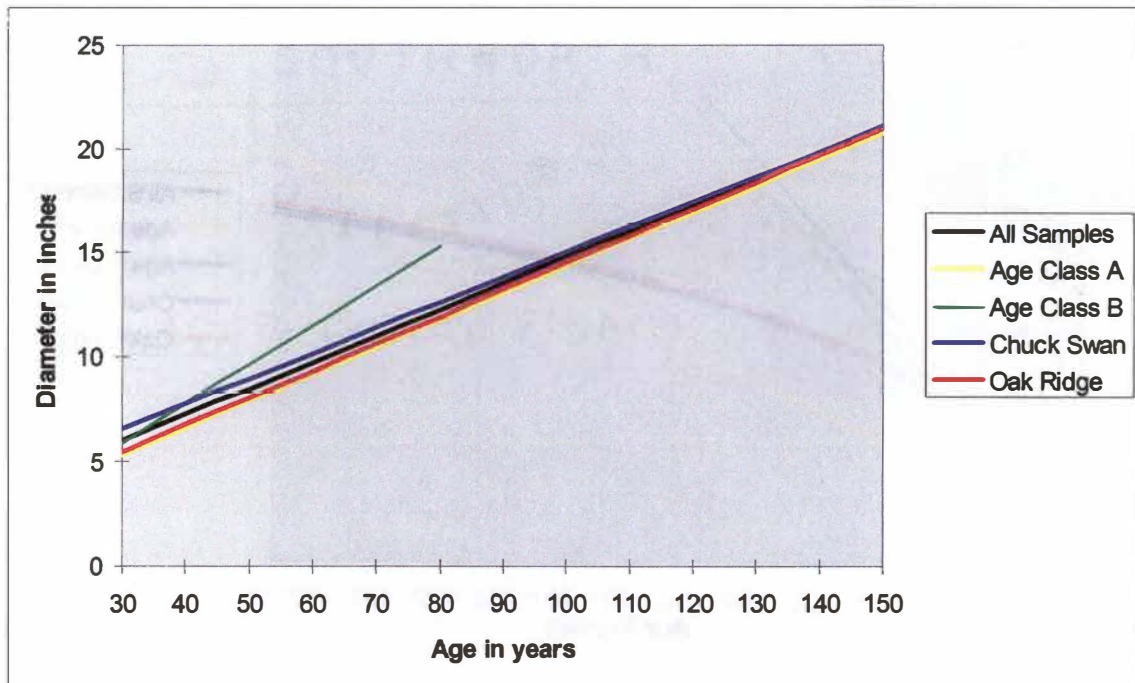


Figure 9: Shortleaf pine diameter-age distribution curves³ for the shortleaf pine development research at the Oak Ridge and Chuck Swan study locations, Tennessee. Curves were generated from single tree coordinate data.

³ All samples: $DBH = 0.126(Age) + 2.197$ $R^2 = 0.82$ $N = 66$
 Age Class A: $DBH = 0.129(Age) + 1.389$ $R^2 = 0.92$ $N = 28$
 Age Class B: $DBH = 0.188(Age) + 0.218$ $R^2 = 0.63$ $N = 38$
 Chuck Swan: $DBH = 0.122(Age) + 2.868$ $R^2 = 0.83$ $N = 20$
 Oak Ridge: $DBH = 0.129(Age) + 1.538$ $R^2 = 0.82$ $N = 46$

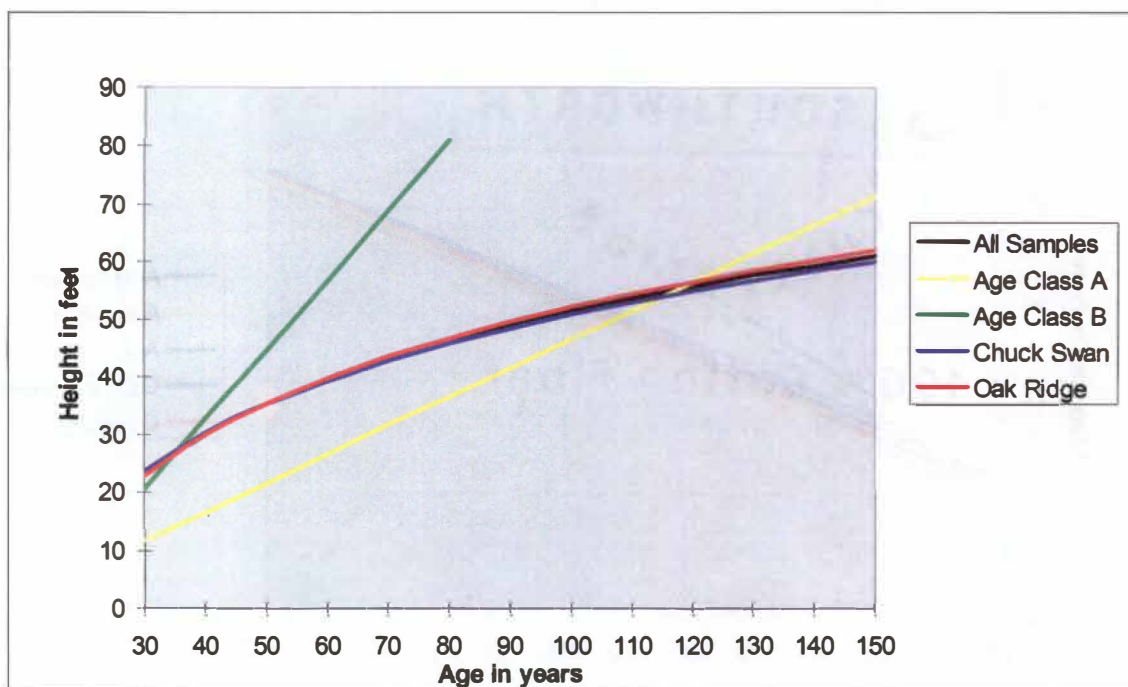


Figure 10. Shortleaf pine height-age distribution curves⁴ for the shortleaf pine development research at the Oak Ridge and Chuck Swan study locations, Tennessee. Curves were generated from single tree coordinate data.

⁴ All samples: $HT = 23.501(\ln \text{Age}) - 56.711$ $R^2 = 0.61$ $N = 66$
 Age Class A: $HT = 0.499(\text{Age}) - 3.381$ $R^2 = 0.77$ $N = 28$
 Age Class B: $HT = 1.210(\text{Age}) - 15.749$ $R^2 = 0.92$ $N = 38$
 Chuck Swan: $HT = 22.774(\ln \text{Age}) - 53.941$ $R^2 = 0.63$ $N = 20$
 Oak Ridge: $HT = 24.357(\ln \text{Age}) - 59.983$ $R^2 = 0.59$ $N = 46$

height-age relationships show the predictive models for this study only. Many more samples would need to be taken in order to construct more reliable predictive models, but these samples represent the trees found on the study area.

The diameter-age curves (Figure 9) and the height-age curves (Figure 10) for each of the locations and cohorts are similar. The curve for the younger cohort B for each figure is skewed somewhat because data was not available beyond age 80.

The diameter-age relationship of shortleaf pine showed a consistent and steady increase in diameter over time. The cumulative diameter growth of the shortleaf resource, taken from increment cores, was plotted over time and compared to the cumulative diameter growth of other neighborhood species (Figure 11). While the cumulative diameter curves for each species seems to mirror each other, the curve for shortleaf is very similar in slope to the curves of the red oak species as well as the fire intolerant mockernut hickory. These three species have similar diameter growth rates. Diameter growth per decade over time is depicted in Figure 12. Sharp spikes in growth for mockernut hickory, yellow-poplar, and Virginia pine occur between 1915 and 1935, indicating their initiation into the neighborhoods. This was the time of the chestnut blight and as American chestnut disappeared from the landscape, species such as shortleaf pine, chestnut oak, scarlet oak, and mockernut hickory could compete well on dry ridges took advantage of the additional growing space.

