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Remnant longleaf pine (*Pinus palustris* Mill.) showing scars caused by the turpentine industry are scattered throughout remaining stands of old-growth longleaf in North Carolina. This thesis uses radial growth and morphological characteristics to examine the long-term effects of turpentining on the growth of longleaf pine trees in North Carolina. In addition, this thesis examines the potential role these culturally modified trees have in increasing our understanding and appreciation for the longleaf savanna landscape. The objectives of this thesis are to: 1) discuss the historical and cultural significance of turpentined longleaf pine trees in North Carolina; 2) examine the long-term effects of turpentining on living longleaf pine trees in North Carolina; and, 3) to examine the effects of climate on the radial growth of turpentined trees over time.

# THE ECOLOGICAL LEGACY OF THE NAVAL STORES INDUSTRY

# IN NORTH CAROLINA

by

Lindsay W. Cummings

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Approved by

Dr. Paul Knapp
Committee Chair

APPROVAL PAGE

This thesis written by LINDSAY W. CUMMINGS has been approved by the following committee of the Faculty of The Graduate School at The University of North Carolina at Greensboro.

| | |
|---|---|
| Committee Chair | Dr. Paul A. Knapp |
| Committee Members | Dr. Dan Royall |
| | Dr. Selima Sultana |

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# CHAPTER I

# INTRODUCTION

Anthropogenic factors are the principal and likely only cause for the disappearance of the longleaf pine (*Pinus palustris* Mill.) savanna that was once the dominant ecosystem in the southeastern United States (Ashe, 1894; Silver, 1990; Outcalt, 2000; Davis, 2006; Joseet al., 2006; Noss, 2013). In the last 300 years, longleaf pine savannas have lost more than 95% of their habitat (Jose et al., 2006). One of the anthropogenic factors contributing to this decline was the collection of pine oleoresin. Used in wooden ship building and maintenance, the products refined from the oleoresin, collectively referred to as “naval stores”, were extracted from the longleaf pine savanna for more than 300 years. The manner in which longleaf pines were tapped for their oleoresin stands out as a distinctive practice of the Southern U.S. The naval stores industry, practices, and culture are closely intertwined with the early history of the Southern U.S. and specifically with North Carolina (Ashe, 1894; Wahlenberg, 1946; Butler, 1998; Outland, 2004).

Longleaf pine has the ability to withstand extensive disturbance (Wahlenberg, 1946). The tree’s resinous nature coupled with its ubiquity in the landscape made the longleaf pine an ideal tree for the naval stores industry. Tapping longleaf pines, a process referred to here as turpentining, was a destructive process; but, with the right care, a turpentine orchard could be worked for scores of decades (Wahlenberg, 1946; Bartram, 1996; Outland, 2004). During colonial times North Carolina was the world-leading producer of naval-stores products (Outland, 2004). It was not until the development of steam engines, steal, and railroads before the pine savannas of North Carolina would finally succumb to the turpentiners and lumbermen.

During the latter half of the $19^{th}$ century, turpentiners and cut-and-run lumbermen vied for virgin stands of longleaf creating a situation in which trees were turpentined for as little as five years before being abandoned (Ashe, 1894; Robinson, 1997; Early, 2004). After the Civil War, narrow-gauge railroads opened vast stands of longleaf, which were too far from waterways to be economically exploited during colonial times (Early, 2004; Chesson, 2012). New chemical products derived from turpentine, in addition to new uses for another byproduct of oleoresin, rosin, led to an increase in the demand and supply of longleaf pine turpentine. Eventually, the paper industry developed techniques to extract turpentine from the wood pulp used in the paper making process, making the turpentining of living pine trees obsolete (Butler, 1998).

Living longleaf pine trees with turpentine scars remain in North Carolina. These culturally modified trees record ecological events such as droughts and fires; and, as living testaments to past anthropogenic influences on the landscape, they possess historical and cultural significance. Remnant trees stand, either alone or in scattered old-growth stands, surrounded now by deciduous forests or its quicker growing sibling, the loblolly pine (*Pinus taeda*) (Jose *et al.*, 2006). The “cat faced” turpentined trees, scarred by the hacks and box cuts that signal their history, provide a tangible, living link to the state’s cultural past, enhance the aesthetic and cultural importance of their respective landscapes, and raise awareness to the connections between the longleaf ecosystem, land use, and the people and heritage of North Carolina.

My goal with this research is to highlight the ecological legacy of the turpentine industry on relic longleaf pine trees, to show turpentine longleaf pine trees should be regarded as part of our cultural heritage and to explain how these culturally modified trees can enhance our understanding of the role of humans as an integral part of the future of longleaf pine savannas in North Carolina. The techniques and tools developed in dendrochronology, or tree-ring dating, offer a scientific method of dating based on the analysis of tree-rings. The non-invasive procedures used in collecting data and the quality of the data gained from the tree-ring record, allow for meaningful analysis of the ecological legacy of turpentining on living longleaf pine. Through the examination of living trees, I have combined dendrochronology and historical research to explore a cultural and ecological legacy of the Tar Heel state.

# CHAPTER II

# BACKGROUND

## 2.1 Geographic Distribution

Upon the arrival of Europeans to North America at the end of the 15$^{th}$ century, the longleaf pine savanna accounted for up to 60% of the coastal plain landscape from southeastern Virginia to eastern Texas (Ware, 1993; Walker & Oswald, 2000; Varner & Kush, 2004; Frost 2006; Figure 3). Pure stands of longleaf pine occupied 24 million ha of the coastal Southeast (Stout, 1993). Further inland, longleaf pine stood co-dominant with loblolly pine, shortleaf pine (*Pinus echinata*), and numerous hardwood species on an additional 14 million ha (Frost, 1993). Acting as a keystone species in the landscape, the longleaf pine habitat created a matrix of savanna, within which other vegetation types and habitats were embedded (Noss, 2013). The ecotones located between the savanna and these embedded habitats created some of the most biologically diverse landscapes in North America (Walker & Peet, 1984; Peet, 2006). The removal of longleaf from the landscape and the conversion of savanna and other imbedded landscapes for human use make the longleaf savanna one the most endangered habitats on Earth (Noss *et al.*, 1995; Varner & Kush, 2004).

Growing in wet flat-woods and savannas, along sand-hill ridges, and on some Piedmont and upland slopes, stands of longleaf pine once spanned a 3200 km swath of the southeast, covering most of the Atlantic and Gulf coastal plain and reaching inland about 320 km (Outcalt, 2000; Figure 3). In Alabama and northwest Georgia along the southernmost extent of the Appalachian Mountains, longleaf stands can still be found on slopes and ridges up to 600 meters above sea level (Outcalt, 2000; Peet, 2006).

The longleaf pines studied in this thesis were found in a variety of edaphic conditions ranging from the extremely xeric, deep sands of the Carolina Bays, to the silty, loamy mix of the Sandhills region's ancient sand dunes, to the more silty upland Piedmont soils of the Uwharrie Mountains. Although only a small sample of the entire range of the species, these field sites illustrate the adaptability of longleaf pine to succeed across a wide swath of Southeastern landscape (Noss, 2013).

The range of longleaf pine has been greatly reduced since the arrival of the Europeans, but the most severe losses happened after the Civil War in the late $19^{th}$ century when steam locomotives opened up vast tracts of virgin longleaf (Early, 2004; Outland, 2004). Anthropogenic processes, including turpentining, logging, species conversion, animal grazing, and fire suppression, have reduced longleaf ecosystems to approximately 776,000 ha (Way, 2011). Longleaf pine currently occupies less than 3% of its historic range (Jose, 2006).

Habitat fragmentation due to road building and continued rural development poses continuing threats to the health and viability of the longleaf savanna ecosystem (Duncan & Schmalzer, 2004). In 2000, less than 1% of the original acreage was being managed sufficiently to ensure perpetuation (Jose, 2006). Only a dozen known old-growth tracts have been documented (Davis, 2006), making the longleaf ecosystem one of the most threatened in North America (Noss *et al.*, 1995). While longleaf stands can still be found across the historic range, those that remain are a small and spatially biased samples of a once extensive and diverse biome (Varner & Kush, 2004; Frost, 2006).

Evidence of extensive turpentine operations can be found in old growth stands across North Carolina although they are concentrated in the western part of the longleaf pine's range in Cumberland, Montgomery, and Moore Counties. Because of these counties' geographic isolation during the 19th century, far from rail or waterway, these remaining longleaf stands were the last to be exploited. By the time the land became accessible to turpentiners, the center of the naval stores industry was quickly moving south into Georgia and Florida and would be all but gone by the early 1900s (Ashe, 1894; Butler, 1998; Outland, 2004).

## 2.2 Fire Dependence, Disturbance, and Community Compositions

Longleaf pine savannas are fire shaped and fire maintained (Outcalt, 2000; Frost, 2006; Noss, 2013). Prior to landscape fragmentation and fire suppression, fire occurred on a 1–8 year cycle across the species' range and was the dominant factor shaping the landscape (Christensen, 1981; Abrahamson, 1990; Ware, 1993; Davis, 2006; Frost, 2006). Longleaf pine has evolved numerous fire-promoting strategies and has one of the shortest fire-return intervals of ecosystems globally (Christensen, 1981; Frost, 2006).

Longleaf pine evolved with fire; seeds require bare, mineral-rich soil exposed by low-intensity ground fires in order to germinate. After germination, the longleaf pine enters a grass-like phase in which the pine seedling remain from 2–20 or more years (Early, 2004; Frost, 2006; Jose, 2006). While in the grass stage, long needles, ranging from 20–45 cm, protect the terminal meristem from the heat of ground fires and allow the tree to survive repeated burnings during which other pine species are readily consumed (Walker & Oswald, 2000; Early, 2004; Frost, 2006). During this time, a long taproot is developed to ensure seedling survival in the sandy, often droughty soils (Walker & Oswald, 2000).

The taproot, which can reach the size of the trunk, extends for up to 3 meters below ground, not only allowing the tree to reach further into the water table, but also protecting it from being uprooted during the frequent tropical storms and hurricanes common to the Coastal Plain. Roots can penetrate water sources nearing 10 meters below ground, making the longleaf more resistant to extreme climactic conditions than other southern pines (Wahlenberg, 1946; Provencher, 2001).

In addition to the grass stage, multiple other morphological characteristics highlight the species' fire adaption. Sloughing bark at the tree's base protects the inner cambium, while a constant shedding of needles quickly builds a resinous fuel bed that encourages fire (Hare, 1965; Mitchell, 2006). Self-pruning of lower branches serves to keep ground fires from spreading to the tree's crown (Schwilk & Ackerly, 2001). The oleoresin produced by longleaf pine contains many highly flammable terpene oils (Outland, 2004; Jose, 2006). Post-mortality, highly flammable heartwood saturated with oleoresin may resist decay for decades, which adds another fuel source for lightning-ignited fires (Outcalt, 2000). Frequent fire and wind disturbances help maintain an open canopy and reduce the growth and encroachment of bottomland hardwoods such as oak, maple, hickory, and other species (Peet & Allard, 1993; Stout & Marion, 1993; Ford *et* *al.*, 2010). Concurrent with the evolution of the longleaf pine, a wide variety of plants and animals adapted to and thrived with frequent, low-intensity fire (Hardin, 1989; Figure 1).

Figure 1. Pre and post burn comparison of the Salters Lake field site. These photographs were taken nine months apart. Notice the difference in growth between the burned left portion of the photographs and the unburned right portions of the photographs. Such fires promote the open habitat required by certain rare plants and animals.

The field sites for this thesis can be described as longleaf-wiregrass ecosystems. While Nichols Tract does not currently fit the description of a longleaf-wiregrass ecosystem, there is evidence that, prior to fire suppression, it resembled a savanna landscape (Allen, 2012). The longleaf-wiregrass variant of the longleaf ecosystem is one of several sub-classifications outlined by Peet (2006).

Based on soil texture and moisture, Peet's (2006) classifications take into account the percentage of silt in the A horizon of the soil profile. Hydric to mesic ultisols support savannas. Mesic to sub-xeric ultisols form the silty uplands. Hydric to mesic spodosols create flatwoods. Sub-xeric entisols create sandy uplands. Super-xeric entisols create sand barrens. This classification breaks down on clayey Piedmont soils near the longleaf's western range limit. Despite the poor soil and frequent dry periods, pine savannas provided productive grazing grounds for large mammals such as bison, deer, and, more recently, cattle (Halls, 1957; Silver, 1990; Early, 2004).

Because edaphic conditions, particularly soil moisture, have a large impact on the growth habits of longleaf, it is important to understand and be cognizant of the local geography of the field sites. Mesic and xeric soils often exist adjacent to each other but separated by a matter of centimeters in elevation. The classification system based on silt content weakens inland from the coastal plain. Dependence on soil-moisture decreases and is superseded by percentage of clay and incident solar radiation (Peet, 2006).

The longleaf savanna is one of the most biologically rich ecosystems in North America (Peet, 2006). Most of the 6,000 vascular plant taxa found in longleaf pine landscapes are found on either the coastal plain or Sandhills region; the Piedmont and montane landscapes are also diverse, supporting a wide variety of endemic plant and animal life (Means, 2006). The only known Piedmont old-growth longleaf stand is the Nichols Tractfield site. Little is known about pre-colonial fire regimes for this landscape, and there is debate about whether longleaf savannas and historic prairie landscapes on the Piedmont resulted from anthropogenic burning (Barden, 1997).

Although geographers have documented that the American Southeast was already a largely humanized landscape when European settlers arrived in the 16$^{th}$ century, there were many areas that showed little or no human influence where longleaf savanna environments were found thriving (Denevan, 1992; Noss, 2013). There is convincing evidence that the native human populations in the Southeast practiced intensive burning, and this burning helped reinforce the natural dominant fire-cycle (Ashe, 1894; Delcourt & Delcourt, 1997; Early, 2004; Frost, 2006). While other anthropogenic factors, including logging, habitat fragmentation, and farmland conversion, contributed to the reduction in the longleaf's range, fire suppression has been the largest factor leading to the decline (Palik *et al.*, 2002).

Arriving Europeans brought with them cultural approaches to the longleaf savanna that led to the habitat reduction observed at present. The surviving turpentined trees found in the remnant old-growth stands across North Carolina provide a tangible, significant link to the land use and cultural attitudes and patterns of the past. These trees should be viewed as part of the state's cultural heritage and should be protected against destruction. In much the same way as mounds, arrowheads, and other archeological evidence of human activity is protected and promoted, these trees are an untapped and largely ignored cultural resource.

### 2.3 Anthropogenic Influence and Cultural Landscapes

While there is no consensus on the total population of Native Americans in the U.S. Southeast in 1492, currently accepted estimates put the number between four and seven million people in all of North America (Silver, 1990; Denevan, 1992; Krech, 1999). The most densely populated areas were California and the Northwest coast, but the Southeast also had a thriving population as many as 10,000 years ago. At the time of the Europeans' arrival, Native Americans had integrated burning into their land management and cultural practices (Delcourt & Delcourt, 1997; Early, 2004; Noss, 2013). Burning the pines was a cultural practice that early rural settlers to the South adapted from the Native Americans as they began to occupy the lands of the Southeast (Ashe, 1894). However, this cultural practice was subsequently suppressed and discouraged, to the great detriment of the savanna (Ashe, 1894; Early, 2004; Noss, 2013).

There is no evidence that Native Americans extracted oleoresin from longleaf pine or any other southern pine. In other areas of North America such as the Northwest U.S., tree species including the ponderosa pine (*Pinus ponderosa*) were debarked for food and raw materials (Styd, 1998; Turner *et. al* 2009). Living trees bearing evidence of past human modification can be classified as culturally modified trees (CMTs) (Styd, 1998). Turpentined trees were modified by a specific culture at a specific time for a specific cultural purpose and comfortably fit the definition of CMTs. In addition to providing a tangible record of past human use, CMTs offer contemporary users of the landscape a point of reflection and connection to past cultures and practices (Eldridge, 1997; Ericsson, Ostlund, & Anderson, 2003). There is a growing interest in turpentined trees, especially the signature cat face scar formations. During research for this thesis, numerous landowners and managers had special trees or stumps they wanted to share (Figure 2).