The growth rates to present of these species as well as the growth rates of the oaks to 1945 increased and then remained somewhat consistent. The final increase in diameter growth rates of shortleaf pine occurs in the early 1940's, before growth rates start to diminish in the late 1950's-early 1960's. These changes could be a result of the lack of

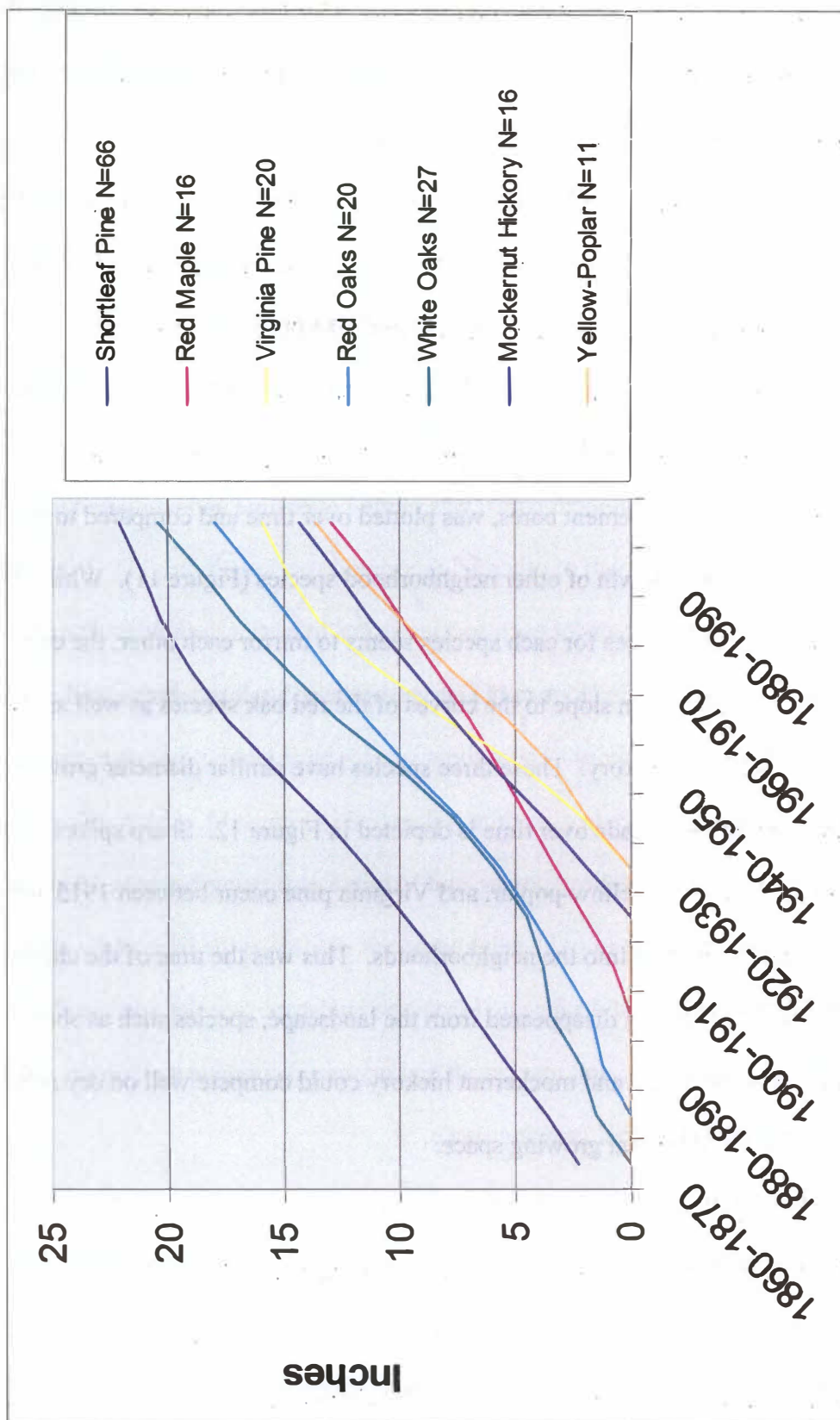


Figure 11. Cumulative diameter growth of species in neighborhoods over time for the shortleaf pine development research at the Oak Ridge and Chuck Swan study locations, Tennessee. Curves were generated from increment cores taken at each neighborhood. "N" is the number of trees sampled for the curves.

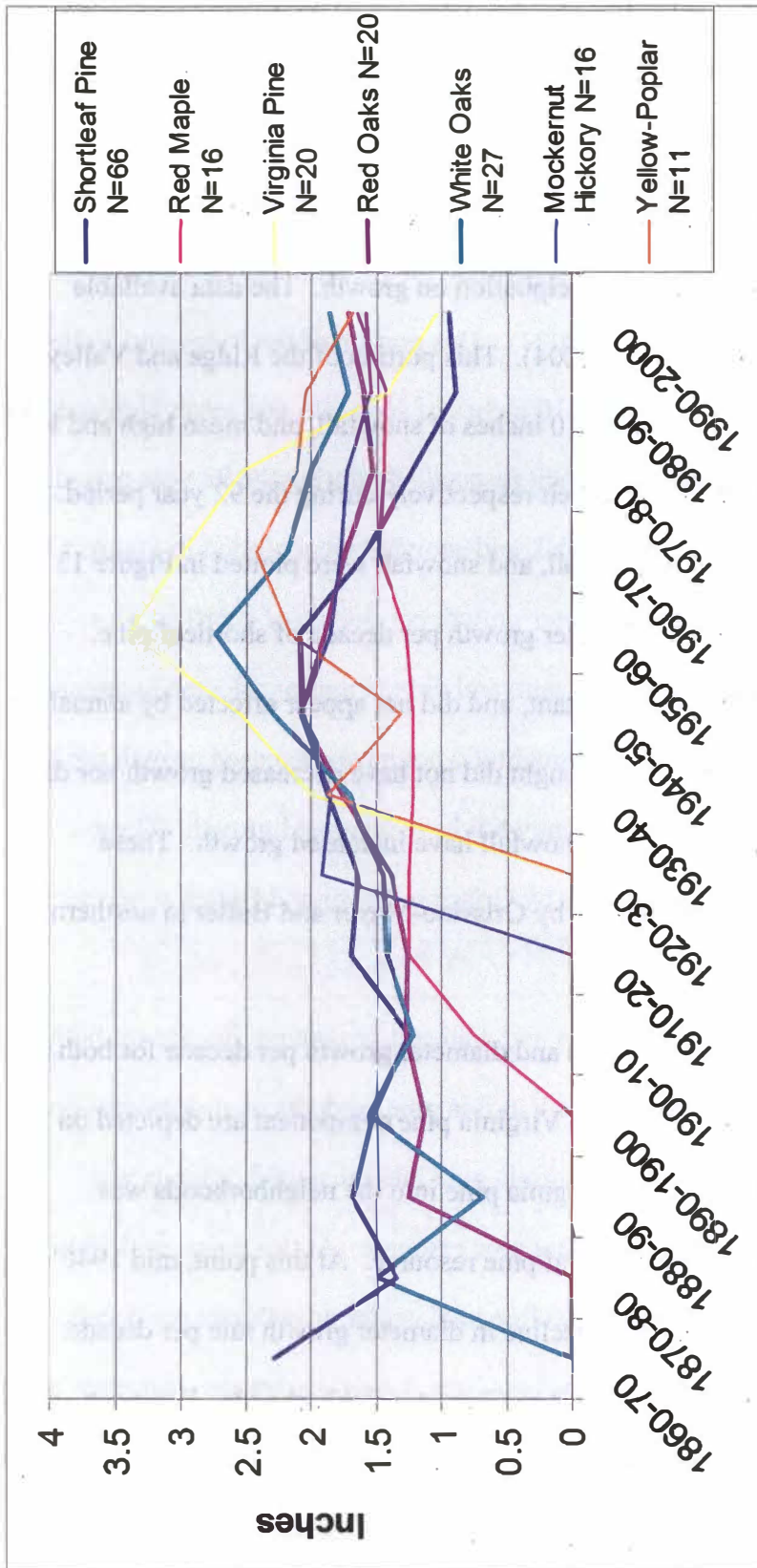


Figure 12. Diameter growth per decade for species in neighborhoods for the shortleaf pine development research at the Oak Ridge and Chuck Swan study locations, Tennessee. Curves were generated from increment cores as well as stem analysis where appropriate. "N" is the number of trees sampled for the curves.

active management on the study locations as TVA and the Atomic Energy Commission were more interested in fire suppression than timber management. This management promoted fully stocked, closed canopy forests.

Diameter growth was compared to the weather conditions within the area to determine the effect of temperature and precipitation on growth. The data available extends back to January 1, 1910 (NOAA 2004). This portion of the Ridge and Valley receives a mean of 47.2 inches of rainfall, 10 inches of snowfall, and mean high and low temperatures of 49 and 69 degrees Fahrenheit respectively during the 92 year period. The annual averages for temperature, rainfall, and snowfall were plotted in Figure 13 along with a trend line depicting the diameter growth per decade of shortleaf pine. Diameter growth remained somewhat constant, and did not appear affected by annual fluctuations in precipitation. Periods of drought did not have decreased growth nor did the periods of increased precipitation and snowfall have increased growth. These findings are supported with climate studies by Grissino-Mayer and Butler in northern Georgia (1993).

Cumulative diameter growth curves and diameter growth per decade for both age cohorts of shortleaf pine and the associated Virginia pine component are depicted on Figures 14 and 15. The introduction of Virginia pine into the neighborhoods was accompanied by Age Class B of the shortleaf pine resource. At this point, mid 1940's, the older cohort, Age Class A, started its decline in diameter growth rate per decade. Virginia pine was not present in any of the Age Class A neighborhoods. However, given the prolific nature of the species and its pyric characteristics, the species was assumed to be present as the older cohort developed. The absence of Virginia pine in the Age Class

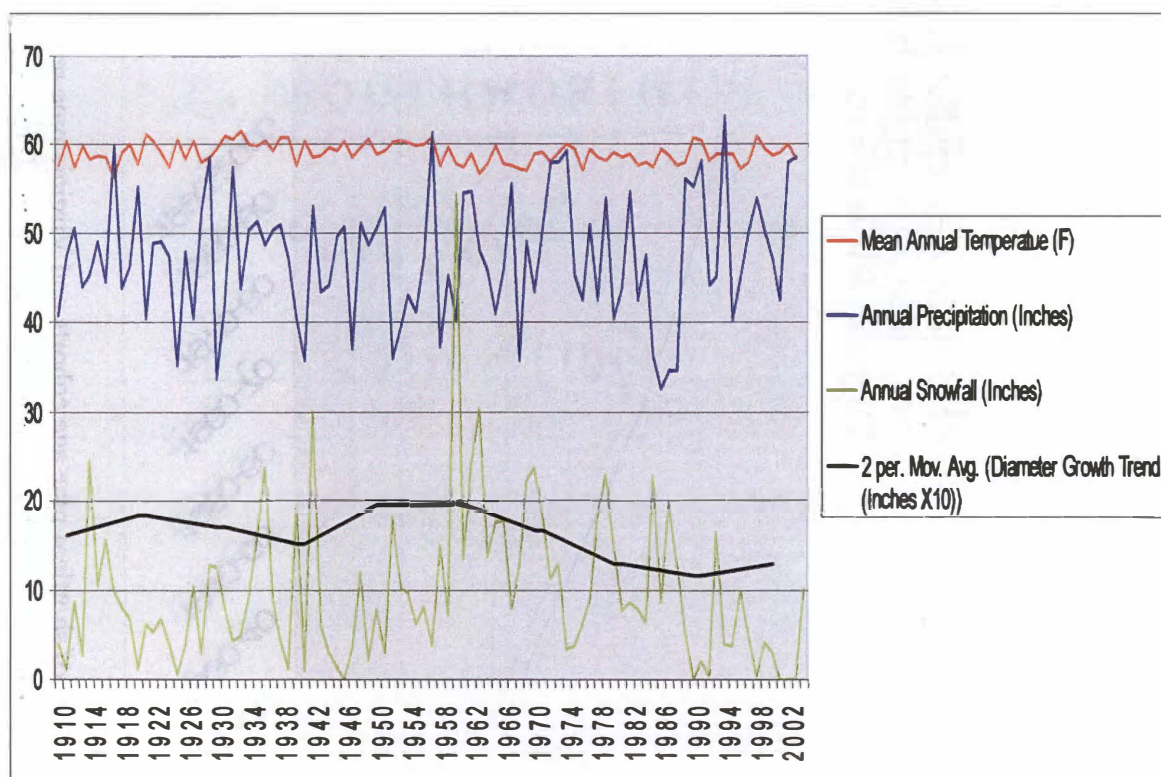


Figure 13. Mean annual temperature, precipitation, and snowfall and the decadal diameter growth trend of shortleaf pine for the shortleaf pine development research on the Oak Ridge and Chuck Swan study locations, Tennessee (NOAA 2004).

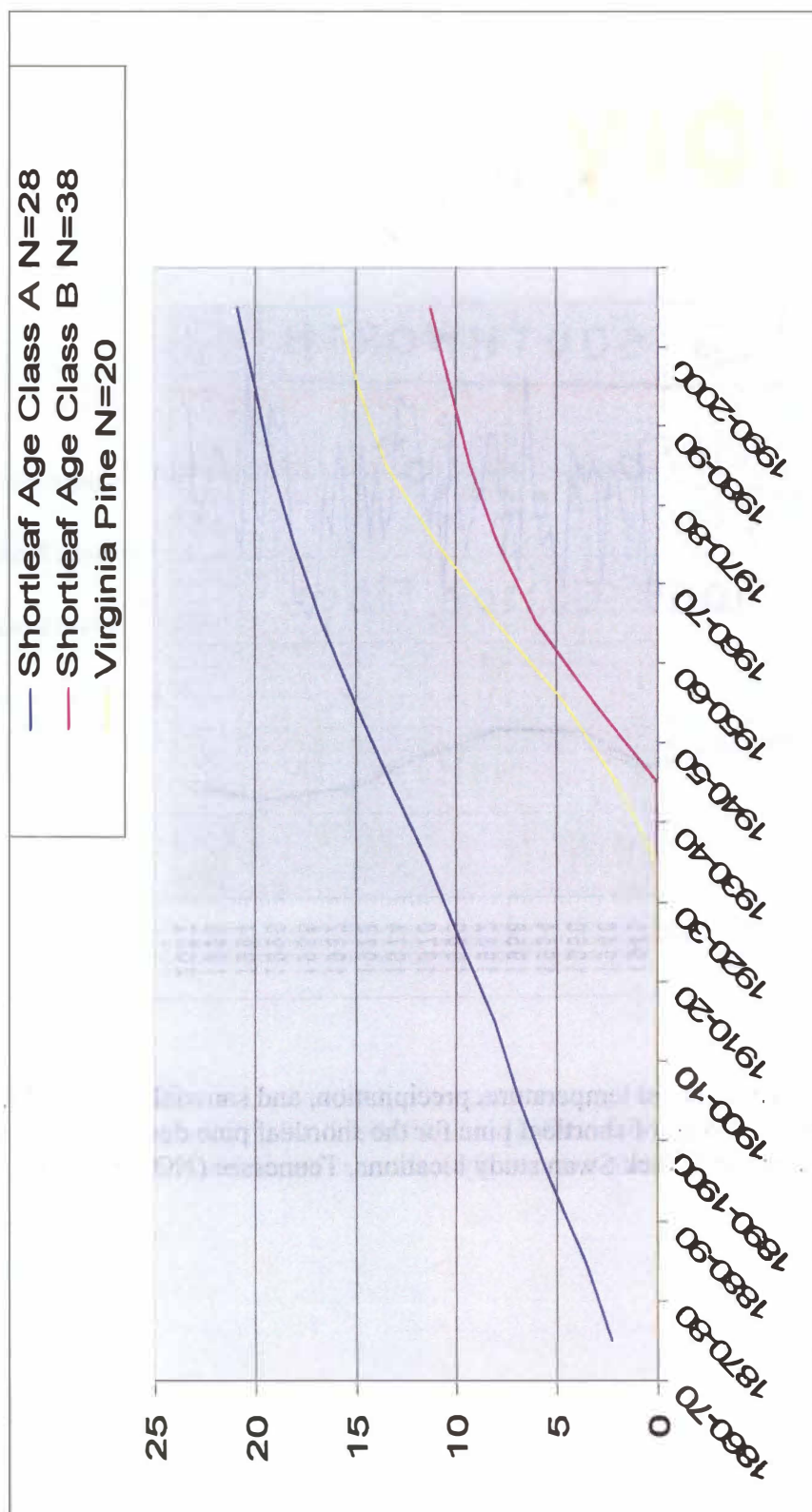


Figure 14. Cumulative diameter growth over time of shortleaf pine age cohorts and Virginia pine resource for the shortleaf pine development research on the Oak Ridge and Chuck Swan study locations, Tennessee. Curves were generated from increment cores taken from each neighborhood. "N" is the number of trees sampled for the curves.