Figure 2. From left: A cat face found in Wake County near Wendell, NC. A cat face located near Carvers Creek State Park. A cat face from a salvaged log pulled from the Cape Fear River to be fashioned into a mantelpiece. A remnant cat face tree in Raven Rock State Park stands in Harnett County. These trees were not included in this study, but they represent meaningful pieces of history and culture to the people who identified and care for them and are examples of CMTs.

The study of turpentined longleaf as CMTs provides information on past land management practices, evidence of migration patterns, and insight into cultural beliefs and attitudes about the environment (Grissino-Mayer *et al.*, 2001). As a group, these remnant turpentine orchards constitute a cultural landscape, providing a lasting physical manifestation of past use, management, and land occupancy (Turner *et al.*, 2009). Currently, there is no special protection given to still-living chipped longleaf pine trees in North Carolina.

There are different levels of interest in turpentined trees as CMTs. At the field sites I visited, great care was being taken to protect the trees from re-introduced ground fires, yet there is no actual strategy or plan to present them as a unified cultural landscape. Few people today recognize turpentine scars or the heritage they represent. Turpentined trees are quite rare in the heavily managed forests of the South, and careful effort should be taken to preserve the few that remain. Additionally, living, turpentined longleaf pine trees are an invaluable asset to programs seeking to preserve the naval stores heritage (Forney, 1987; Butler, 1998).

The longleaf savanna is thought to have developed in North Carolina some 5,000 years ago, well after humans are believed to have come to the region (Delcourt & Delcourt, 1997; Outcalt, 2000; Frost, 2006). This implies that the ecosystem likely has always existed with some level of anthropogenic disturbance. Understanding the human role in this ecosystem, both past, present, and future, will help conservationists identify strategies of interaction with the landscape that increase its resilience and biodiversity. Turpentined longleaf pines provide a point of reference and discussion for broadening our understanding of our role in the longleaf pine savanna.

### 2.4 The Naval Stores Industry

The term “naval stores” refers to the collection of oils, resins and gums, and tar from pine trees for use in shipbuilding and maintenance and is an ancient practice (Butler, 1998; Outland, 2004). Shipwrecks in the Mediterranean dating to 2600 BP show naval stores were carried on board (Butler, 1998). In 1608, the first shipment of naval stores was sent from the present day United States to England (Gamble, 1921). The Southeastern forests would become the major source of naval stores production in the United States, and at times the world, until the industry’s demise in the mid-20$^{th}$ century (Butler, 1998; Outcalt, 2000; Outland, 2004).

The first record of naval stores produced in North Carolina was in 1636—17 years before the first homestead of a settler was established—when a visitor sailing from Bermuda up the Chowan River discovered men collecting "spirits of rosin" (Clay, 1975). North Carolina became the world leader in the production of naval stores in the 1800s, by which time the state's residents had earned the moniker "tar heels" due to the prevalence of tar, pitch, and gum production centered in the state (Lefler, 1954). Early production of naval stores revolved around the collection of downed tree limbs, called lightwood or fatwood, which was subsequently processed in tar kilns built near the collection sites (Robinson, 1997; Outland, 2004). Lightwood from old-growth pine trees consisted of knots and limbs that had fallen to the ground. Such wood was saturated with oleoresin, which was extracted by heating, but not igniting, the wood. Tapping pines for oleoresin began as early as 1700, but it was not until industrial uses were found for turpentine in the 1800s, that the damaging practice of turpentining became widespread (Butler, 1998). The various methods for obtaining and processing naval stores from the longleaf pine are depicted in Figure 3.

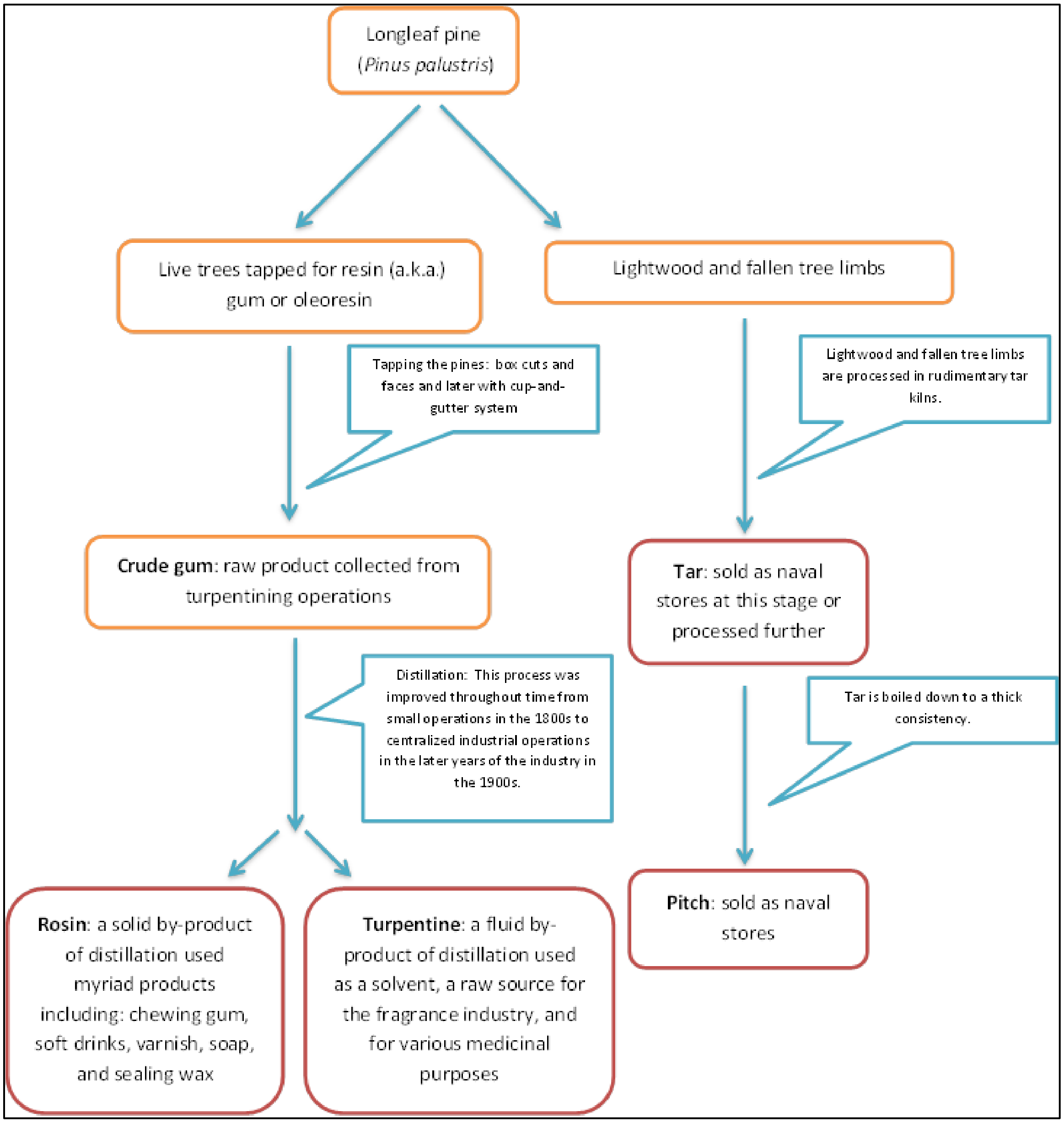


Figure 3. A flowchart depicting the various ways longleaf pines were utilized for tar, pitch, rosin, and turpentine.

The method ultimately adopted in the United States of tapping a pine for oleoresin follows as described from accounts in Ashe (1894), Butler (1998), and Outland (2004). First, a "box" was cut into the base of the tree. Above the box, workers would cut a "streak" on the tree weekly with a special axe called a "hack". The lower portion of this surface was called a "face", "cat face", or "chevron." Oleoresin would seep from the fresh wound and into the box (figure 4).

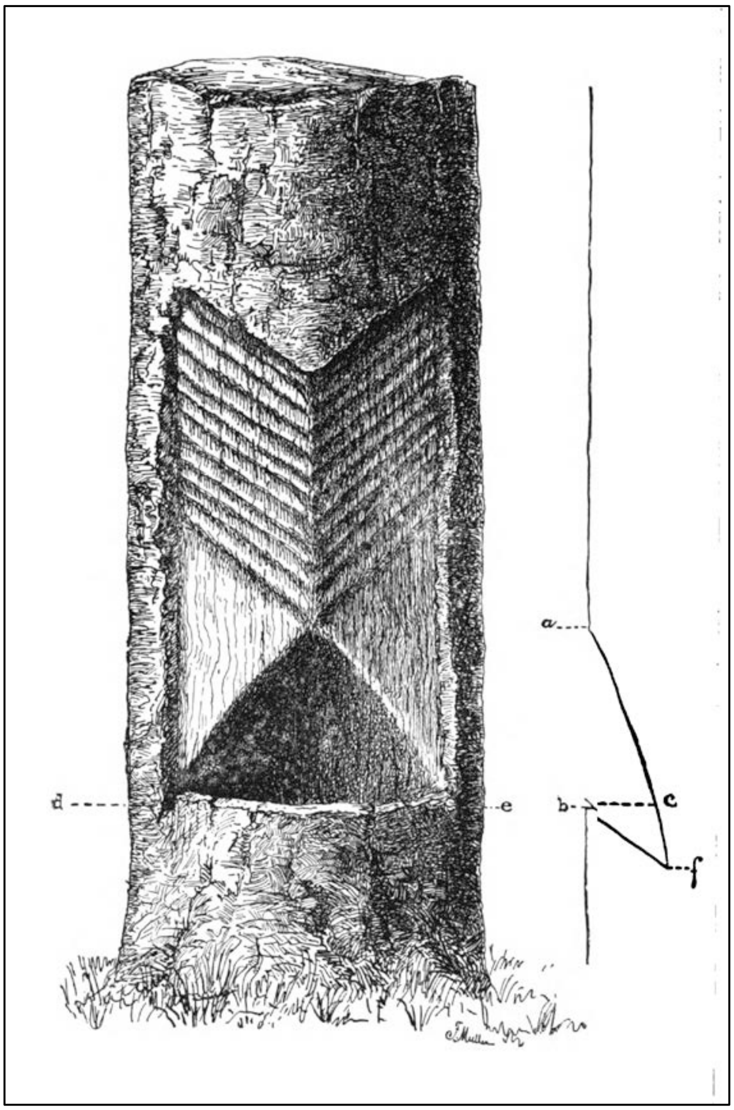


Figure 4. A drawing of a typical turpentine box cut and chipped face. The box cut's angles are illustrated in the profile sketch at the right of the frame. Reprinted from Ashe, 1894.

Workers would use special tools called “dip irons” to ladle the fresh oleoresin into containers for processing. The oleoresin is produced by the pine tree in vertical and horizontal resin ducts, which run the length of the tree (Gerry, 1922). When an injury occurs naturally, the resin serves to limit damage to the tree by repelling insects, closing wounds, and creating an inhospitable environment for bacteria and fungi. Repeated chipping during the growing season stimulated new duct formation and increased the flow of oleoresin. During the time of slavery, slaves usually performed this labor-intensive work in plantation settings, while, after the Civil War, large, mobile operations were established. Then laborers were, for the most part indentured servants with little to no personal freedom or rights (Outland, 2004). The industry relied on cheap labor and a continuous, accessible supply of virgin longleaf pine, both of which diminished as the years progressed (Butler, 1998).

### 2.5 Naval Stores in North Carolina

During the first decades of the 1800s, applications for rosin, turpentine, and tar grew beyond ship-related products to include soap, paint thinner, and sealant (Outland, 2004). Turpentine continued to find new uses such as a flea repellent and a remedy for respiratory disease. In 1830, the rubber industry found it made better tires, and it was used as a substitute for whale oil for lamp light. In 1847, North Carolinians produced an estimated 800,000 barrels (in the 1800s, a barrel held approximately 30.5 gallons, increasing to 50 gallons by the 1900s) of turpentine (Butler, 1998; Outland, 2004). North Carolina remained the country’s major source of gum naval stores until the depletion of longleaf pine stands in the 1880s precipitated a southward shift in the industry to South Carolina, Georgia, and Florida.

During the economic rebuilding that took place after the Civil War, the turpentine industry reached the westernmost stands of longleaf in North Carolina. Moving raw resin was an expensive and arduous process, which confined the production of turpentine to areas near navigable waterways or railroads (Outland, 2004). In the early 1800s, the savannas and forests of Moore and Montgomery County (in Sandhills and Piedmont regions of NC) were largely untouched, virgin forests (Ashe, 1894; Early, 2004; Davis, 2006). Based on U.S. Census data, the total value of turpentine and tar produced in Montgomery County, which did not receive sufficient rail service until the 1890s (Chesson, 2012),  was less than $10,000 in both 1870 and 1880 (United States Department of the Interior, 1872). In neighboring Moore County, which received rail service in the mid-1870s, the value of tar and turpentine produced rose from under $20,000 to more than $200,000 during the same period (United States Department of the Interior, Census Office, 1872; United States Department of the Interior, 1883).

By 1874, the railroad had reached Southern Pines, NC in Moore County and, by the end of the century, Troy, NC in Montgomery County (Chesson, 2012; Owen, 2013). Railroads opened up the last virgin stands of lumber in the state to turpentining and lumbering (Ashe, 1894). In an 1893 report on the state of North Carolina forests, forester W.W. Ashe (1894) states that the number of turpentine distilleries in Montgomery County rose from zero in 1880 to 12 in 1893 producing 22,000 barrels of rosin.

The railroad not only drew the turpentine camps and lumber speculators, it also drew tourists and the wealthy to the Sandhills area. The field sites at Carvers Creek and Weymouth Woods are located on the former estates of wealthy railroad and coal tycoons who built winter estates in the Sandhills region following the opening of the railroad. In fact, the sole reason for the existence of living turpentined trees and the numerous turpentined stumps found at Carvers Creek and Weymouth Woods, is the fact that turpentining and logging were stopped when the estates were purchased by their new wealthy owners from the north. This moment heralded a cultural shift away from extracting resources out of these landscapes and towards using the landscape for recreation and tourism (Hood, 2006). At Carvers Creek and at Weymouth Woods, turpentined trees stand next to the winter retreats and provide striking evidence of the different American cultures that have occupied the land over the last two centuries.

Aside from the few exceptions such as Carvers Creek and Weymouth Woods, by 1893 the longleaf pine forests of North Carolina had been largely exhausted. Only 55,876 acres of longleaf remained for turpentining at the end of the $19^{th}$ century (Ashe, 1894). The naval stores industry would continue for decades longer further to the south. During this time, the industry adopted a more conservative “cup-and-gutter” extraction method. In Georgia and Florida, slash pine (*Pinus elliottii*) replaced longleaf pine as longleaf stands were depleted. In 1903, Dr. Charles Herty patented the cup-and-gutter system that replaced the box cut with a tin or clay cup. The innovation of the Herty-cup system led to a renewed interest in turpentining activities in southern states (Hodges, 2006). As longleaf pine forests had been decimated in North Carolina by 1900, the Herty-cup system was not used to great extent in the state. For my research, only trees at the Nichols Tract field site show evidence of the utilization of Herty’s cup-and-gutter system.

By 1950, most turpentining activity had ceased in the United States (Outland, 2004). Competition from the paper and pulp industries, which found methods to convert wasted by-products into turpentine and other chemicals, rising labor costs, and depletion of pine stands led to the demise of the industry in the country (Early, 2004; Outland, 2004). Aside from the turpentined trees and tar-kilns, the landscape retains little evidence of this important cultural and industrial endeavor.