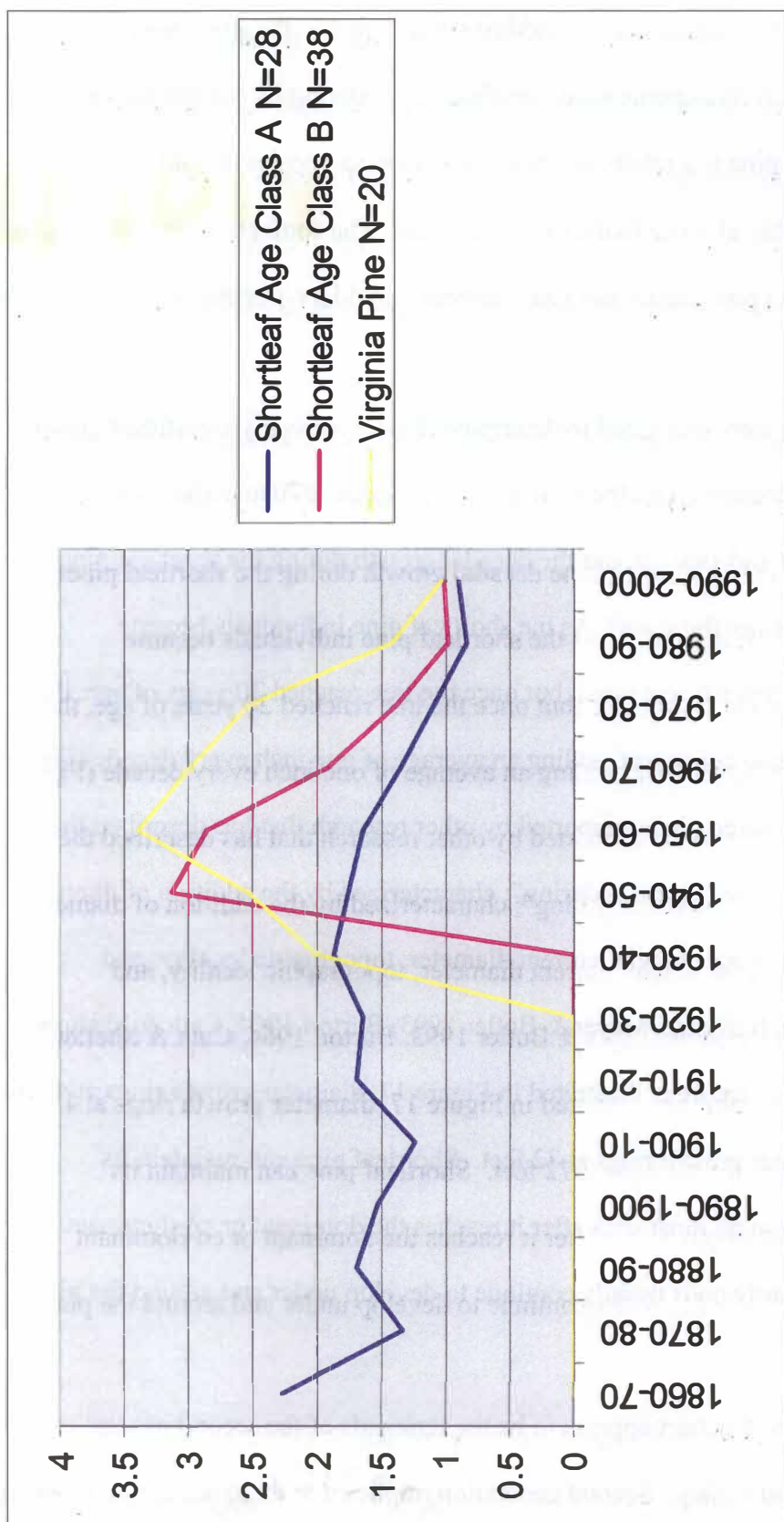


Figure 15. Diameter growth per decade of shortleaf cohorts and Virginia pine for the shortleaf development research on the Oak Ridge and Chuck Swan study locations, Tennessee. Curves were constructed from increment cores and as well as stem analysis where available. Sample numbers represent both cores and cookies from stem analysis. "N" is the number of trees sampled for the curves..

A neighborhood could be attributed to windthrow losses due to the shallow-rooted nature of the species as well as its extreme shade intolerance hindering its competitive ability to regenerate. Virginia pine is a relatively short-lived pioneer species and this may contribute to its possible absence in the older age class. The southern pine beetle is also devastating to Virginia pine stands and past outbreaks could have removed the older, less vigorous stems.

Shortleaf pine were examined to determine if there were any significant growth differences between decades. Did the total growth between 1870 and 1880 differ from growth between 1970 and 1980 or, did the decadal growth during the shortleaf pines' second decade differ from the sixth? As the shortleaf pine individuals became established, diameter growth was rapid, but once the tree reached 20 years of age, the diameter growth became consistent, adding an average of one inch every decade (Figure 16). This growth characteristic is supported by other research that has described the growth of shortleaf pine as "space enduring"; characterized by the addition of diameter annually independent of age, height, current diameter, topographic locality, and competition pressures (Grissino-Mayer & Butler 1993, Burton 1964, Cain & Shelton 2000). This ubiquitous nature is illustrated in Figure 17, diameter growth rings at 4 feet, and Figure 18, diameter growth rings at 72 feet. Shortleaf pine can maintain its dominance and position on most sites after it reaches the dominant or co-dominant positions; however hardwoods usually continue to develop under and around the pines (Baker 1991).

The Age Class A cohort appears to be the remnants of the second generation forest of the Ridge and Valley. Second generation implies that these are not members of

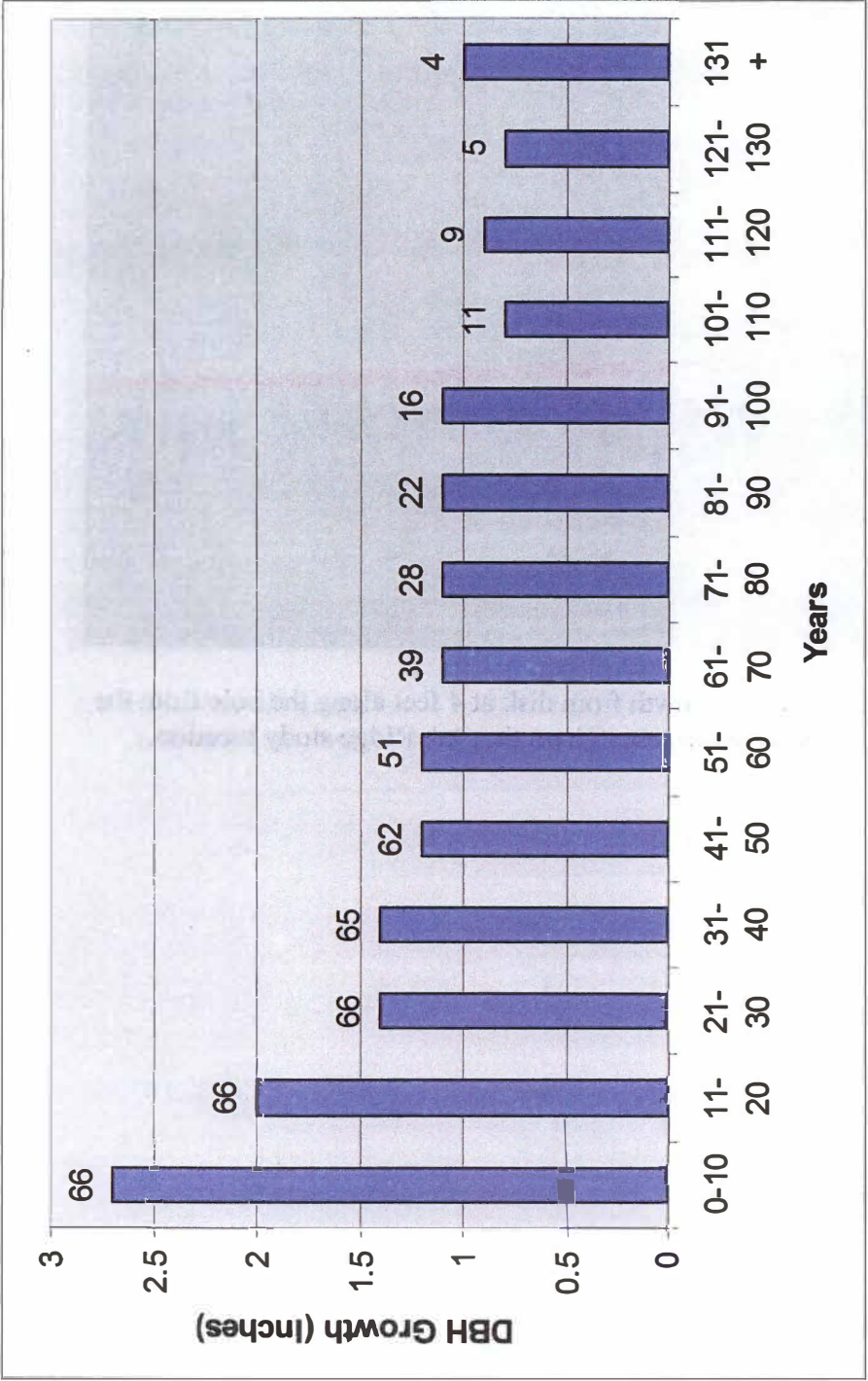


Figure 16. Decadal diameter growth of shortleaf pine as it ages for the shortleaf pine development research on the Oak Ridge and Chuck Swan study locations, Tennessee. Data is for both cohorts combined and derived from stem analysis. Data labels are the number of samples for each time period.

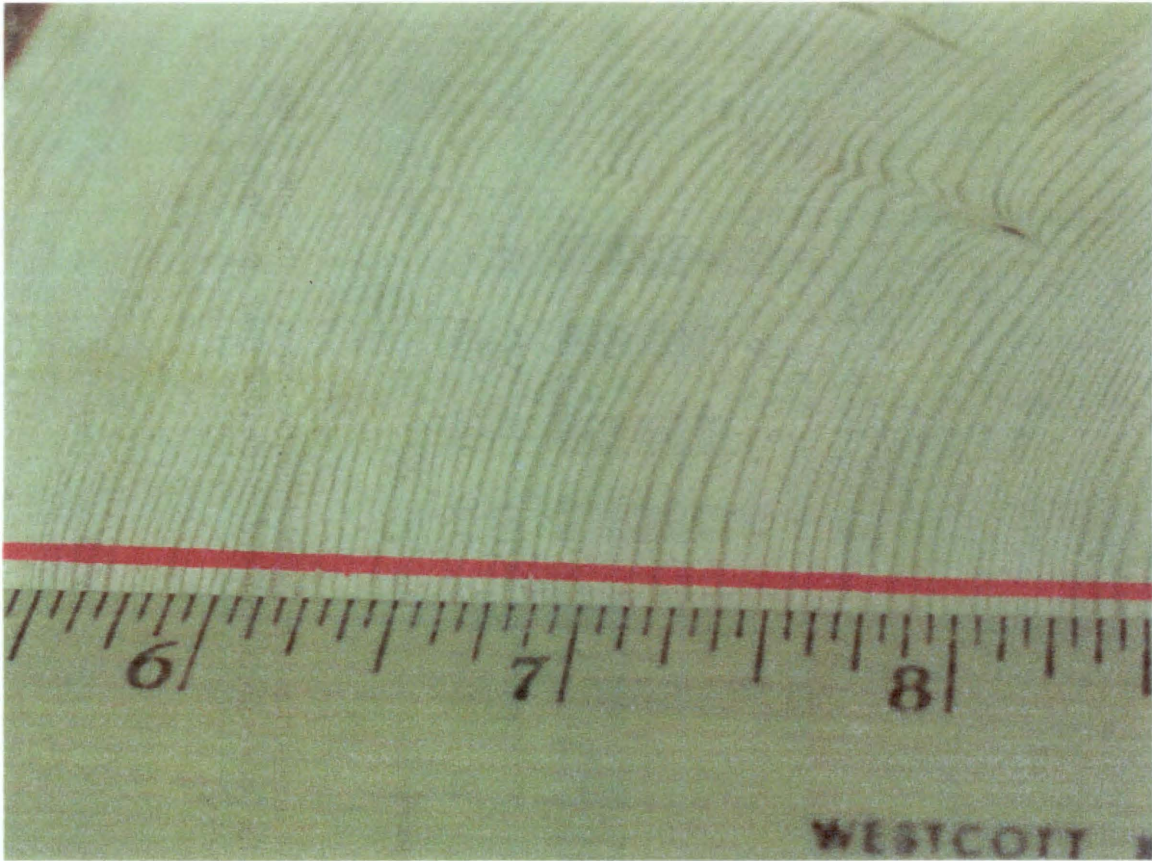


Figure 17. Shortleaf pine diameter growth from disk at 4 feet along the bole from the shortleaf pine development research on the Oak Ridge study location, Tennessee.

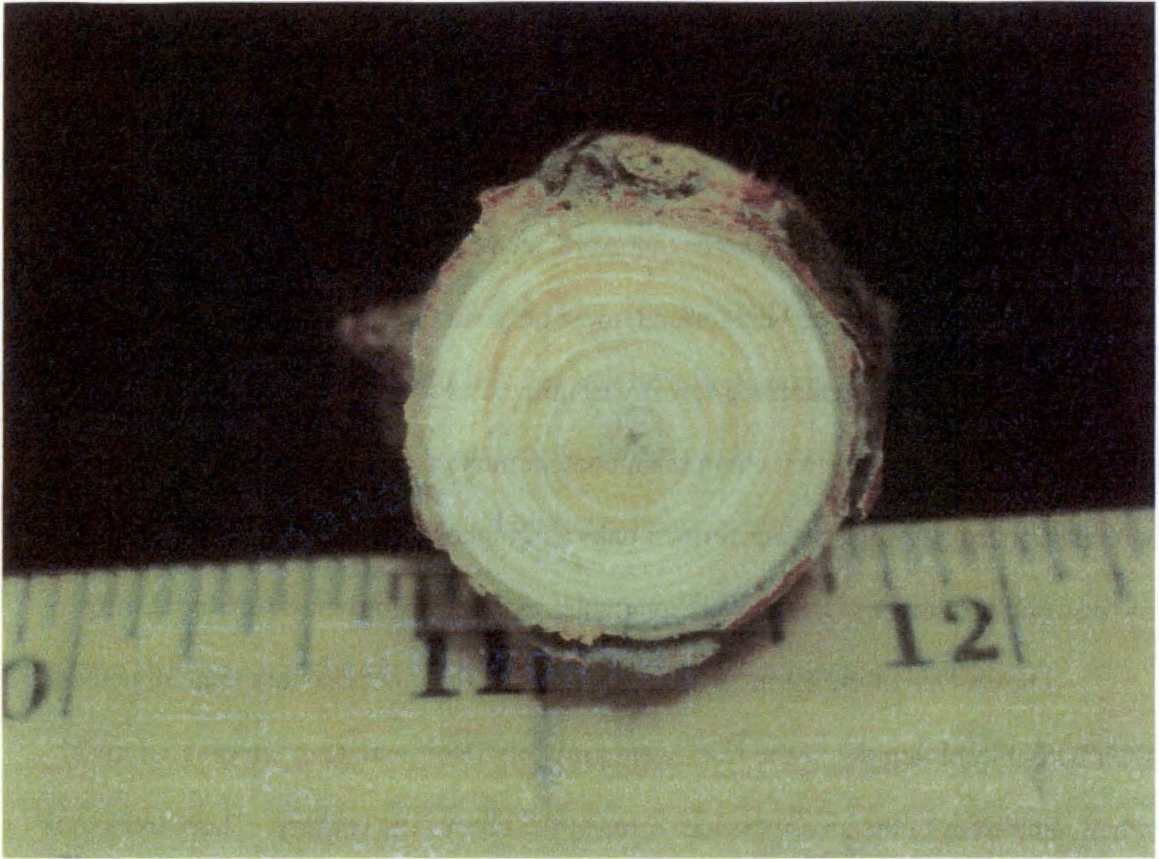


Figure 18. Shortleaf pine diameter growth from disk at 72 feet along the bole from the shortleaf pine development research on the Oak Ridge study location, Tennessee.

the virginal forests that dominated the landscape prior to European settlement. Very few hardwood trees associated with the pines of this age class graded above a 3 on the log grading scale (Rast et. al 1973), indicating that these pines that are now in the overstory positions were more than likely trees that were deemed undesirable during the logging operations at that time. The best formed, most utilized, largest timber species were harvested. Most of the remaining forest was utilized as firewood; however, shortleaf pine would have been left due to its high resin content making it poor firewood. In conjunction, some of the poorer formed oaks and hickories would have also been ignored as firewood if other hardwoods were available, easing the burden of fuel harvesting.

The crowns of the remnant pines in Age Class A comprise less than 30 percent of their height implying that these trees were probably intermediate or suppressed trees when other trees in the area were harvested at the turn of the century. These trees took advantage of increased space in canopy openings to increase in height and diameter. The average live crown percentages of the oaks were more than 50 percent indicating that the crowns expanded over time as growing space became more available and casting shade upon the forest floor (Table 9). Aerial photography from 1935 showed that the forest cover along the slopes and ridgetops at the Oak Ridge site was sparse; consisting of individuals that were free to grow as a result of harvesting and agricultural practices.

Neighborhood X5 is a typical representative of the cohort. Located at Chuck Swan on a ridge with a north facing aspect, X5 is comprised of a dominant 26-inch, 110-foot shortleaf pine, two co-dominant scarlet oaks 14 and 16 inches in diameter and 90 feet tall, and a dominant 26-inch white oak, 105 feet in height. Both of the oaks are 37 feet from the pine. This neighborhood was initiated around 1872 (Figure 19). From

Table 9. Average live crown percentages in all study neighborhoods, dominant and co- dominant crown positions for the shortleaf pine development research on the Oak Ridge and Chuck Swan study locations, Tennessee.

Species	Live Crown Percentage
Shortleaf pine	34
Virginia pine	28
Red oak species	48
White oak species	53
Mockernut Hickory	45
Yellow poplar	40
Red Maple	57