## 2.6 Cultural Practices and Turpentining

Cultural attitudes and practices hindered the adoption of more conservative turpentining methods in the U.S. Southeast even though the boxing of turpentine trees was known to be unnecessary and destructive (Ashe, 1894; Butler, 1998; Outland, 2004). In the preface to the North Carolina Geological Survey’s 1894 publication on the forests of eastern North Carolina, Editor J.A. Holmes laments the destructive practice:

> Indeed, nothing in the way of forest management could be more reckless and destructive than the treatment of our long-leaf pine forests during the past few decades. In the boxing for turpentine the trees have been cut so deeply and so extensively that both their vitality and strength have been greatly weakened, and the storms have prostrated many of the finest specimens…

Holmes promoted the “French system” and later championed Herty’s cup-and-gutter system. The practice of boxing trees dates to the 1700s in the United States, and as early as 1715, the method was considered wasteful and destructive (Butler, 1998) (Outland, 2004).

The conservative French method of turpentining called for chipping long, vertical strips in the tree; a chip was made in the tree and a cup then placed directly under the chip. The worker would move up the face of the tree, chipping and raising the cup periodically throughout the growing season (Ashe, 1894; Gamble, 1921). The practice in the Southeast was to let the resin flow into the box at the bottom of the face. The box cut not only covered more surface area of the tree than the French method, it also required the resin to run down the entire face of the tree. Such resin was referred to as “scrap” and produced an inferior grade of turpentine and rosin (Butler, 1998; Outland, 2004: Figure 5).

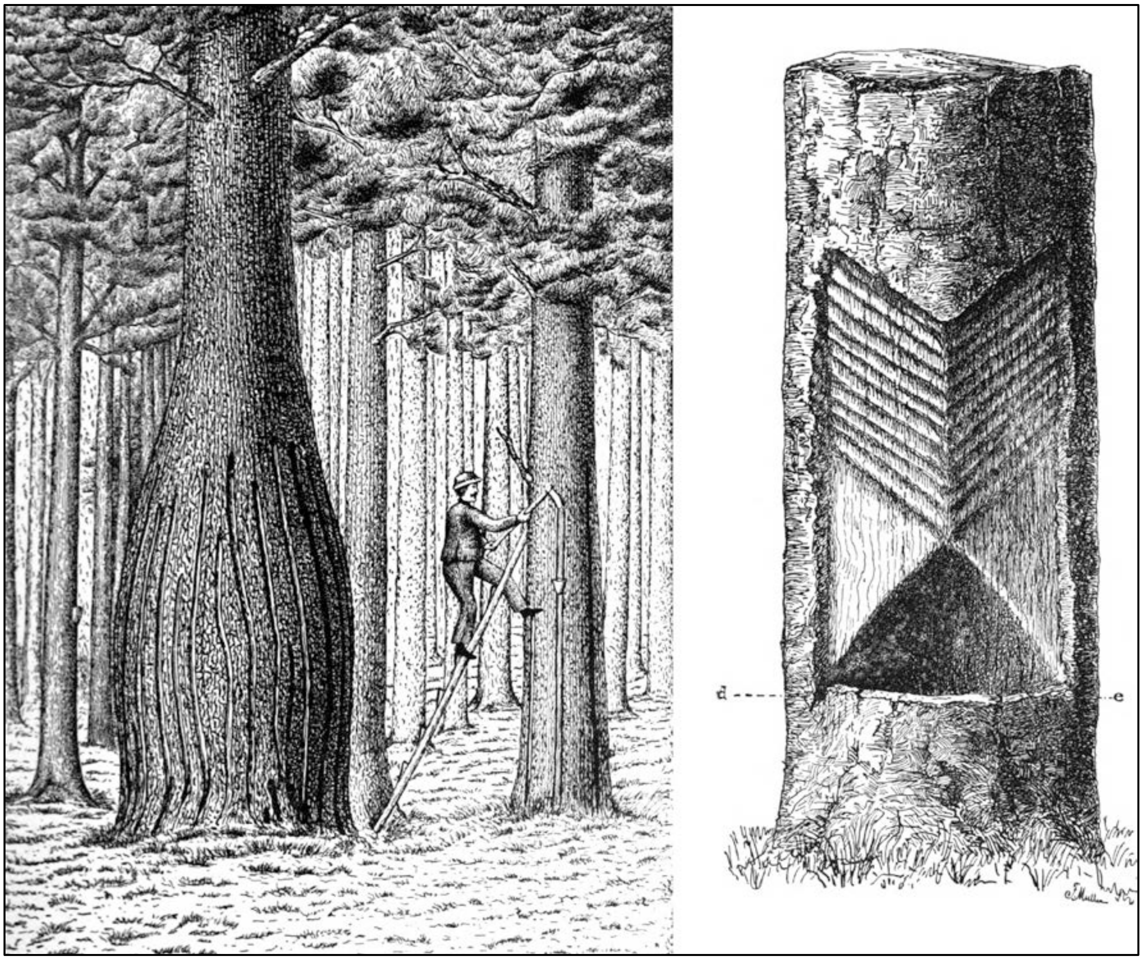


Figure 5. The French method (left) relied on long vertical strips, while the American method (right) utilized a large face and box. The French method resulted in less damage to the tree and, thus, longer operations. Reprinted from Ashe, 1894.

It is worth noting the difference in land management of turpentine-producing pine forests between the French and the Americans. In France at the beginning of the 19th century, Napoleon began a process of reclaiming wasteland in Landes, an area in southeastern France. With strict controls from the central government, the French turpentine forest prospered (Outland, 2004). Unlike the Americans, the French followed a production method that permitted the continual production of naval stores from the stands for up to 80 years. In the colonial U.S. South, plantation owners would routinely work their longleaf pines for 30 years or more (Ashe, 1894; Gamble, 1921); but during the post-Civil War turpentine boom, trees were worked for as little as five years before becoming unproductive (Butler, 1998). The quickening pace of destruction in the latter half of the $19^{th}$ century was noticed. Historian Robert Outland III sums up the situation in *Tapping the Pines* (2004) as follows:

> Where France had created a highly successful naval stores industry from a once-barren sand region, the American South had accomplished the opposite, transforming a healthy pine forest into a near-worthless wasteland. Moreover, the southern United States possessed more environmental advantages – better soil, longer growing season, and more plentiful rain – than the Landes region, but was still outpaced.

Neither industry leaders, the state government of North Carolina, nor the United States government sought in any meaningful way to conserve or limit the damage done by turpentining in the longleaf pine belt. It was not until the 1920s that the United States government began researching improved methods of extracting naval stores from living pine trees (Gamble, 1921; Butler, 1998; Outland, 2004). By this time, the industry had almost entirely left North Carolina. Like other southern industries in the post-Civil War period, the turpentine industry lacked investment, research, or innovative thinkers. The failure to adopt less-destructive practices was also rooted in the discrimination of the predominantly African-American work force. It was widely believed that the black workers lacked the mental capacity to learn a new method of turpentining and would resist learning a new method (Outland, 2004; Figure 6).

Figure 6. This undated photo shows a turpentine worker chipping a face and using the cup and gutter collection method. The method was common in the waning days of the turpentining industry in the United States. Photo courtesy of the North Carolina Department of Cultural Resources (NCDCR).

Producers, including Dr. Herty who patented the cup-and-gutter system, had little faith the all-black labor force “could be taught to work in any but the orthodox way” (Outland, 2004). Like the trees they worked, black laborers were exploited; little to no regard was paid toward their health or civil rights. (Outland, 2004; Owen, 2013). After the abolition of slavery, white owners and operators of turpentining companies used discrimination and oppression to continue to force black laborers into working the turpentine orchards. Camps in this period were located 19–32 km from the nearest road and could not be accessed without permission from the company manager (Butler, 1998; Ouland, 2004). Intolerable work conditions contributed to a labor shortage in the turpentining industry as other sectors in the Southeast enjoyed economic growth during and after World War II (Butler, 1998; Outland, 2004).

The turpentined longleaf pine at my field sites display box cuts and cat faces, indicating they were subject to the box cutting method of turpentining. Each tree represents the individual worker's style and technique. Each face gives evidence to the amount of time a tree was worked, and many of the trees show two or three separate faces. The markings imbedded in these trees display the individual and collective culture of this bygone industry. The cultural legacy represented in living turpentined trees is quickly fading. Turpentined trees are more likely to break during a storm, be exposed to infection, and suffer damage from ground fire (Ashe, 1894; Early, 2004). My research has uncovered no list of known living turpentined trees in North Carolina. Likewise, little effort has been taken to promote the cultural importance of the locations of old turpentined orchards on state and federal land.

# CHAPTER III

# METHODOLOGY

## 3.1 Site Selection

Site selection was limited to known locations of sufficient populations of living turpentined trees in order to perform meaningful analysis. I restricted my search to areas within the borders of North Carolina. I further concentrated my search in the western and southern part of the longleaf's range in the state because: 1) the area has seen the least amount of disturbance; 2) the dates of turpentining operations can be linked to railroad expansion, legal records, and census figures; and, 3) the Sandhills and the Carolina Bay ecosystem exhibit distinct mixtures of cultural and physical landscapes, of which turpentined longleaf pine trees are a part (Figure 7).

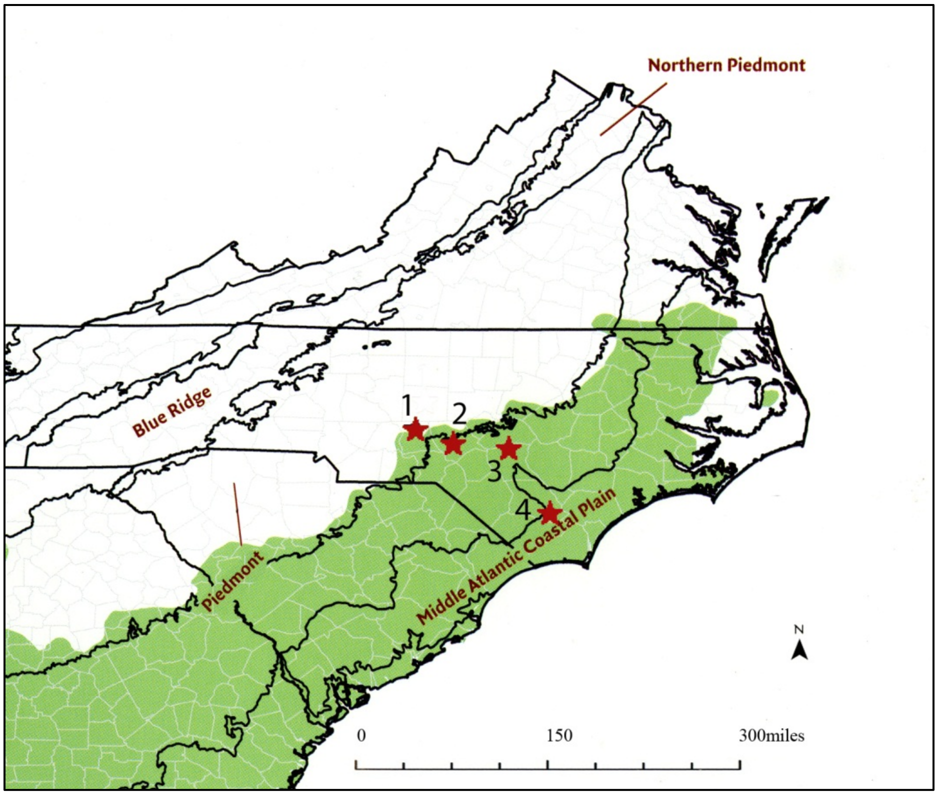


Figure 7. Field sites marked with a star. Green shading shows the natural range of the longleaf pine and black lines denote state boarders and eco-regions of the Mid-Atlantic Coastal plain, the Sandhills, and the Piedmont. Sites are numbered as follows: 1) Nichols Tract, 2) Weymouth Woods, 3) Carvers Creek, and 4) Salters Lake.

### *3.1.1 The Nichols Tract*

The Nichols Tract is likely the last, best, and only example of old-growth longleaf pine remaining in the North Carolina Piedmont. A few old-growth specimens remain scattered in the adjacent Uwharrie National Forest, but at the Nichols Tract there are intact stands and stumps that date back over three centuries, providing evidence that this is a landscape that has not been significantly altered for agricultural purposes in recent times (Figure 8). The land was purchased from the Nichols family in 2011 by the North Carolina Zoo for plant preservation and environmental education.

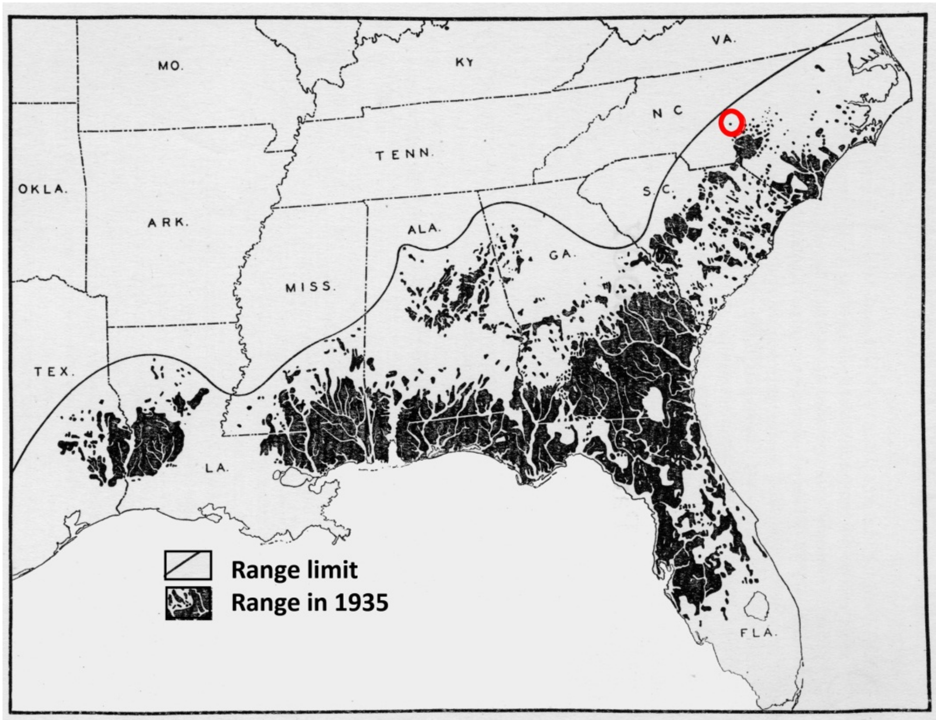


Figure 8. The red circle in the photograph is the approximate location of Nichols Tract. This map was published by the United States government in 1935 to highlight the remaining longleaf growth in the Southeast. The Sandhills region (directly south of the red circle), contained the largest tracts of virgin longleaf pine at the time the map was first compiled. Adapted from Wahlenberg, 1946.

Originally purchased by the Nichols family in the early years of the 19th century, it was not until the railroad came to Troy in 1895 that the stand was turpentined and lumbered (Allen, 2012; Chesson, 2012). The Nichols family continued logging operations until the 1930s when Margret Nichols halted the logging of longleaf. Aerial photographs document the growth of understory plants and hardwoods that moved into the landscape following fire suppression and as mature longleaf were logged.

N.C. Zoo's rare plant botanist, Nell Allen, oversaw the re-introduction of fire to the property in 2013. According to Allen (2012), there was a fire in the 1930s that burned the area, but there is no documentation of the Nichols burning the land. I obtained fire-scarred stumps from the property, which document a five-year fire period in the mid-1800s.

Eleven trees showing turpentine scars were found on the property. Numerous stumps with box cuts on two or more sides were found throughout the property. It was common practice to simultaneously chip the faces of the most productive trees on two or three sides during the turpentine boom of the 1880s (Outland, 2004; Allen, 2012). The trees with multiple faces that were no longer producing adequate quantities of oleoresin would be removed and the remaining single-faced trees would continue to be worked for a number of years before being harvested themselves. For reasons unknown, the turpentined longleaf trees at the Nichols site remain.

Some trees do not show signs of being boxed, nor is there any evidence of employment of the Herty-cup method (Figure 9). It is possible these trees were worked as late as the 1930s, although Allen and area historians doubt this, instead putting the date closer to the turn of the 20th century (Chesson, 2012). While this research does not directly address the question of when the tree were first worked, data gathered here will assist in endeavors to establish a beginning date for turpentining.

Figure 9. Two examples of turpentined trees at Nichols Tract show different amounts of scarring. Notice the protruding face on the tree in the photo on right. The diagonal chip marks are clearly visible.

The turpentined trees at Nichols Tract have already been used in conservation programs, educational outings, and as tools for exploring the region's cultural heritage (Allen, 2012). A nature trail is being built through the old turpentine orchard, and care is being taken to preserve the trees from fire, which was re-introduced in 2013. Fire and growth suppression from encroaching hardwoods are the biggest threats to the trees at Nichols Tract (Allen, 2012). Data from this study will help better understand and care for these few remaining living turpentined longleaf pine.

### *3.1.2 Weymouth Woods*

The 364 ha Weymouth Woods-Sandhills Nature Preserve is a remnant of an estate once owned by James Boyd, a coal magnate from Pennsylvania, who purchased Weymouth Woods as a winter retreat and hunting ground. At its largest extent, the Weymouth estate comprised just under 635 ha, making it one of the largest privately-owned tracts of land in Moore County in the early 1900s (Hood & Stach, 2011). The field site is located next to the Weymouth Woods estate and is also referred to as the Boyd Tract. The Boyd Tract was formerly part of Shaw’s Ridge, a property named after the Shaw family, Scottish immigrants who were the first European settlers to the area (Hood & Stach, 2011; Owen, 2013). The land was sold to James Boyd in 1904 and was the scene of a destructive fire in 1909 (Owen, 2013). Although the turpentining industry in the region reached its peak shortly after the railroad came to Manly, NC in 1874, there is historical evidence of turpentine production during the preceding decades (Hood & Stach, 2011). Turpentine production stopped after the Boyd purchase (Owen, 2013).

After his purchase of the land, Boyd employed landscape architect Alfred Yeomans to develop the Weymouth Heights subdivision on the site of the discontinued turpentine orchards. Many old-growth and turpentined trees are thriving, scattered in private yards throughout the neighborhood. Hundreds of old-growth trees remain in Weymouth Heights and in the adjacent Boyd Tract. These trees compose a significant cultural landscape, shaped by the African-Americans and Scottish-Americans who worked the land for industrial purposes and by the development of Weymouth Heights and the subsequent landscape use by wealthy Americans in the industrial New-South. As part of the nature preserve and local cultural activities, the turpentined trees at Weymouth Heights are being used to educate and inform the public about their past and the past of their land (Owen, 2013; Figure 10).

Figure 10. Undated photograph of turpentine operations in Pinehurst (near Weymouth Woods) depicting typical working conditions. Notice the worker (left) dipping oleoresin from a box, while another worker (background) scrapes dried oleoresin from a face. Photo courtesy of the NCDCR.

Weymouth Woods sits on the western edge of the Sandhills region. The Sandhills region runs from North Carolina, through South Carolina, and into Georgia. The region formed from a strip of ancient beach dunes deposited during the Miocene Epoch some 20 million years ago (Noss, 2013). Underlying this sand are clayey sands and gravel that slow the percolation of rainwater and send it sideways. This phenomenon and the local topography created seepages and pocket wetlands throughout the region. The Sandhills Game Land is dedicated to the preservation of 26,000 ha of the Sandhills habitat, encompassing a range of ecosystems and endemic plant communities.

Burning has been re-introduced to Weymouth as a land control technique, but land managers are wary of fire due to possible negative effects on the turpentined pines (Owen, 2013; Varner *et al.*, 2005). Restoring fire to long un-burned longleaf landscapes can damage the root zone, which may have risen into the organic layer of humus that has accumulated on the ground during the absence of fire.

### *3.1.3 Carvers Creek*

Carvers Creek State Park is located on the eastern edge of the Sandhills region. Part of the Long Valley Farm, the land was in the possession of the Rockefeller family throughout the 20th century. The North Carolina state park system acquired the land in 2005, and a park is scheduled to open to the public in 2013. The Rockefellers, of Standard Oil fame, developed the land in the 1920s. Originally settled by Europeans in the 1750s, the field site at Carvers Creek differs from the Weymouth Woods site in that it underwent earlier and more extensive exploitation by turpentiners and lumbermen. In his 1894 report on the state of the naval store industry in North Carolina, forester Ashe records the establishment of the first turpentine distillery at Fayetteville in 1844. That same year, boxes were cut in nearby Manchester, NC. By 1850, a plank road linked High Point to Fayetteville. Another road radiated from Fayetteville to western Cumberland County. The turpentined trees at Carvers Creek may have been worked from as early as 1844  Ashe, 1894; Hood F. D., 2006).

Prior to Long Valley Farm, the land was worked as a 5,300 ha turpentine orchard by the McDiarmid family (Hood, 2006).  The McDiarmids lost possession of the farm due to hard economic times in 1892 when it was auctioned off to a northern lumber company (Hood, 2006). The year 1892 was likely the last year of turpentining operations on the farm and serves as a demarcation point between the culture that had shaped the land during the 19th century and the emergence of new economic and cultural influences that would shape the South during the 20th century. Families such as the Reynolds, Greys, Rockefellers, and Boyds owned property, spent time in the pines of the Sandhills, and had a lasting impact on the landscape.

Turpentining gave way to logging or to leisure activities of the wealthy. Eventually, Long Valley Farm was incorporated into the Rockefeller's Overhills Estates and provided the family and their guests with hunting grounds, a working farm, and thousands of acres of privacy. Like Weymouth Woods, the Carvers Creek site is a concentrated mixture of cultural and ecological landscapes. With an abandoned millpond on the property and evidence of tar kilns on the property, the Carvers Creek turpentined longleaf pines have the potential to become a valuable resource for the park. Growing next to and under the turpentined pines are varieties of wire grass and the carnivorous pitcher plants, which provide evidence this soil has not been greatly disturbed by humans in past centuries. The area extending from Weymouth Woods east through the Sandhills Game Land, the U.S. military base at Fort Bragg, and ending at Carvers Creek is part of a unified cultural landscape, and the presence of living turpentined trees serves to solidify that connection.

### *3.1.4 Salters Lake*

Salters Lake is located on the Coastal Plain in central Bladen County. It belongs to a different climate zone than the field sites on the Sandhills and Piedmont. The field site at Salters Lake sits atop the sandy ridge deposits found around the southeastern rim of Salters Lake, a Carolina bay. Carolina bays are elliptical depressions scattered across the Coastal Plain and Piedmont from Delaware to northern Florida (Jose *et al.*, 2006; . The bays are most abundant in the Atlantic Coastal Plain of the Carolinas. It is theorized that the sandy ridges accompanying the bays were deposited by wind eons ago after the formation of the bays (Carver & Brooks, 1989). It is in this white sand that the study stand of turpentined longleaf pine is growing (Figure 11).

Figure 11. A turpentined longleaf (left) at Salters Lake is now home to a family of red-cockaded woodpeckers. Notice the flat top on this tree, which indicates old age. The sandy soil (right) does not retain water and is nutrient poor.

The trees at Salters Lake show signs of being turpentined heavily. Most trees show two or more faces, and many have active or inactive red-cockaded woodpecker nests. Historical evidence shows this land was in use during the mid-1700s and was worked until depletion in the 1920s (Ashe, 1894). Ashe (1894) describes the area around Bladen, NC as a barren wasteland on which second growth longleaf was being worked for turpentine. The state of North Carolina began to manage the land in 1939. An adjacent Carolina bay, Jones Lake, opened in 1939 as the first North Carolina state park for African-Americans. The North Carolina state park system at the time was a racially segregated system; state policy barred African-Americans from all other state parks.

As a remnant turpentine orchard, an endangered Carolina bay forest ecosystem, and the state's first park for use by African-Americans, I include it in my study. This landscape represents the culturally managed longleaf pine in an aesthetically pleasing and unique setting. The presence of turpentined longleaf at the park is underutilized, but the old orchard remains a place of interest for visitors and park attendants alike. Inclusion of the Salters Lake site allows comparisons between turpentined and non-turpentined trees on the Atlantic coastal plain. Salters Lake represents a large collection of turpentined trees and stumps in a functioning Carolina bay habitat. The turpentined trees provide shelter for a thriving population of federally endangered red-cockaded woodpeckers and serve as a destination for hikers and visitors at the park.

## 3.2. Data Collection and Processing

### *3.2.1 Field methods*

At each of the four field sites, samples were taken from two different populations of mature longleaf pines (turpentined and non-turpentined). At each site, 11–16 trees were sampled from each population (turpentined and non-turpentined) giving a sample depth of 26–32 total trees at each field site. For the non-turpentined trees, only healthy trees without signs of scarring, rot, or deformation were selected. Based on field observations, a bias was towards the oldest non-turpentined trees. For turpentined trees, selection was less robust. At some sites, every available turpentined tree was sampled. At the sites where turpentined trees were more numerous, I avoided sampling trees with two or more faces. Turpentine workers would sometimes rest their crop for a number of years before putting trees back into production. The repeated turpentine periods appear in the tree record. In order to maintain a strong correlation within the site sample, and in an effort to compare trees that had undergone the same amount of modification, I selected for turpentined trees showing one or two turpentined faces.

Two core samples were removed from each tree using a 5.15 mm Swedish increment borer. No less than 30 non-turpentined samples were collected from each site, and no less than 22 turpentined samples were collected from each site. For each tree, I measured tree height (m), diameter at breast height (DBH) (cm), needle length (cm), and location (longitude and latitude). Data gathered from tree cores included total ring width (TRW) and, in cases where pith is present, approximate tree age.

I recorded field notes to describe the overall appearance of turpentined trees in the landscape. Care was taken to sample turpentined and non-turpentined trees from the same geographic location. This was possible at all sites except for Weymouth Woods. At Weymouth Woods, the non-turpentined trees were collected at a different time and with a different team than the turpentined trees. While the two sampling areas are on the same property, they do not overlap, which is the case for the three other sites. Not all turpentined trees displayed full faces. I did not receive permission to sample through the face of the turpentining scars on turpentined trees nor did I receive permission to remove larger cross sections with a chainsaw. As this is a study examining the long-term effects of turpentining on living longleaf pine and not an effort to identify absolute dates of the period of turpentining, it is unnecessary to sample through the turpentined face on turpentined trees.

### *3.2.2 Lab methods*

Core samples were air dried for at least 24 hours and mounted on wooden strips with wood glue. Dry, mounted samples were sanded with a progressively finer grit sand paper (120–1500 grit) until cell structure was visible. After sanding, each sample was cross-dated. Cross-dating allowed for the detection of false or missing rings in individual cores. After cross-dating, samples were measured using the computer program WINDENDRO. From WINDENDRO, I made measurements of total ring width (TRW). TRW correlates with precipitation and drought (Meldhal *et al.*, 1999). During turpentining, TRW is somewhat reduced in correspondence with a reduction in overall vigor (Wahlenberg, 1946).

## 3.3 Data Analysis

Chronology statistics, including inter-series correlation (IC)–how well individual core matches each other–and mean sensitivity (MS)–amount of variation year to year in TRW–were obtained using the computer program COFECHA. For each site, basal area increment (BAI) was formulated. BAI is a measure of the annual growth of a tree's area ($cm^2$). Using BAI allowed me to compare yearly growth between turpentined and non-turpentined trees at each site regardless of tree age. The chronologies were not de-trended in anyway. De-trending would reduce stand characteristics and could weaken the differences between turpentined and non-turpentined trees.

To assess the morphological differences between turpentined and non-turpentined trees, I tested if correlations were present between IC and MS using a modified *z*-test (Fisher, 1921). I used the standard, two-sample *t*-test to test for differences in diameter, height, and needle length between turpentined and non-turpentined trees.

TRW and DBH were combined for each tree to produce a measure of annual area growth ($cm^2$) referred to as BAI. Using BAI in place of TRW controlled for any relationship between TRW and tree age and possible problems associated with curve fitting during standardization. As a tree grows radially, each successive yearly ring must cover a greater area, typically leading to narrower rings as a tree ages. Curve-fitting standardization may not always properly account for this, whereas this problem is inoperative when using BAI. Additionally, due to rotted areas in the cores of most turpentined samples (>95%), I was unable to determine the age of turpentined trees and therefore could not perform standardization (Figure 12).

Figure 12. A rotted section in a core sample from Carvers Creek. This core was cross-dated prior to the rot; but, in most samples, areas of rot prevented accurate dating of earlier years. Pith is to the left for scans of tree-ring samples in this paper.

I performed regression analysis on the difference in yearly BAI between turpentined and non-turpentined trees over time to identify any long-term differences in the growth trend between the two populations. Lastly, I used regime shift analysis (Rodionov, 2004) to compare the BAI of turpentined and non-turpentined trees at each site over time. Regime shifts are defined as rapid reorganizations from one relatively stable state to another; regime shift analysis is used to study aquatic climate ecosystems (Rodionov, 2005) but has applications in the field dendrochronology (Knapp & Soulé, 2008).

I used the Visual Basic application for Microsoft Excel provided by the United States National Oceanic and Atmospheric Administration (NOAA, Regime Shift Detection, 2013). The program detects shifts in both the mean level of fluctuations and the variance of the series for a defined *p*-value (a *p*-value = .05 was chosen for this analysis). The program allows the user to set the length of the regime analysis from time spans ( $\geq$  years). Because the duration of turpentining activities at field sites ranged upwards from five years, I set the regime shift analysis to cover periods as little as five years. The program analyses the data over five-year intervals and creates an output graph showing average BAI on the Y-axis and the length of the regime on the X-axis. Shifts in regime signify large-scale shifts in the behavior of the dataset that might not be apparent in the raw data.

### 3.4 Climate, Soil, and Other Data

Measurements of BAI from turpentined and non-turpentined trees were compared against the Palmer Drought Severity Index (PDSI). The PDSI is a measurement of soil moisture based on recent precipitation and temperature (Palmer, 1965). The PDSI value is centered at zero; negative readings indicate drier soil-moisture conditions with negative 2 considered moderate drought. As the PDSI is based on instrumental records beginning in the 19th century, the data for early years in the record are sometimes unreliable (Alley, 1984; Keim, 2003).

In order to capture the longest growth period possible, including late season hurricanes, a six-month time period from May–October was selected for the years 1895–2010. The sites are in the southern Piedmont and southern Coastal Plain climate zones. I selected droughts consisting of two or more consecutive readings of a PDSI value of -2 on the PDSI scale for turpentined and non-turpentined trees. I analyzed BAI during droughts by comparing average BAI for each population at each site to the BAI during drought periods. By creating a break in the tree's cambium, the turpentined face reduces the ability of a tree to take-up water. I hypothesized that there would be a significant difference in the growth between turpentined and non-turpentined trees during drought due to the possibility of cavitation in tree cells during drought conditions. I hypothesized this cavitation would reduce the vigor of turpentined trees over longer time spans (>100yrs) compared to non-turpentined trees.