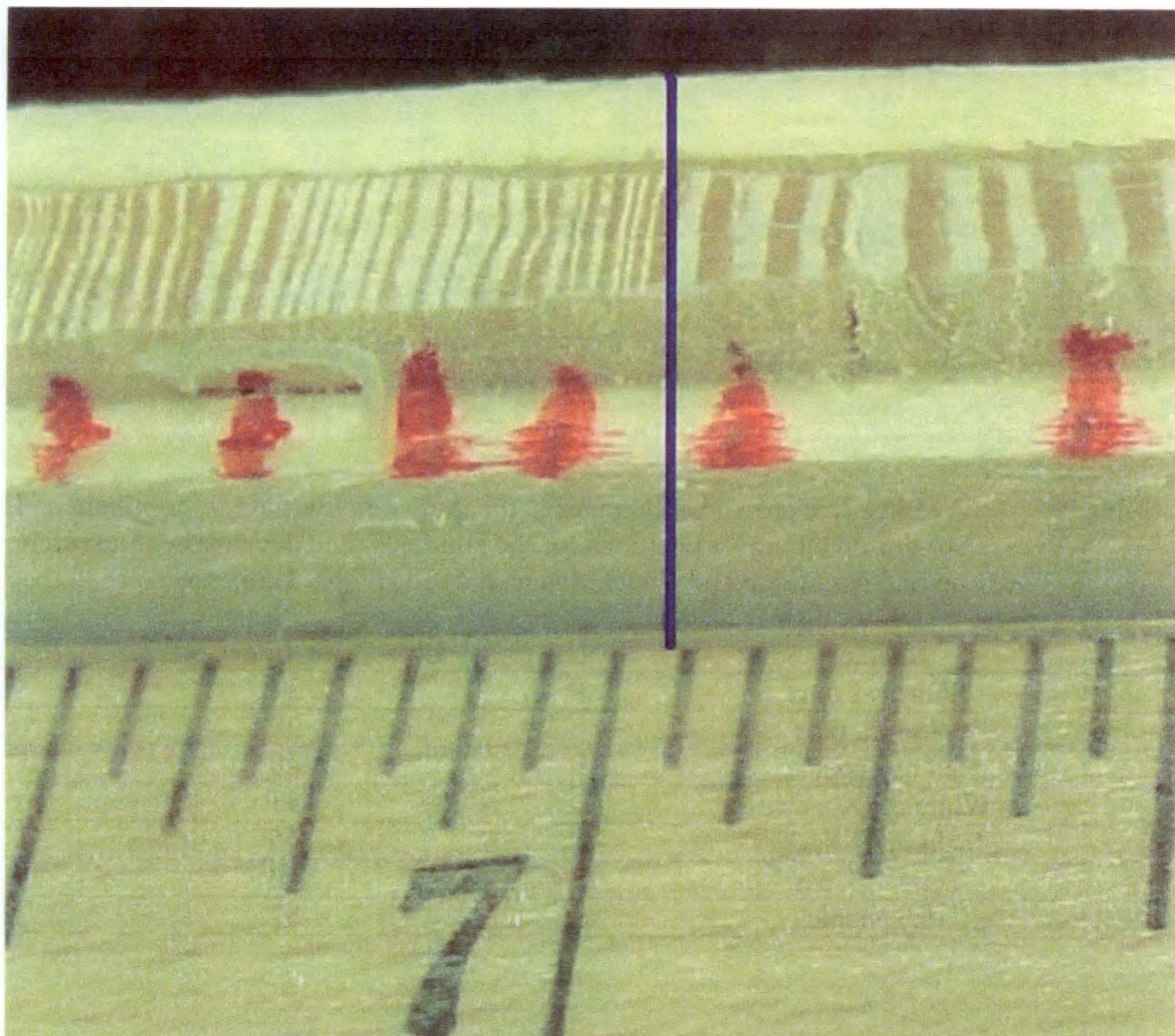


Figure 19. Diameter growth reaction to release for shortleaf pine; growing from left to right. Blue line indicates a harvest or disturbance event that created growing space. Sample from the shortleaf pine development research at the Chuck Swan study location, Tennessee.

diameter growth patterns, the trees seemed to respond to a release around the turn of the century (Figure 19) implying that the surrounding competition had been removed in a harvest event, or other disturbance, allowing these shade-intolerant species to move into upper positions in the canopy.

These harvests and disturbance events would have promoted regenerative conditions for shortleaf pine; exposed mineral soils and abundant light to the forest floor. As the process of burning the land to promote herbaceous vegetation for cattle grazing continued (Crocker 1987), conditions improved for the regeneration of shortleaf pine. Burning would have also controlled competing vegetation such as mockernut hickory and other fire intolerant hardwoods. Weak physical evidence, in the form of fire scars on increment cores, supports the anecdotal evidence of wildfires in 1931 and 1951. The fires of 1953 were noted to have run across the ridgetops of the Chuck Swan site unchecked according to Division of Forestry personnel⁵.

The Great Depression, the arrival of TVA, and need for raw building materials to support the United States military effort in World War II had created conditions to increase shortleaf pine resources. Figure 8 depicts the increase in shortleaf pine initiation in the 1930-40's as land was cleared by subsistence farmers. However, as land ownership shifted from private to federal hands over the next decade, and management shifted from utilitarian to preservation objectives, shortleaf regeneration declined. These shifts promoted mixed hardwood forests, allowing shade tolerant hardwoods to move upward into canopy positions and dominating more growing space hindering pine regeneration. Those neighborhoods that were created just prior to the federal government

⁵ Chuck Swan Manager, Darren Bailey supplied this information in May 2003.

moving into the Ridge and Valley define the younger pine cohort, Cohort B. Examining the aerial photography series at both Chuck Swan and Oak Ridge, a progression toward canopy closure can be seen. Early images indicated a savannah-type forest and as time progressed, these protected abandoned lands succeeded into closed canopy mixed hardwood forests with only pockets of pine resources.

The dominant canopy species of the Age Class B cohort are shortleaf pine and white and red oaks. A noticeable difference in these neighborhoods compared to the Age Class A cohort is the greater presence of mockernut hickory in the co-dominant canopy position as well as in the same age class. Conditions were apparently suitable for shortleaf pine regeneration yet with a lack of a consistent fire regime, mockernut hickory developed along with the pine resource.

Neighborhood MZ, a southern aspect bench plot at the Oak Ridge site, is a typical example of this younger cohort. It was initiated in 1935 and was composed of a dominant shortleaf pine and co-dominant scarlet and chestnut oaks and a mockernut hickory. All neighborhood trees are within the 14 inch diameter class and the hardwoods were graded as a 3 or worse. The live crown ratios of the hardwoods were around 50 percent, while the live crown percentage of pine was 32 percent. All of the neighborhood trees regenerated within three years of each other. This even-aged regeneration was a common factor within the Age Class B cohort, a possible result of the lack of disturbance events since the late 1940's. The idea of consistent, "enduring", growth defines this cohort. Even with a much smaller live crown, the shortleaf pines were able to develop diameters and heights equal to or greater than the adjacent hardwood species.

Southern pine beetle epidemics in 1953, 1976, and 1998 impacted the population of shortleaf pine in the Ridge and Valley. These outbreaks are cyclical in nature (Price et. al 1992), and both shortleaf pine cohorts were affected. By killing over-mature, or poorly growing individuals and eliminating over-stocked or stagnant stands, the shortleaf resource found itself as a remnant of its previous population. Beetle outbreaks aided in the succession of the Ridge and Valley to a mixed hardwood-pine landscape. As this mixed forest grew and incorporated the shortleaf pine remnant, individual shortleaf pine trees were sheltered from future southern pine beetle outbreaks.

SECTION 5

Questions of Regeneration and Future of the Species

The oldest shortleaf pine cohort appears to regenerate and develop the younger cohort, and yet for a variety of reasons the youngest cohort has not been able to establish the dominance of the species on the landscape as found in previous generations. That raises an interesting question: What is the future of the shortleaf pine component? The pessimist would argue that the species is destined to disappear; the optimist would have to admit that without extensive assistance the pessimist would be correct. This section will examine the question of why the younger cohort, Age Class B, has not been successful in regenerating shortleaf pine and what can be done to encourage its regeneration.

Regeneration Outcomes

The chances of a successful shortleaf pine regeneration event is improved when mineral soil is exposed by burning coupled with a good seed production year (Baker 1991, Boggs & Wittwer 1993, Lawson 1986). With the knowledge of past harvesting techniques and the known practice of burning lands to prepare them for agricultural and pasture usage, this research proposes that excellent conditions were in place for the establishment of Age Class A which in turn established Age Class B.

Shortleaf pine has shown a propensity towards growing at a consistent rate; yet compared to other southern pine it is considered a slow growing species (Kitchens 1986, Murphy 1986). With an average live crown percentage of 34, visual inspection of the

study trees would indicate that there is an expected decline in vigor. This lack of vigor could play a significant factor in lack of regeneration. Most of the tree's vitality is in maintaining the continued existence of the tree in the stand and not seed production (Oliver & Larson 1990, Bramlett 1965, Bramlett et.al 1977).

An indicator that vigor corresponds with regeneration is the lack of productive viable seed in cones of the felled trees. Vigorous, large crowned trees produce the most seed. Where light, nutrients, moisture, and space are optimum, seed yield increases (Wittwer & Shelton 1991). The crowns in this study contained very few cones with most of them empty of seeds or desiccated. The cause might be a component of timing. Decades of poor to no seed production across the range of shortleaf pine have been reported (Haney 1962, Stephenson 1963, Bramlett 1972, Ferguson 1975, Shelton & Wittwer 1992). The species tends to go through cycles of poor seed production to higher levels. Conditions have evolved to the point that the shortleaf pine resource under current management conditions that suppress fire in the Ridge and Valley does not develop adequate seed to continue its replacement. Increased age of the resource and a possible lack of reproductive vigor may also be factors in the lack of shortleaf pine seed production.

The last major wildfire in the area occurred in 1951⁶. This event would have initiated reproduction in the region and study areas if viable seed were available. Large public forest ownerships, such as TVA and ORNL, knew the dangers that fire could bring

⁶ According to Darren Bailey, Chuck Swan Wildlife Management Area Forester, in discussions relating to the site history.

to their properties and fire control efforts were emphasized. Very few new seedlings were initiated as a result of this event.