Soil data were obtained from the United States Department of Agriculture (USDA). At each site, care was taken to select turpentined and non-turpentined trees from the same topographic and edaphic locations. Soil textural classes were recorded for each site. Slight changes in topography and the underlying edaphic conditions of many longleaf savanna habitats create micro climates that can vary widely over short spatial scales (≤ 10m) (Peet, 2006; Noss, 2013). At the Weymouth Woods field site, I was not able to sample turpentined trees in the same area as non-turpentined trees. Slight changes in local topography could affect the outcome of the data at the Weymouth Woods site.

CHAPTER IV

RESULTS

## 4.1 Results

Statistical procedures used to compare turpentined and non-turpentined trees assume the data are from normally distributed populations, have constant variance, and are independent. The data for this study met these criteria. However, the data are not from a random sample. Results from this study pertain only to the field sites under examination. General inferences about turpentined longleaf pine based on these data would be imprudent as would predictions for future behavior.

## 4.2 Needle Length, DBH, and Height

I used a two-sample *t*-test to test for significant differences in morphological characteristics between turpentined and non-turpentined trees at each site. All tests for significance were one-sided. Results of the *t*-test for needle length between turpentined and non-turpentined trees showed a significant difference for the Nichols Tract ($p < .001$) (Table 1).

Table 1. *T*-test results for needle length on turpentined and non-turpentined trees by site.

| Needle Length (cm) between Turpentined and Non-Turpentined Trees by Site | | | | | | |
|---|---|---|---|---|---|---|
| **Site** | **Mean: Turpentined** | **Std. Dev.: Turpentined** | **Mean: Non-Turp.** | **Std. Dev.: Non-Turp.** | ***t* value** | ***p* value** |
| Nichols | 23.0667 | 1.5475 | 27.6933 | 1.4846 | -7.7128 | <.001*** |
| Weymouth | 25.800 | 1.9774 | 25.4960 | 2.4034 | .3856 | .3513 |
| Carvers | 26.9173 | 1.6617 | 27.1287 | 1.39675 | -.3771 | .3545 |
| Salters | 25.0945 | 2.7900 | 25.6400 | 2.2095 | -.5566 | .2914 |
| Significance codes: '***' .001 '**' .01 '*' .05 | | | | | | |

Results of the *t*-test for DBH between turpentined and non-turpentined trees showed significant differences for Weymouth Woods ($p = .003$), Carvers Creek ($p = .016$), and Salters Lake ($p < .001$) (Table 2).

Table 2. *T*-test result for DBH between turpentined and non-turpentined trees by site.

| DBH (cm) between Turpentined and Non-Turpentined Trees by Site | | | | | | |
|---|---|---|---|---|---|---|
| **Site** | **Mean: Turpentined** | **Std. Dev.: Turpentined** | **Mean: Non-Turp.** | **Std. Dev.: Non-Turp.** | ***t* value** | ***p* value** |
| Nichols | 60.3000 | 7.9554 | 59.5933 | 11.3772 | .1701 | .4332 |
| Weymouth | 63.3438 | 9.0530 | 52.7133 | 11.37264 | 2.8889 | .0036** |
| Carvers | 64.2333 | 10.6450 | 55.800 | 9.6968 | 2.2682 | .0156* |
| Salters | 58.5455 | 6.7433 | 47.800 | 5.4011 | 4.5138 | <.001*** |
| Significance codes: '***' .001 '**' .01 '*' .05 | | | | | | |

Results of the *t*-test for tree height between turpentined and non-turpentined trees showed no significant relationship. The strongest evidence existed for Weymouth Woods ($p$ = .056) (Table 3).

Table 3. *T*-test result for height between turpentined and non-turpentined trees by site.

| Height (m) between Turpentined and Non-Turpentined Trees by Site | | | | | | |
|---|---|---|---|---|---|---|
| **Site** | **Mean: Turpentined** | **Std. Dev.: Turpentined** | **Mean: Non-Turp.** | **Std. Dev.: Non-Turp.** | ***t* value** | ***p* value** |
| Nichols | 18.6364 | 1.7477 | 19.4533 | 2.2376 | -1.0050 | .1625 |
| Weymouth | 19.6125 | 2.6701 | 17.9000 | 3.1330 | 1.6413 | .0558 |
| Carvers | 17.0933 | 2.7784 | 17.7733 | 2.6284 | .6886 | .2483 |
| Salters | 16.1273 | 1.8868 | 16.1733 | 1.9237 | -.0608 | .4760 |
| Significance codes: '***' .001 '**' .01 '*' .05 | | | | | | |

## 4.3 Site Age

It is possible to ascertain the age of a tree from the number of tree-rings in the core sample if the sample approaches pith. Pith or curvature, indicating proximity to pith, was reached in the majority of the non-turpentined cores for this study (Figure 13).

Figure 13. A non-turpentined tree-ring sample from Weymouth Woods shows curvature around the pith (left side of photo). The rings become progressively narrower as the tree ages (from left to right), which is typical for most samples.

Due to the destructive nature of the turpentining industry in the United States, >95% of the turpentined tree cores in this study show rot in the core sample. Rotten sections obscure the ring record and, when present, prevent cross dating of the rotted section. Tree ages for the turpentined samples, therefore, do not reflect the maximum age of the tree. It can be assumed that tree age of the turpentined trees is > 40 years older than the non-turpentined trees as these trees were first utilized for production when their DBH was at least 10–12 inches (Ashe, 1894; Mohr, 1896; Robinson, 1997; Table 4).

Table 4. Statistics on ages for turpentined and non-turpentined samples by site

| **Site** | **Oldest Sample** | **Median Age of Chronology** | **Mean Age of Chronology** |
|---|---|---|---|
| Nichols Turpentined | 161 | 107 | 114.55 |
| Nichols Non-Turp. | 241 | 132 | 136.27 |
| Weymouth Turpentined | 305 | 175.5 | 183.75 |
| Weymouth Non-Turp. | 280 | 176 | 169.87 |
| Carvers Turpentined | 218 | 121 | 125.87 |
| Carvers Non-Turp. | 248 | 91 | 110.33 |
| Salters Turpentined | 153 | 116 | 115.55 |
| Salters Non-Turpentined | 248 | 91 | 110.33 |

At Weymouth Woods the oldest sample (305 years) was from a turpentined tree. At all other sites, the non-turpentined sample depth was greater than turpentine sample depth. Mean and median age differed among sites and was older for Nichols Tract and

Weymouth Woods non-turpentined chronologies. Carvers Creek and Salters Lake had older median ages for the turpentined chronologies.

### 4.4 BAI

For each site, BAI was plotted for turpentined and non-turpentined trees against time (Figures 14–17). BAI measurements are plotted in $cm^2$ on the Y-axis. Years in the chronology are plotted on the X-axis. The beginning year for each chronology was based on a sufficient sample depth ($n \geq 5$) for both turpentined and non-turpentined trees. The longest chronology is from Weymouth Woods, and extended from AD 1800–2010. Chronologies for Nichols Tract and Carvers Creek extend from AD 1880–2010. The Salters Lake chronology spans AD 1890–2010. Chronologies are discussed based on their geographical location. Starting from the Nichols Tract in the northwest and traveling southeast, the sites are as follows: Nichols Tract, Weymouth Woods, Carvers Creek, and Salters Lake.

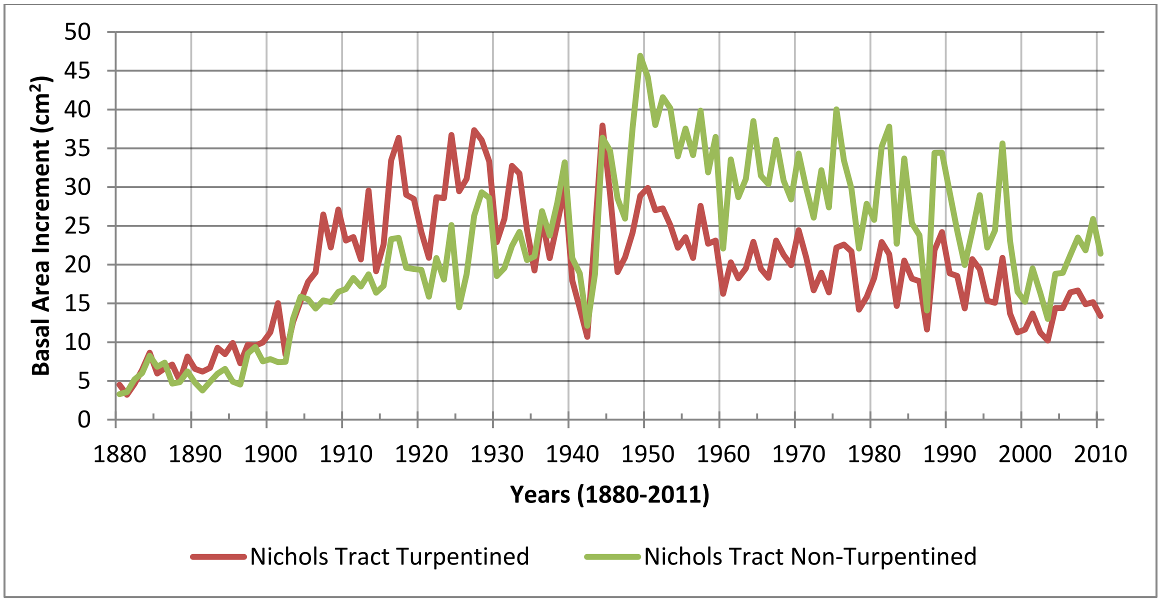


Figure 14. BAI for Nichols Tract turpentined and non-turpentined trees 1880–2010.

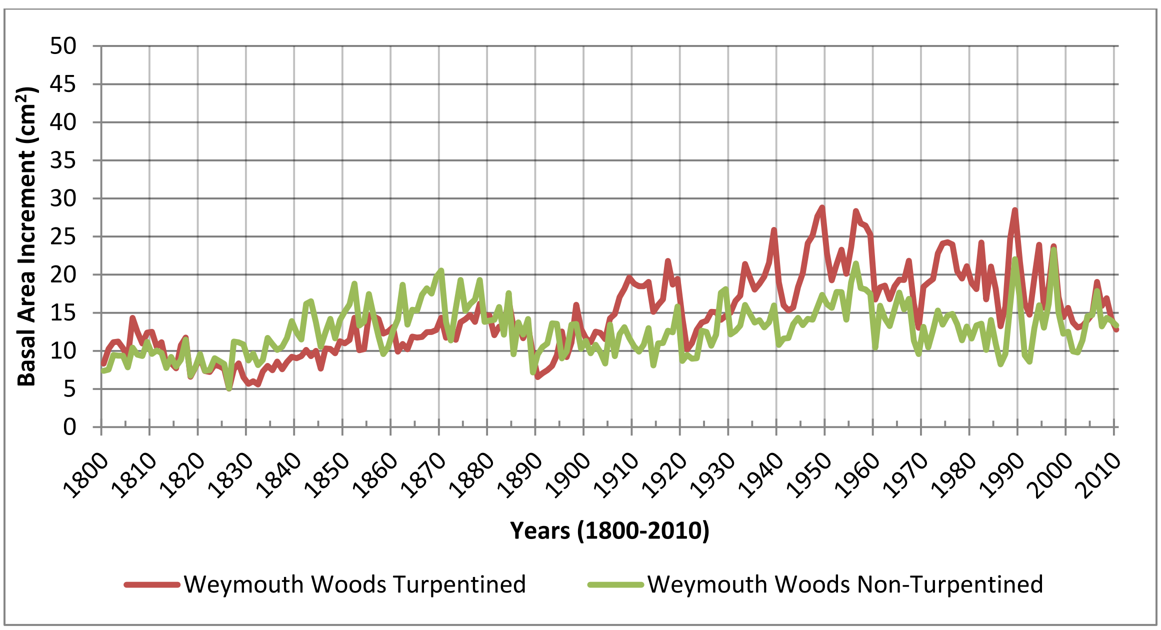


Figure 15. BAI for Weymouth Woods turpentined and non-turpentined trees.

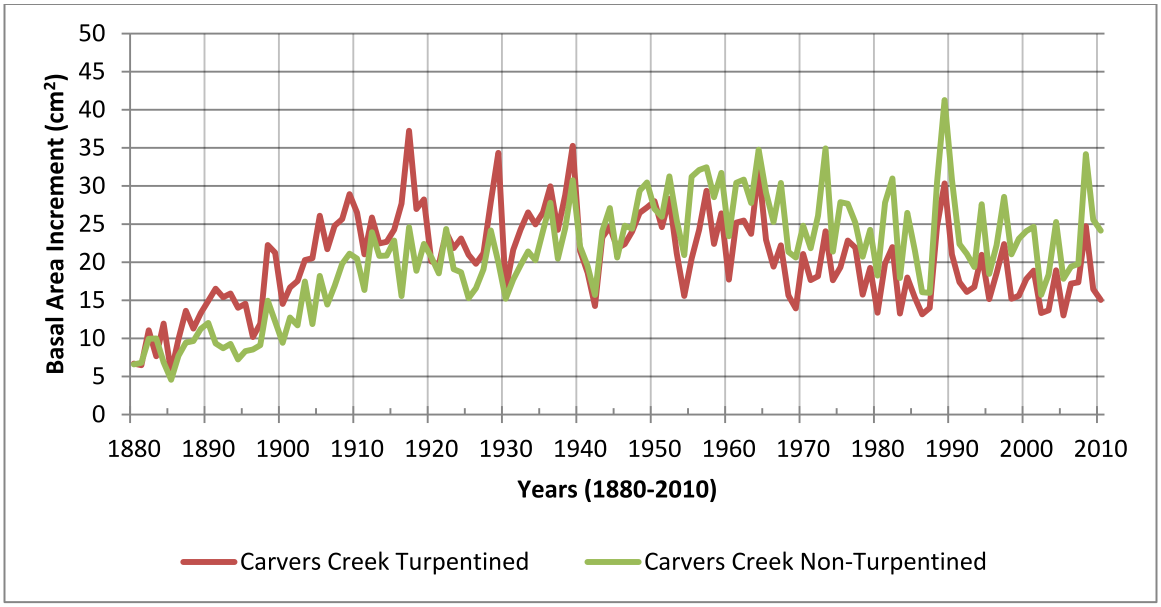


Figure 16. BAI for Carvers Creek turpentined and non-turpentined trees.

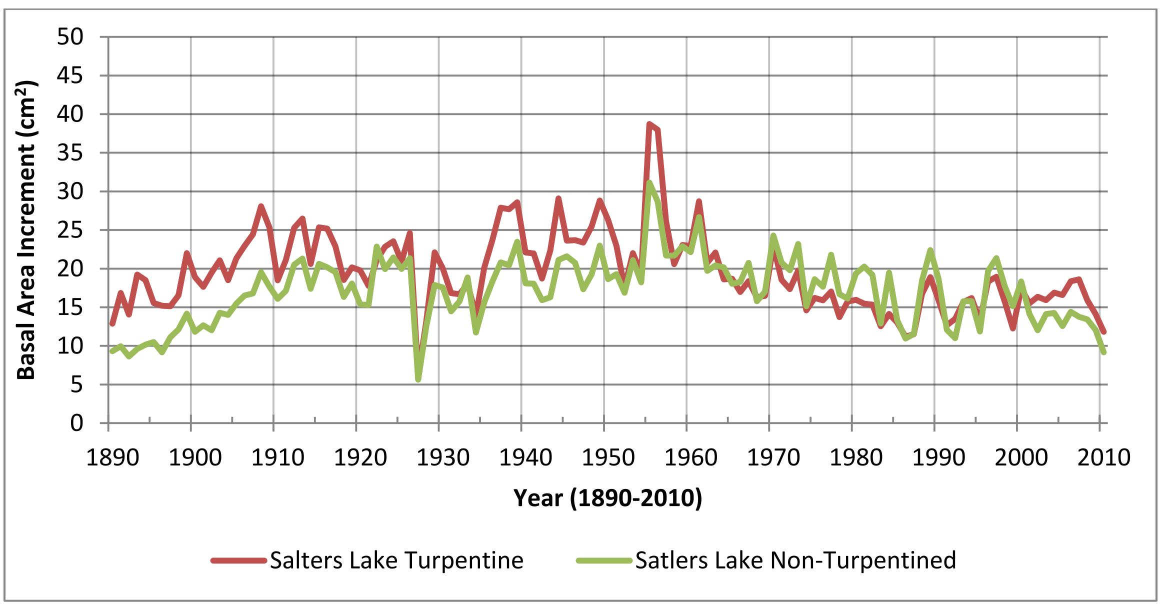


Figure 17. BAI for Salters Lake turpentined and non-turpentined trees.

### 4.5 Differences in BAI

To compare differences between turpentined and non-turpentined trees at each field site, I subtracted non-turpentined BAI from turpentined BAI for each year in the series. I plotted the results and used simple linear regression to fashion a trend line (Figures 18–21). Positive numbers on the Y-axis indicate turpentined trees' area growing more that year, while negative numbers on the Y-axis indicate that non-turpentined trees grow better that year. The values on the Y-axis represent annual growth in area in $cm^2$. The resulting graph shows which chronology (turpentined or non-turpentined) is growing more in a particular year in $cm^2$ and the relative trend of the difference over time.

The R value listed with each figure indicates the relative strength of the trend line to explain the regression of the data through time. Higher R values indicate a stronger relationship between the trend line and the data. Assumptions about linear regression have not been met for these data, and the R values should not be used for interpretation or prediction but rather as a visual aid in helping assess the movement in the difference in BAI between turpentined and non-turpentined trees over time at a particular site. The following graphs visualize turpentined tree growth in relation to non-turpentined tree growth over time.

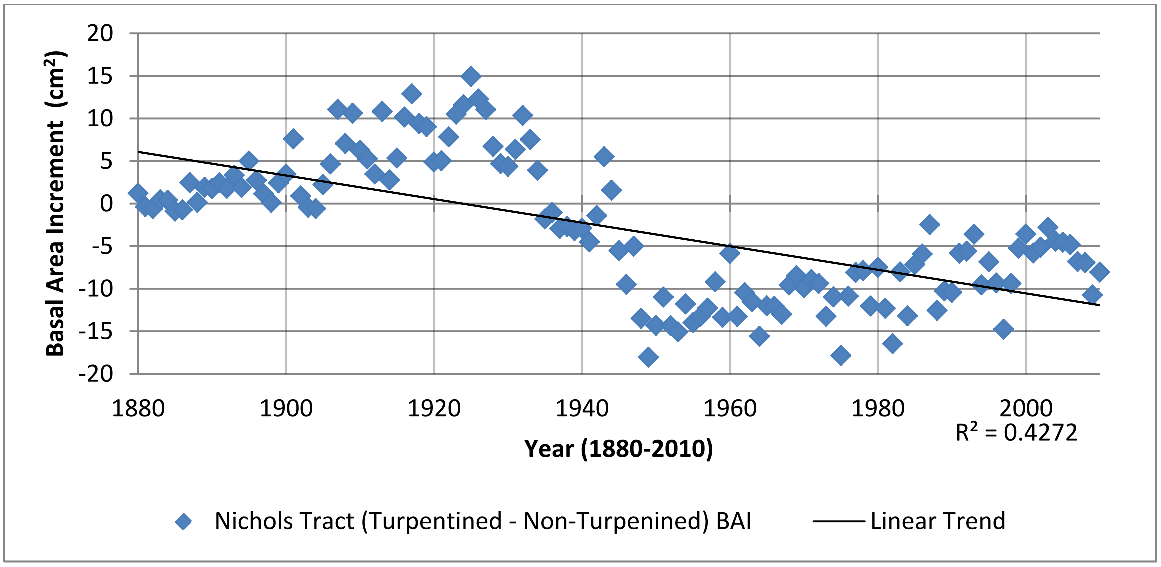


Figure 18. BAI turpentined chronology – BAI non-turpentined chronology over time at Nichols Tract.

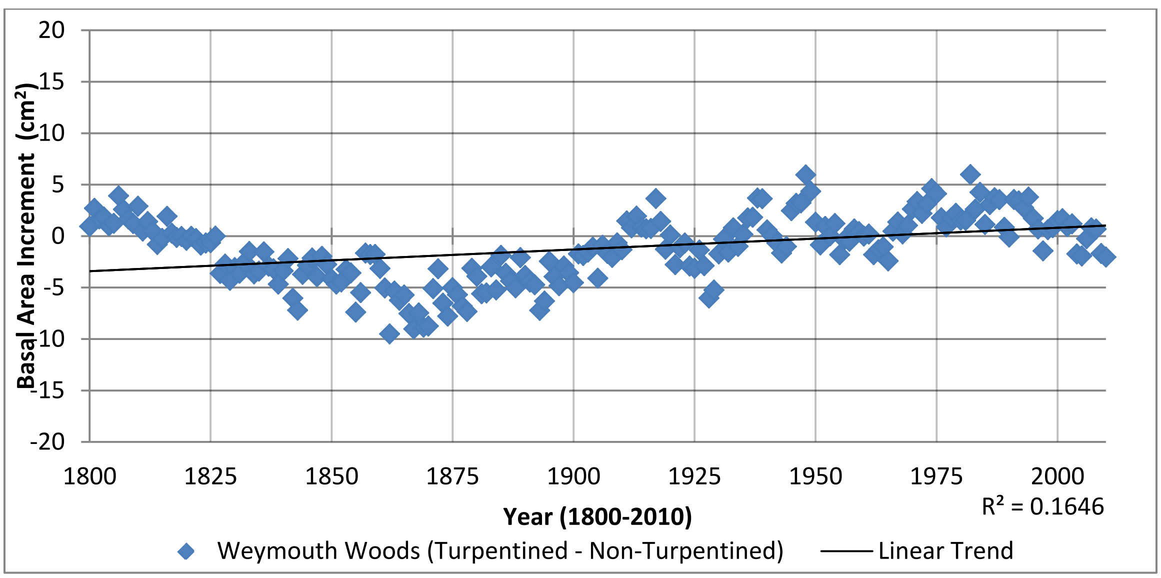


Figure 19. BAI turpentined chronology – BAI non-turpentined chronology over time at Weymouth Woods.

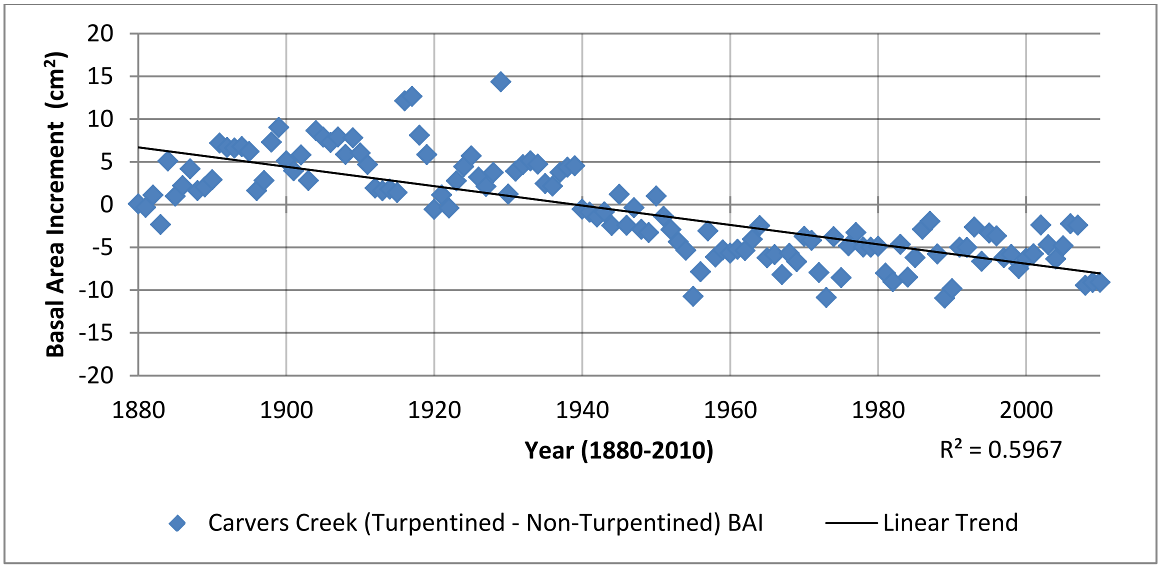


Figure 20. BAI turpentined chronology – BAI non-turpentined chronology over time at Carvers Creek.

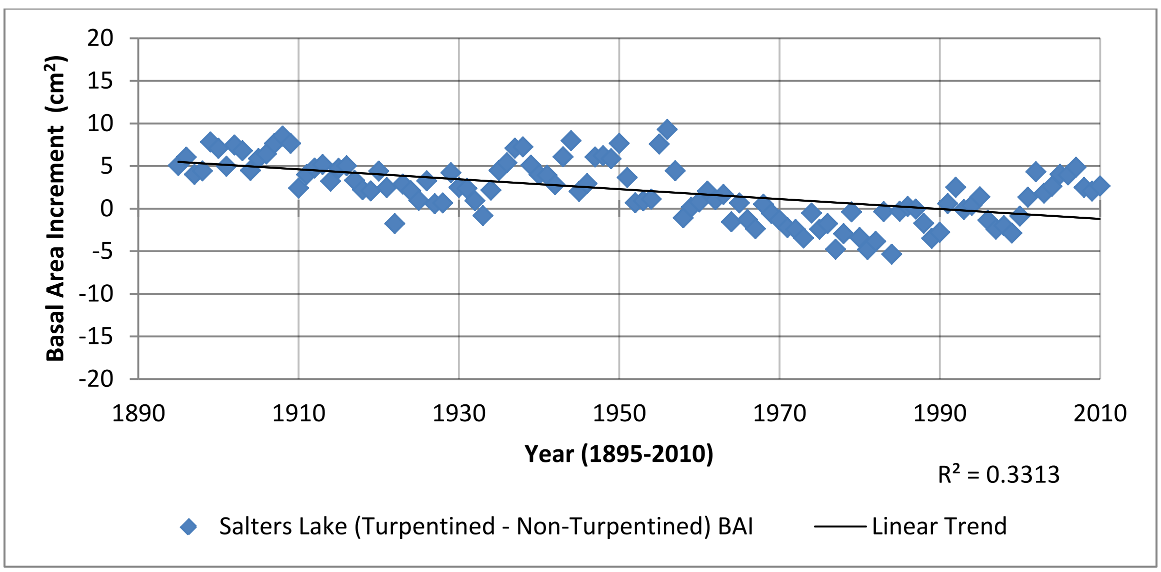


Figure 21. BAI turpentined chronology – BAI non-turpentined chronology over time at Salters Lake.

### 4.6 Regime Shift

Regime shift analysis shows divergence between the turpentined and non-turpentined chronologies (Figures 22–25). Since the 1950s, regime shifts for turpentined and non-turpentined chronologies at Nichols Tract and Carvers Creek have coincided intra-site. This pattern is not apparent for Weymouth Woods or Salters Lake. Weymouth Woods is the only site with a known chronology spanning the period of turpentining (Figure 15), as evidenced by the alignment of the regimes in the beginning of the chronology.

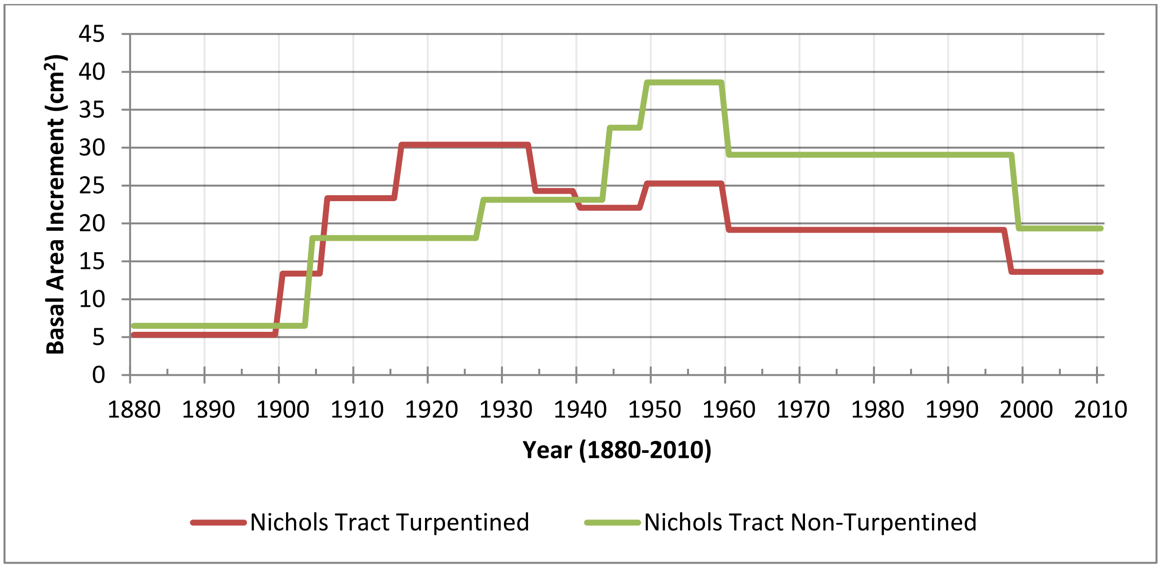


Figure 22. Mean BAI for turpentined and non-turpentined chronologies during regime periods at Nichols Tract.

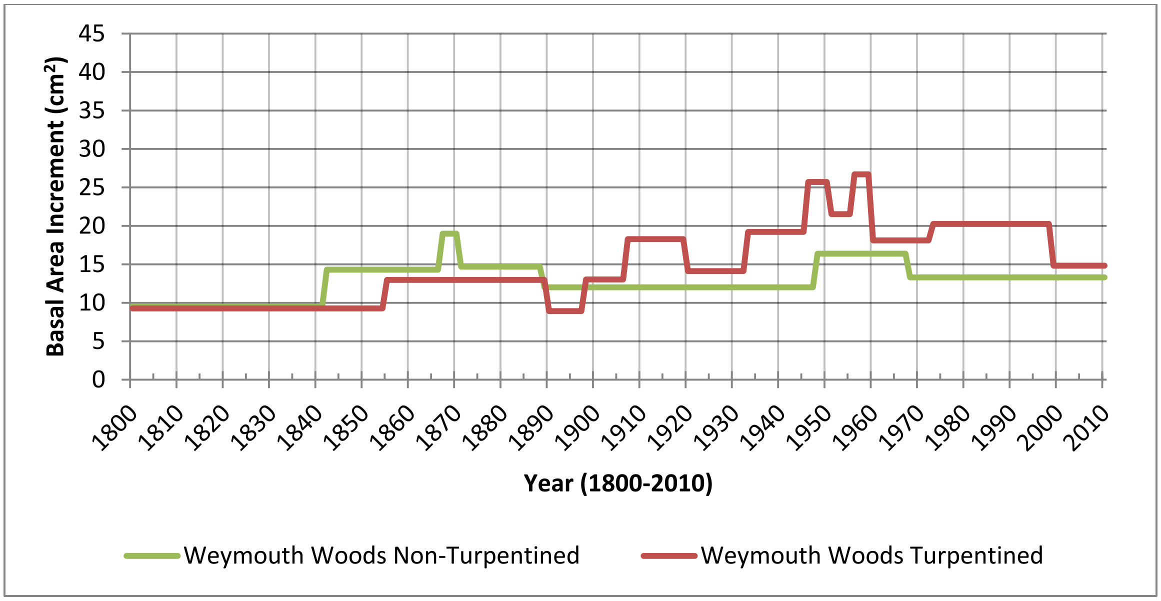


Figure 23. Mean BAI for turpentined and non-turpentined chronologies during regime periods at Weymouth Woods.