Fires had effects on the structure and composition of neighborhoods in the study area. The crowns of shortleaf pine, in comparison to the neighboring competition, were relatively small indicating low vigor. The lower the vigor the less likely that seed and cone production will be emphasized. Research has shown that seed production increases when trees are released (Wittwer et al. 1996). In stands where stocking levels exceed 90 square feet of basal area per acre, seed production significantly declines (Guldin et al. 1991). Many of the stands in the region would have exceeded this limit, being overstocked. A similar situation is currently being experienced with overstocked or over-mature stands in regards to the latest southern pine beetle outbreak.

The southern pine beetle and the suppression of fire were “natural” reasons why shortleaf pine has declined in the Ridge and Valley. Another factor is the introduction of loblolly pine to Tennessee. The intensive harvesting and fires of the region between 1880 and 1930 assisted in producing regeneration events. However, by the late 1950’s, plantation forestry had exploded in the southeast with nearly 15 million acres in loblolly pine plantations. Loblolly pine, a species that had been relegated to the south of Tennessee, was adopted by forest industries as they moved into the southeast (Branen & Porterfield 1971). The species grows at a much faster rate than the native species of Tennessee, on a wider variety of sites, and can be managed for multiple markets. This adaptive feature, coupled with the genetic improvement programs that allowed for the northern extension beyond its native habitat, has made loblolly pine the “king pine of the south” (Branen & Porterfield 1971).

As landowners became aware of the economic potential from the planting and managing of loblolly pine, plantations were established on abandoned farm lands, marginal hardwood sites, and cutover sites. With federal government cost share opportunities and the power of the dollar influencing landowner's decisions, lands that were historically shortleaf pine sites quickly were overtaken and converted to loblolly pine plantations. Loblolly became the preferred species because of its vigorous growth, producing 1.6 to 6.3 m³/ha/yr of cellulose more than shortleaf pine (Williston 1958, 1967, 1972). On low-quality ridge sites, 10 year old loblolly pine was 2.1 meters taller and 2.5 cm larger in diameter than shortleaf pine (Loftus 1974).

Loblolly pine appears to be the much more commercially acceptable species when compared to shortleaf pine. The literature suggests otherwise if the management objectives are set on longer rotations (Strub 1991). On especially drier sites, shortleaf pine stands can generally carry more stems and more basal area per acre than loblolly stands (Williston 1972). When shortleaf stands reach age 20, their height and diameter growth is similar to loblolly pine (Branen & Porterfield 1971). When stand rotations exceed 50 years for dry or infertile sites such as ridges and benches, shortleaf pine should be considered as an alternative to loblolly pine based on volume production (Williston and Dell 1974). However, for greater volume and growth rates in a shorter rotation, loblolly pine is favored because of the time value of investments.

Re-establishing the shortleaf resource

A plethora of research projects have examined both natural and artificial regeneration techniques (Burton 1964, Baker 1991, Wittwer et al. 2003, Boggs &

Wittwer 1993, Shelton & Wittwer 1996, Guldin & Heath 2001). A summary of these formed three basic fundamental observations:

1. Shortleaf pine is a native species to this region and will grow well,
2. If natural regeneration is the chosen process, substantial seed production must be available, coupled with a disturbance regime; something not common in the region, and
3. Competition must be controlled early for all regenerative methods.

Along with these three fundamentals is that the current generation of landowners have favored loblolly pine plantations more than any other pine regeneration technique. Also, on the marginal sites, many landowners have settled for the production of poor quality hardwoods.

Burton's (1964) work focused on emphasizing that shortleaf pine grows well on the poorer sites in the area compared to other native species. Plantations were established in the Norris watershed in 1943 and compared 20 years later. The soils in the study were low in nutrients, had potential problems of soil erosion, and were comprised from dolomite and limestone with very little depth to bedrock. The plantation comparisons examined several species including shortleaf pine, several white and red oak species, and yellow-poplar. Survival of shortleaf pine over the 20 years exceeded 70 percent. Yellow-poplar survival percentages were 50 percent. Oak survival rates over the 20 year period were below 10 percent. Of the species investigated, shortleaf pine diameter and volume production was the greatest. Volume production of shortleaf pine was 11.5 cords per acre, nearly doubling yellow-poplar. This study is similar to the findings of Graney

(1991) and Guldin (1986) that state that on the poorest sites, shortleaf pine will perform the best.

Natural Regeneration Methodology

Natural regeneration ensures that a local seed source will be returned to the site. A key to using natural regeneration effectively is having an abundant seed source. A majority of the shortleaf pine individuals in the Ridge and Valley region are over-mature and thus potentially poor seed producers. Those that are vigorous enough to produce seed are too often solitary individuals in otherwise hardwood stands. Thus natural regeneration in the area may not be feasible.

Environmental factors also contribute to poor seed production. Studies have shown that below freezing temperatures during flower development (Campbell 1955), insect and wildlife damage (Yearian & Warren 1964, Ebel & Yates 1974, Trousdell 1954), and precipitation levels and timing (Lawson 1986) all influence seed production negatively and can not be controlled by land managers.

Shelton and Wittwer (1996) noted that seeds occurring both before (in-place seed) and after (seeds from residual stand) the regeneration cut must be considered when evaluating regeneration potential. The opportunity to secure natural shortleaf pine regeneration generally lasts for three years after site preparation, and possibly longer on poorer sites (Shelton & Wittwer 1992). Tree tops are another potential contributor to natural regeneration. When regeneration cuts were applied early in the fall, shortleaf pine cones from tops left on site were able to disperse up to 93 percent of their viable seed in time to germinate the following spring (Shelton & Cain 2001). In addition to leaving the

tops of shortleaf pines on site following harvest to improve regeneration, Shelton and Cain (2001) also suggested that these tops be scattered evenly across the site. The movement of the tops allows for cone dispersal, soil scarification, and enhances abilities to disperse seedlings across the site instead of focusing the reproduction all in one area around the top (Grano 1949, Shelton & Murphy 1999). With shortleaf stocking levels being low, especially as remnants in mixed hardwood stands, these cutting methods would not be successful or practical in the Ridge and Valley as compared to stands that are fully-stocked with shortleaf pine. Clearcutting is probably the best regeneration technique followed by intensive site preparation and artificial planting (Mann 1973, Barnett et. al 1986).

Seedbed conditions are vital for shortleaf germination. A scarified, exposed mineral seedbed has proven to be the best condition to promote natural regeneration (Cain 1987). A negative exponential relationship between litter depth and seedling establishment exists (Grano 1949). This relationship becomes even more magnified when the litter layer is comprised of hardwood litter, with nearly 5 times fewer pine seedlings becoming established in hardwood litter levels compared to pine litter levels (Clark 1948, Grano 1949). The importance of seedbed conditions and the impact of competition on hindering early shortleaf pine seedling growth suggests that a pro-active management scheme must be implemented.

The most efficient and effective technique to prepare the seedbeds for seed germination and reduce competition is the use and return of burning. Ideally, a preparatory burn would be initiated at least 6 years before the regeneration cut (Crow & Shilling 1980). Considering the hardwood composition of the mixed hardwood stands,

such burns may need to be initiated much closer to the harvesting date and with a much lower intensity so the harvestable hardwood timber is not damaged. The intensity of post-harvest fires directly impacts the amount of seed needed for proper stand stocking. An investigation by Boggs and Wittwer (1993) in the Ouachita Mountains focused on this relationship. Site preparation fires were ignited at various intensities and the site was direct-seeded to mimic natural seed fall. To reach a stocking level of 1000 seedlings/acre after one year, nearly 2 pounds of seed would have to be applied per acre on an unburned seedbed while 0.55 pounds of seed, substantially less seed, would be required to reach that same stocking level on sites prepared by a hot burn. A single pound of seed roughly equals 46,000 individual seeds (Krugman & Jenkins 1974).

Mechanical operations on sites after seed-fall should be discouraged as seeds may be buried in the resulting debris. However, properly timed and appropriate intense operations will aid in scarification of soil before seedfall and promote germination. A mechanical operation to increase seed production is gap thinning (Yocum 1971).

Shortleaf pine seed-trees, 8 to 12 inches in diameter, were identified and all competing trees within a 30 foot radius were removed by either cutting or herbicide application. The release approximately doubled cone production and caused a small, but significant increase in the number of seeds per cone (Yocum 1971). The increased cone and seed production is attributed to the removal of competing hardwoods and increased soil moisture availability (Phares & Rodgers 1962). A more recent replication of this study where gaps ranging from 0.1 to 1.0 acres were constructed discovered 53,000 sound seeds per acre were distributed within the gap (Wittwer et al. 2003). These operations have been conducted along the ridges of the Ouachita Mountains of Missouri and

Arkansas where the shortleaf pine resource is in greater abundance compared to the Ridge and Valley. However, such gap producing mechanisms would assist seedling establishment in the Ridge and Valley if used with an intensive competition control regime, such as herbicide application. Considering the amount of younger seed-trees present on the study plots as well as the competing hardwood cohorts in the neighborhoods, a gap removal would create substantial growing space and allow ample sunlight to the forest floor. This practice would also retain the mixed hardwood-pine component many landowners have accepted in this area.