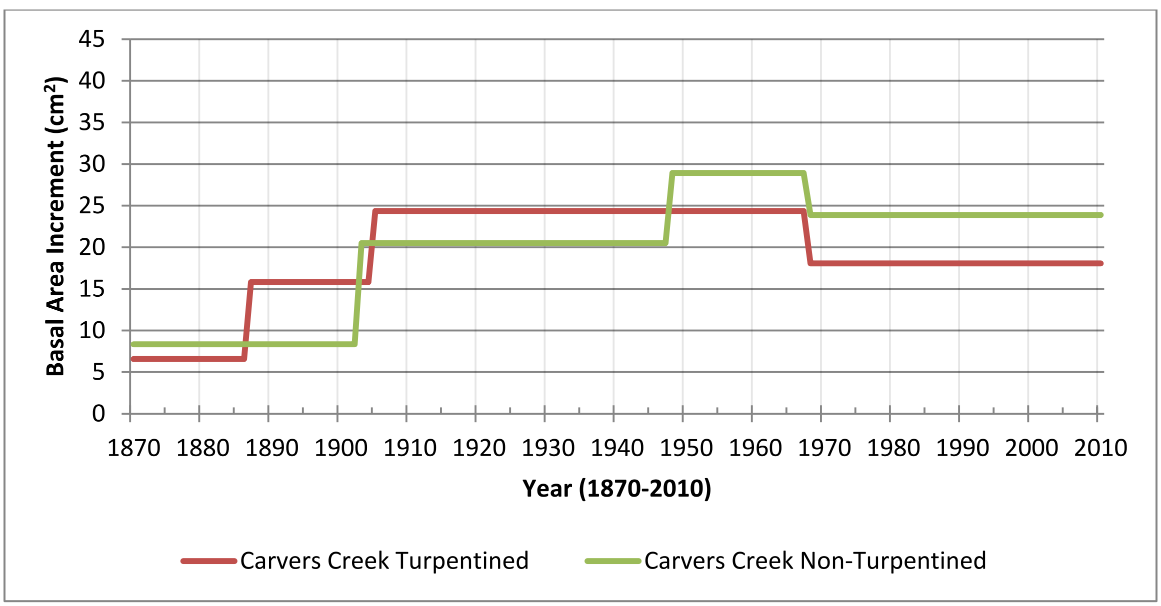


Figure 24. Mean BAI for turpentined and non-turpentined chronologies during regime periods at Carvers Creek.

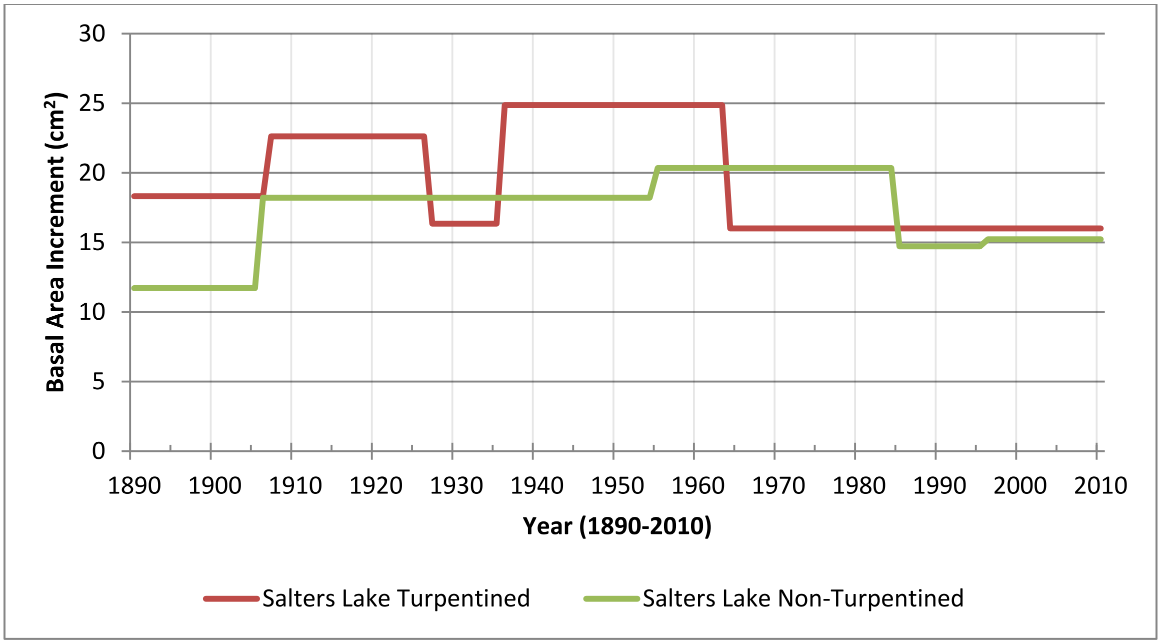


Figure 25. Mean BAI for turpentined and non-turpentined chronologies during regime periods at Salters Lake.

### 4.7 BAI During Moderate-to-Severe Drought Events

In order to compare the responses of turpentined and non-turpentined trees to prolonged drought events (close to or greater than -2 on the PDSI scale), I compared the average BAI for both turpentined and non-turpentined chronologies during drought events to average growth. I averaged the turpentined series compared BAI during drought events with the mean BAI for the turpentined series. I did the same for the non-turpentined series (Figures 14–17). The Y-axis shows the percent of average growth for that particular event. The X-axis represents when the drought event ended. A value of one (1) signifies average growth during that event. A value <1 indicates below-average growth, while a value >1 indicates above-average growth for that period. Nichols Tract, Weymouth Woods, and Carvers Creek are all located in North Carolina Climate Division 5. The drought events for these sites ranged two–four years for the following periods: AD 1925–1927, 1940–1941, 1986–1988, and 1999–2002 (Figures 26–29). Salters Lake is located in North Carolina Climate Division 6. The drought events for this site ranged one–four years for the following periods: AD 1925–1927, 1930–1933, 1940–1941, 1951–1954, 1986, and 2002. The PDSI period spanned the following months: May, June, July, August, September, and October.

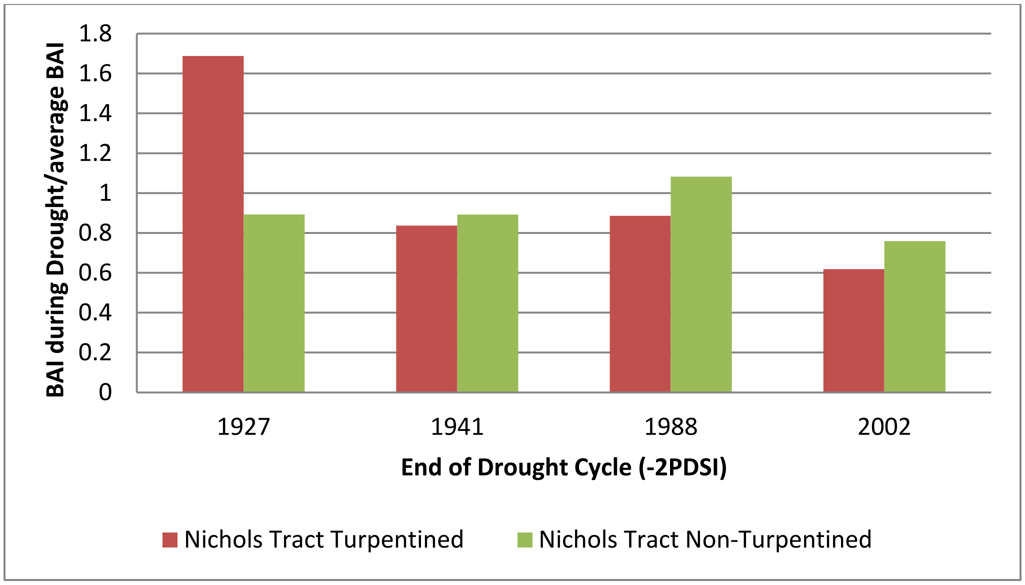


Figure 26. Nichols Tract BAI during drought events as a proportion of mean BAI for select drought events.

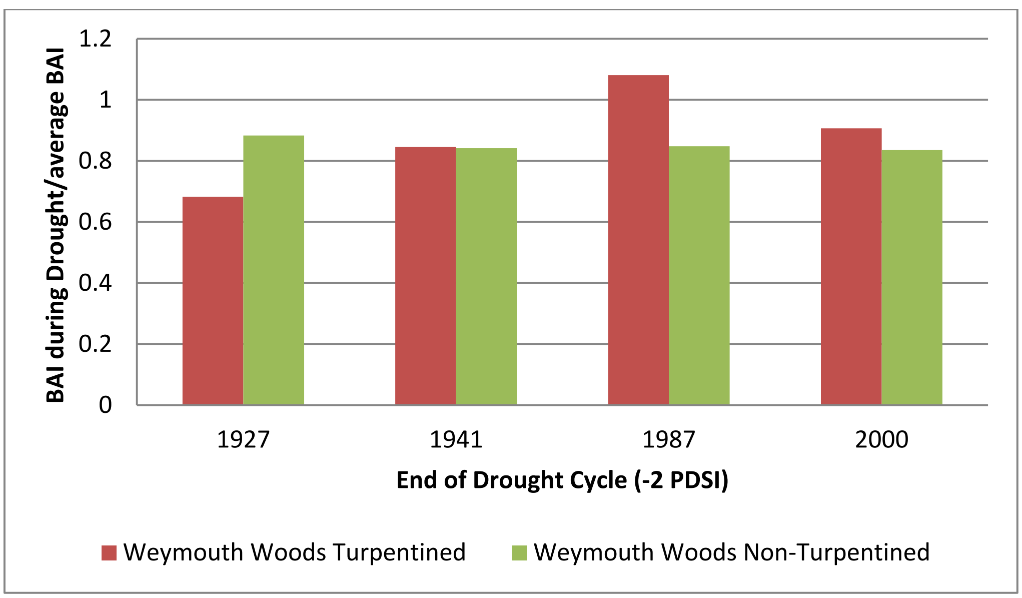


Figure 27. Weymouth Woods BAI during drought events as a proportion of mean BAI for select drought events.

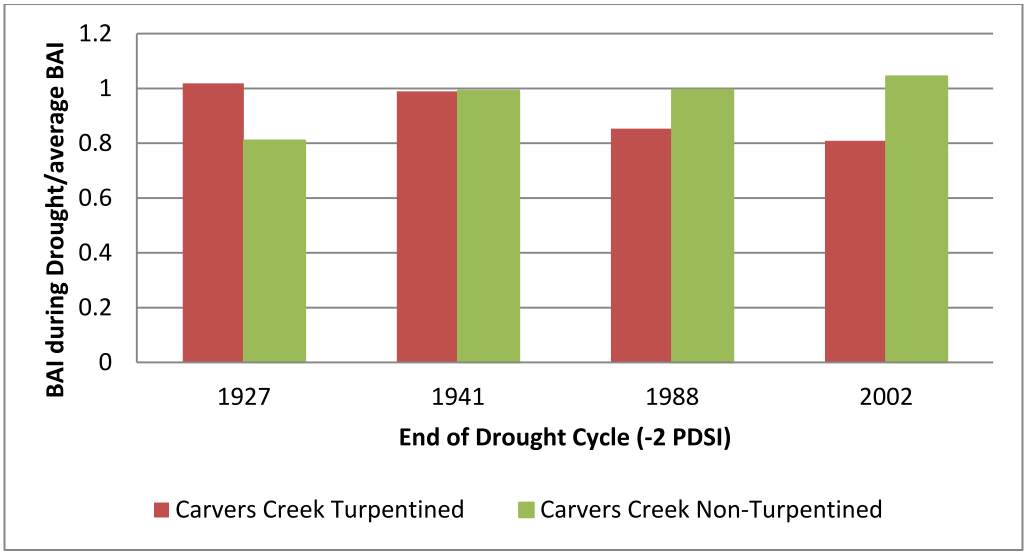


Figure 28. Carvers Creek BAI during drought events as a proportion of mean BAI for select drought events.

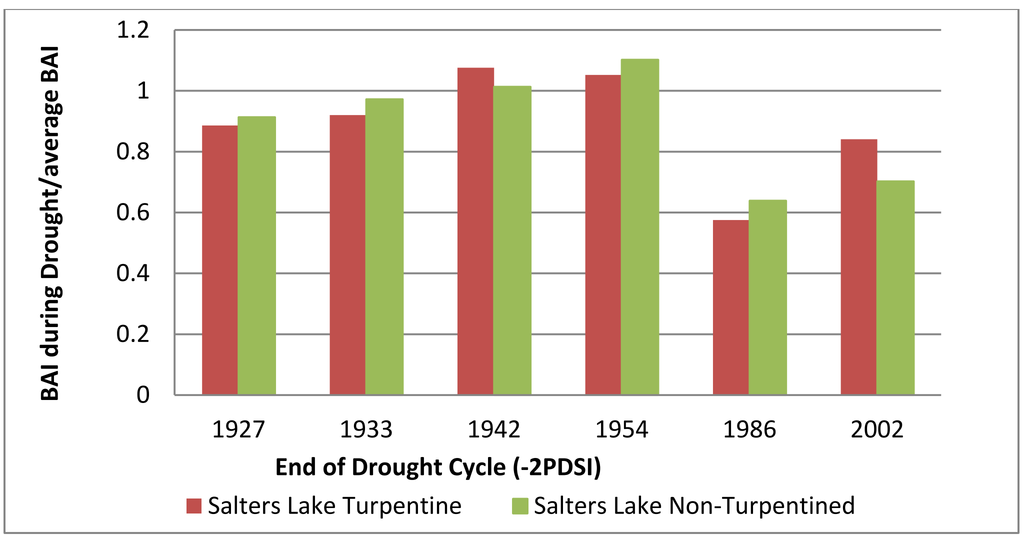


Figure 29. Salters Lake BAI during drought events as a proportion of mean BAI for select drought events.

### 4.8 Inter-series Correlation and Mean Sensitivity Analysis

Descriptive statistics from the computer program COFECHA explain the quality of each site's chronology in terms of correlation with itself and movement in TRW over time. These statistics include the sample size (*n*), inter-series correlation (IC), which measures the strength of the common signal of the chronology and serves as a measure of chronology reliability (NOAA, User guide to the COFECHA output files, 2008), and mean sensitivity (MS), the relative change in ring-width from year to year (Table 5). IC and MS both range from zero to one, with higher IC signifying site homogeny, and higher MS signifying greater inter-annual ring-width variability.

Table 5. COFECHA output for turpentined and non-turpentined chronologies.

| **Site** | ***n*** | **Inter-series Correlation** | **Mean Sensitivity** |
|---|---|---|---|
| Nichols Tract Turpentined | 20 | .510 | .302 |
| Nichols Tract Non-Turpentined | 30 | .572 | .319 |
| Weymouth Turpentined | 29 | .502 | .290 |
| Weymouth Non-Turpentined | 27 | .537 | .290 |
| Carvers Creek Turpentined | 29 | .527 | .312 |
| Carvers Creek Non-Turpentined | 28 | .525 | .325 |
| Salters Lake Turpentined | 24 | .512 | .278 |
| Salters Lake Non-Turpentined | 25 | .478 | .277 |

Mean sensitivity and inter-series correlation were similar between turpentined and non-turpentined chronologies. A modified *z*-test to test for significance between correlations returned no significant differences in IC and MS for turpentined and non-turpentined trees. I used the two-sample *t*-test to test for significant differences in MS between turpentined and non-turpentined trees at each site. COFECHA produces a MS and standard deviation value for each sample in the chronology, then pools these values into a chronology MS and standard deviation. Using these data, I was able to test for differences in MS between turpentined and non-turpentined chronologies (Table 6).