Artificial Regeneration Methodology

Artificial regeneration refers to the addition of growing stock to the land through the planting of seedlings or the direct seeding method. Genetic tree improvement programs for shortleaf pine began in 1959 in southern Arkansas and northern Louisiana. Tennessee's program started in 1967 at sites managed by the Division of Forestry at Pickett State Forest and by TVA near Norris (USDA-FS 1982). These programs have made great gains in improving the tree's productivity, but not nearly as great as the improvements made in loblolly pine. Much of the research to develop genetic improvements of loblolly pine originated from timber industries and began many years prior to genetic programs for shortleaf pine. Genetically improved shortleaf pine seedlings have higher rates of survival compared to natural seedlings. Volume gains are estimated to be between 10 and 15 percent (Kitchens 1986). Volume improvements lead to shorter rotations which translate into much higher economic gains. Financial gains of nearly 25 percent are estimated, and on some acres where growing timber might be a

financial loss, especially in degraded stands, artificially regenerated shortleaf pine stands have turned a loss into a gain (Kitchens 1986). An often overlooked aspect in genetic improvement is stem straightness. Since straightness has a high heritability, phenotypic selection for straightness has continued this improvement (McConnell 1983). With its straight form and lack of taper compared to loblolly pine, rotations of shortleaf pine targeted for sawtimber produces a superior harvestable product compared to other pine species (Kitchens 1986).

The reproduction technique used most often for establishing artificial regeneration is clearcutting followed by site preparation and planting. This method has proven effective in reforesting sites with most species of pine. A combination of chemical application and burning, or “brown and burn” techniques, has successfully prepared the planting beds and reduced competition (Stewart 1978). Clearcutting provides an accessible means of reforestation following a harvest, allows sites to be planted, allows operations to be concentrated in time and space, and ensures that few large competing trees are left on the site. However, there are several drawbacks including the lack of merchantable materials for a relatively long period of time, the need for competition control due to emergence of aggressive herbaceous vegetation and stump/root sprouting woody vegetation, and a less aesthetically desirable condition. The current social climate in Tennessee leans against the idea of clearcuts and forest conversions. In order to avoid some of the social stigma, and possibly to meet several landowner objectives in one technique, the idea of underplanting shortleaf pine has been explored (Guldin and Heath 2001).

Underplanting shortleaf pine consists of planting seedlings within a partially harvested stand. The process addresses multiple goals: provides income to the landowner through the partial harvest of what pines are available as well as selected hardwoods, maintains an aesthetically acceptable forested landscape, and maintains both hardwoods and pines on the landscape.

An unreplicated case study was conducted in the Ouachita Mountains exploring the idea of planting pines under an overstory of oaks and hickories (Guldin & Heath 2001). Shortleaf pines were removed from the stand and five overstory hardwood retention rates were applied; 0, 10, 20, 30, and 40 square feet of basal area. As expected, considering the shade intolerance of shortleaf pine, the seedlings did best where the entire overstory was removed. Diameter and height of seedlings declined as basal area retention rates increased. However, seedling plantings in all treatments or overstory retention rates were considered successful after seven years. Guldin and Heath's (2001) evidence revealed that even under the 40 square feet application, suppression to the point of mortality did not occur. Height development and quadratic root collar diameter for the treatments varied but their slopes were relatively similar across treatments with the most growth occurring on the sites with the least amount of retention. Thus, underplanting shortleaf pine might be a desirable alternative.

Landowners have three management options that would maintain, or increase, shortleaf pine number and volume within the Ridge and Valley. The establishment of plantations appears to be the most advantageous to landowners whose objectives are solely pine related. The plantations have the highest economic costs, expressed in high capital outlays and long rotation periods, but they also ensure the greatest chances of

success. Shortleaf pine develops slower than loblolly pine over the first ten years but after age 50 shortleaf growth rates exceed that of its loblolly pine. When rotations are expected to be in excess of 50 years and early revenues from thinnings are not vital, shortleaf pine is the species of choice (Strub 1991). Site preparation costs are higher with plantations, but a key to lowering the costs is in establishing plantations on marginal sites. Since shortleaf pine does much better than its competition on poor sites, site preparation costs decrease as site quality decreases (Baker 1991).

Where landowner objectives are more diverse, for example, in the management of mixed-species stands for wildlife or aesthetics, then the gap process or the retention program would be suitable. Both require higher skill levels with regards to harvesting to minimize residual stand damage and securing natural regeneration from seed. If natural regeneration is not effective, the supplemental planting of seedlings may be required to maintain shortleaf pine in the stand. These two techniques allow the landowner to manage the pine component over a long period of time, promoting it to the dominant canopy as other overstory or surrounding competition is removed or controlled. This process also allows the landowner to select the best quality hardwood to grow and increase in value on the site. A final advantage to these two techniques is once there is a substantial pine seed source established, the rate of pine regeneration under a hardwood midstory and understory canopy occurs in a shorter period of time after hardwood control than a similar forest that is occupied by established herbaceous vegetation (Cain 1991). Seedfall within the gap and retention programs would be more likely to establish regeneration quicker following a release compared to seedfall into a clearing dominated by briars, grasses, and vines.

Given the inherent nature of shortleaf pine to be managed on long rotations and the risk associated with carrying growing stock for 60 to 80 years, landowners would have to be convinced to plant or promote the regeneration of the species by some financial incentive. The costs associated to ensure regeneration success on small acreages may make the idea unfeasible. The availability and adaptability of loblolly pine seedlings will continue to promote this species as the favored commercial product in the region unless an incentive program is created and quickly adopted for shortleaf pine.

Conclusion

Shortleaf pine is in peril in the Ridge and Valley as well as other areas of Tennessee. The species is in danger of being abated as conditions for natural regeneration decline, landowner preferences lean to pine in shorter rotations or hardwood sawtimber, and artificial regeneration of loblolly pine is favored over shortleaf pine.

The shortleaf pine ecosystem has changed over the last century. Disturbances were once frequent occurrences. Frequent fires moving across the landscape, low-intensity harvests to provide resources from fuel to lumber, cattle grazing amongst the trees, and southern pine beetle outbreaks all were influential in creating the ideal conditions for shortleaf pine to flourish and thrive. Now with the infrequent use of fire, conditions for regeneration and perpetuation of the shortleaf pine resource are fading.

This study assessed the present condition of the shortleaf pine resource and reconstructed the development patterns through the use of chronosequences at two sites in the Ridge and Valley. While disturbances were varied and frequent in the past, the current public ownership of the sites has limited disturbances and hindered the species' continuation. Two shortleaf pine cohorts exist in the Ridge and Valley; the younger being the offspring of the older cohort and coming into existence during the 1930's and 1940's. Conditions have evolved so that progeny from this younger cohort has not successfully survived. However, the development of both cohorts displayed "space enduring" qualities. The average diameter growth per decade was nearly an inch, independent of weather conditions and competition. While live crown percentages were smaller than the competing hardwoods, shortleaf pine maintained itself on the landscape, often developing diameters and heights similar to that of the hardwood competition.

Aerial photography, historical documentation, interviews with resource managers and historians, and the data collected from field studies were all compiled and evaluated. The present state of the shortleaf pine resource in the Ridge and Valley indicates that the species is not regenerating, is overmature in most areas, and can only be found as remnant individuals and groups. Management practices are suggested to perpetuate the resource. If these practices are not implemented, the remnants will continue to succumb and the shortleaf pine resource will diminish.

This study was conducted on lands that have been under public management for nearly 80 years. The protection and management that has been applied to these lands may be different than the lands under private management. However, our observations are that the shortleaf pine resource may be in further peril on privately managed sites as fewer remnant groups and individuals exist on privately managed lands.

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VITA

Patrick Daniel Cassidy was born in Bluefield, W.Va. on September 3, 1974 to Patrick and Karen Cassidy. Graduating from Austin High School in Decatur, AL in 1992, he went on to attend Mississippi State University in Starkville, MS and was awarded a B.S. in forestry with a concentration in environmental sciences in 1998. While at MSU, Daniel worked as a co-operative education student with Champion International in Courtland and Russellville, AL serving as a private landowner assistance forester.

From there he went to the University of Tennessee-Knoxville and completed a M.S. in forestry under the guidance of Dr. David Ostermeier in the spring of 2001. His research focused on the utilization of internet technologies in arena of landowner and extension agent education. During his studies with Dr. Ostermeier, Daniel became interested in the field of extension work and partnered with Dr. Wayne Clatterbuck to complete this dissertation which is the culmination of his Ph.D. in natural resources. Under Dr. Clatterbuck's leadership, Daniel has constructed the Southern Pine Beetle website and conducted various landowner education meetings and resource training programs.

Married to Laura Bollinger from West Memphis, AR, Daniel enjoys spending time golfing, hiking, and entertaining his two year old son Michael Isaac. He desires to continue his work in forestry focusing in the field of extension; hoping to one day serve as a university extension specialist or professor.

Handwritten text, mostly illegible due to extreme fading. The text appears to be organized into several paragraphs, with some lines starting with capital letters or numbers. The handwriting is cursive and somewhat slanted.

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