Table 6. *T*-test for Mean Sensitivity between turpentined and non-turpentined chronologies by site.

| **Site** | ***n*** | **MS** | **Std. Dev.** | ***t* value** | ***p* value** |
|---|---|---|---|---|---|
| Nichols Turpentined | 20 | .302 | .871 | -.0624 | .4752 |
| Nichols Non-Turp. | 30 | .319 | 1.024 | | |
| Weymouth Turpentined | 29 | .290 | .459 | .0000 | .5000 |
| Weymouth Non-Turp. | 27 | .290 | .635 | | |
| Carvers Turpentined | 29 | .312 | .715 | -.0573 | .4773 |
| Carvers Non-Turp. | 28 | .325 | .974 | | |
| Salters Turpentined | 24 | .278 | .639 | .0041 | .4983 |
| Salters Non-Turpentined | 25 | .277 | 1.021 | | |

### 4.9 Further Analysis of Weymouth Woods

The nature of the Weymouth Woods site allowed for a more in-depth analysis. Weymouth Woods had the longest usable chronology. MS between the two chronologies did not significantly differ. There was also historical evidence that the turpentining industry was not active after 1904 at the site (Hood & Stach, 2011; Owen, 2013). The site has a long-documented history from the ownership of the Shaws through the Boyd purchase to today. The land is protected from development as part of the Sandhills Nature Preserve and contains old-growth and virgin longleaf pine. Furthermore, there is a possibility that a number of the older trees from the non-turpentined chronology may in fact have been turpentined, but the scars have since grown over. To explore this possibility, I visually inspected the oldest samples from the non-turpentined chronology. I found that old non-turpentined cores (≥ 200 years) behaved similarly to the turpentined cores between the years 1880–1905.

I combined the turpentined and non-turpentined chronologies into a third chronology for Weymouth Woods to evaluate how the two chronologies behaved together. In addition, I analyzed only the chronologies of post-turpentining years (1901–2012) with COFECHA to determine if the combined chronology's statistics might differ from the others post-turpentining (Table 7).

Table 7. Weymouth Woods IC and MS for altered chronologies.

| Comparison of Inter-series Correlation and Mean Sensitivity for Turpentined vs. Non-Turpentined Chronologies at the Weymouth Woods Field Site | | | |
|---|---|---|---|
| **Chronology** | ***N*** | **IC** | **MS** |
| Combined (1800-2012) | 56 | .520 | .292 |
| Turpentined (1800-2012) | 29 | .502 | .290 |
| Non-Turpentined (1800-2011) | 27 | .537 | .290 |
| Turpentined (1901-2012) | 29 | .538 | .291 |
| Non-Turpentined (1901-2011) | 27 | .499 | .292 |

To test for differences between turpentined and non-turpentined chronologies, I performed a multi-ANOVA procedure on the Weymouth Woods chronologies, modeling BAI as a response against year and against treatment (turpentined, non-turpentined) (Table 8).

Table 8. Multi-ANOVA results for differences in turpentined and non-turpentined chronologies at Weymouth Woods (1800-2010).

| **Multi-ANOVA: BAI Response**<br>**Location: Weymouth Woods**<br>**Time Period: 1800-2010** | **Sum of squares** | **d.f.** | ***f* value** | ***p* value** |
|---|---|---|---|---|
| ID: turpentined /non-turpentined | 1136 | 1 | <.0001 | <.001*** |
| YR: year (1800-2010) | 89378 | 210 | <.0001 | <.001*** |
| ID:YR | 20363 | 210 | <.0001 | <.001*** |
| Residuals | 362696 | 7813 | | |
| Significance codes: '***' .001 '**' .01 '*' .05 | | | | |

Multi-ANOVA results indicate a significant difference in the factor ID (turpentined/non-turpentined) indicating a statistically measurable difference in the two populations' BAI means over time ($p < .001$).

# CHAPTER V

# DISCUSSION

To my knowledge, there has been no prior published research comparing the ring structure of remnant turpentined to non-turpentined longleaf pine trees in North Carolina. Grissino-Mayer *et al.* (2001) published a study that used tree-rings to date turpentined slash pine in Georgia. Their study used dendrochronology to date the periods of turpentining. The slash pine turpentining industry in Georgia occurred more recently (circa 1940) than the turpentining industry, based on the longleaf pine, in North Carolina (circa 1850–1880) (Veitch, 1936; Henderson, 1968). There have been numerous investigations into the physiology and growth of turpentined longleaf pines but no recent examination of the legacy effects of turpentining on longleaf pine exists (Ashe, 1894; Mohr, 1896; Wahlenberg, 1946; Dyer, 1960; Butler, 1998; Outland, 2004).

## 5.1 Effects of Turpentining on Longleaf

The boxing of longleaf pine had the most profound effect on its survival (Ashe, 1894; Butler, 1998; Outland, 2004). Most of the losses in the turpentining industry were due to the effects of wind on the weakened box cut pines, followed by fire on the turpentined face and increased insect damage (Ashe, 1894; Wahlenberg, 1946). Since my research focuses on living turpentined trees, I have limited my discussion on the effects of turpentining to the physiological differences in the growth and development of the tree.

Wahlenberg’s *Longleaf Pine: Its Use, Ecology, Regeneration, Protection, Growth, and Management* (1946) is a valuable resource describing the effects of turpentining on longleaf pines. Wahlenburg (1946) writes that longleaf pine could be worked for five tosix years before being rested, after which the trees could be “back faced,” chipped on a fresh face on an un-wounded area of the trunk, for another five to six years. Larger trees could be exploited again after another period of resting. Furthermore, turpentining always preceded lumbering by three years or more.

Wahlenburg (1946) reports that the life of green needles was reduced from three to two years on newly boxed and heavily chipped longleaf pine. Latewood growth was reduced in the new growth of the turpentined tree (Gerry, 1916). Tree height reduction due to turpentining was variable, and on hardpan soils with poor soil conditions, there was no difference in height between turpentined and non-turpentined trees. Two faces on a single tree reduced height, but this too varied by site and from tree to tree within a site (Harper, 1930). Chipping depth narrowed the ring growth and negatively affected the amount of latewood growth. Ring growth during turpentining varied from tree to tree (Figure 30).

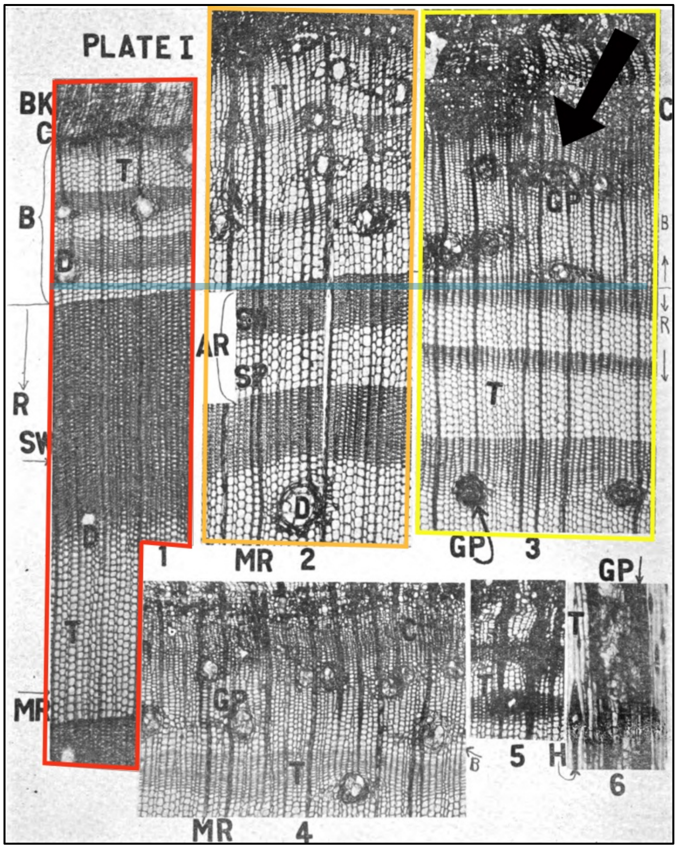


Figure 30. Highlighted samples in the photograph show the different effects chipping depth has on the ring width of longleaf pine. The blue line indicates the beginning of tormenting on the individual trees. The tree on the left (red) had deep chip marks. The tree on the right (yellow) received only light chipping. Adapted from Wahlenberg, 1946.

During active chipping and oleoresin collection, turpentining reduced the diameter growth of old-growth trees by about 25% (Wahlenberg, 1946). As did latewood growth and needle growth, diameter growth varied widely within site from tree to tree. In a study on a virgin stand of timber that had been worked heavily for four years, it was found that only five percent of turpentined longleaf had severely impeded growth, while another five percent were apparently unaffected (Cary, 1933). The remaining 90% suffered various reductions in growth.

Turpentining longleaf pine stimulated new resin duct formation behind and above the wound, often in groups within the annual ring (Gerry, 1922; Figure 29). Resin production from turpentining would saturate the xylem with resin, a process called resinosis (Wahlenberg, 1946; Butler, 1998). Resinosis due to turpentining extended radially from the wound toward pith. The resin ducts themselves would increase up to ten fold in size around the wound site (Snow, 1949).

There is a pronounced period of growth in longleaf pine post-logging or other disturbances that open the canopy (Wahlenberg, 1946). While turpentining, longleaf pines experienced a 20–40 percent growth reduction in DBH and height, but the tree is able to recover to pre-turpentining growth rates with decades post-turpentining. Wahlenburg (1946) notes that turpentined longleaf pine in the Piedmont and Sandhills resume height and diameter growth at faster rates than natural release events such as wind, fire, or selective logging.

Results from my four field sites concur with previous findings that test the effects of turpentining on longleaf pine. Below, an overview of the results is discussed, followed by individual sites' results. I discuss Weymouth Woods in considerable detail as it had the longest usable chronology from both the turpentined and non-turpentined trees, was the only field site where the chronologies extended before documented turpentining activities, and had known dates of when turpentining ceased.

## 5.2 Morphological Characteristics

### *5.2.1 Needle Length*

Needle length was only significantly different at Nichols Tract (1), where the mean non-turpentined needle length was significantly (one-sided $p < .001$) longer than the mean turpentined needle length (27.7 cm vs. 23.1 cm). Further data collection and testing should be carried out before any conclusions can be drawn about this result. My method of needle collection was to gather the samples from the base of each sampled tree. Sampling from the tree itself after the cessation of needle growth would be a further step that could confirm the results found in this study. Prior studies have shown turpentined trees to have a shorter period of needle growth during turpentining (Wahlenberg, 1946), but no evidence exists showing that turpentining produces shorter needles or shorter-lived needles post-turpentining activities.

### *5.2.2 DBH*

Recording DBH for turpentined trees was problematic due to the nature of the turpentine scars as the trees tend to bulge at the base around old box cuts. I took care to avoid overly wide or bulging trees, as any bulging would affect the DBH measurement.

For all sites, mean DBH was larger for turpentined trees than for non-turpentined trees, but the measurements varied in significance (Table 2). There was no statistical difference between DBH at the Nichols Tract. The largest and most significant difference ($p < .001$) was Salters Lake where turpentined trees were on average over 10 cm larger than non-turpentined trees. These results concur with Wahlenberg's (1946) observations of longleaf pine. The act of chipping and boxing a tree increases growth immediately around and above the wound. Subsequent years' growth tends to create a bulge at the base of the tree. This bulging also occurs in non-turpentined old-growth trees after a release event (Harper, 1930; Wahlenberg, 1946). Old-growth trees, nearly cylindrical and in a closed canopy, will grow around their base in much the same way as turpentined trees when released from competition (Wahlenberg, 1946).

**Nichols Tract**

There was no statistical difference in the DBH at the Nichols Tract (one-sided *p* value =.4332). Historical records and the tree-ring chronology show a major release event at the Nichols Tract around 1904–1908 (Figure 14). In 1895, the Page family, sawmill owners and turpentine transporters, extended the railroad line into Troy, NC, which is 10 miles south of the Nichols Tract. By 1898, the railroad lines had been extended closer to the property (Chesson, 2012). The arrival of the railroad, with the explicit purpose of providing lumber for the Page's sawmills and to transport turpentine barrels, coincides with the release date found in the tree-ring record.

The chronology for non-turpentined trees at Nichols extends back to AD 1771, and there is evidence in the form of turpentined stumps that the stand dates back to the 15$^{th}$ century. The tendency for old-growth trees to grow outward at the base when exposed to a release event might explain the lack of difference in the DBH between turpentined and non-turpentined trees. Another way to test for differences would be to measure the trees well above breast height, although this would be difficult to do in the field in comparison with the DBH measurement.

### Weymouth Woods

Weymouth Woods showed a significant difference in DBH (one-sided *p* value =.0036) between turpentined and non-turpentined trees; turpentined trees were over 10 cm larger in diameter than non-turpentined trees. Trees at this site were similar to trees at Carvers Creek and Salters Lake in that the turpentined trees showed pronounced bulging at the base. This bulging produced “hips” on the tree from the new growth surrounding the box face. The DBH resulting from turpentining concurs with prior research by Wahlenburg and others.

### Carvers Creek

Carvers Creek shows similar DBH results (one-sided *p* value =.0156) to the other Sandhills site Weymouth Woods. The difference at Carvers Creek was slightly lower (8 cm on average) than Weymouth Woods but still pronounced.

### Salters Lake

The difference between the DBH for turpentined and non-turpentined was the greatest at Salters Lake (10.7 cm difference; one-sided *p* value <.001). With the sandy soil and poor growing conditions at Salters Lake, longleaf pines are limited in growth potential. Due to the limiting soil conditions (poor water retention, low nutritive value) of the sandy Carolina Bay rim of the Salters Lake tract, it is likely the turpentined trees were still able to gain as much nutrition from the soil as the non-turpentined trees. The non-turpentined trees saw no advantage over the turpentined trees because the harsh environment restricted growth.

### *5.2.3 Height*

The turpentined longleaf pine trees sampled for this study had more gnarled and sparser crown formations than the non-turpentined trees. Turpentined trees had fewer branches and more signs of damage in the crown. Despite this noted difference in the appearance of the crown, there was no statistical difference in height between turpentined and non-turpentined trees (Table 3). At Nichols Tract, Carvers Creek, and Salters Lake the non-turpentined trees were taller on average. At Weymouth Woods, the turpentined mean height was slightly higher than the non-turpentined mean height, although this could be due to differences in the sampling procedures as the two data sets for this site were collected at different times by different teams.

### *5.2.4 Age*

The measurements for age of turpentined trees do not reflect the absolute age of the tree (Table 4). I have included the data to illustrate the difference between the chronologies. The non-turpentined chronologies reached pith for the majority of samples, while the turpentined chronologies did not. Despite the similar ages of the chronologies, the turpentined trees are most likely older. Trees were not routinely used for turpentining until they reached 20 cm DBH, at which time most longleaf pine were at least 30-years-old (Butler, 1998).

## 5.3 Radial Growth

### *5.3.1 BAI*

An overall pattern was found in BAI growth between turpentined and non-turpentined trees where turpentined tree growth accelerated post-turpentining for a number of years post-turpentining (Figures 14–17). At each site, the turpentined and non-turpentined trees show similar BAI patterns during 1940–2000, but the relationship weakens during the past decade. Only the Weymouth Woods chronologies extend to the pre-turpentining period (Figure 15) and the BAI pattern between turpentined and non-turpentined chronologies diverges around 1860 and again in 1890, which corresponds to historical records and oral accounts of active turpentining periods. During 1900–1930, when turpentining ceased, turpentined tree growth rebounded similarly to release event such as logging or wind throw. A similar, but less apparent result is evident at Carvers Creek (Figure 16). The rebound effect can be seen from 1895–1940. At Carvers Creek, turpentining would have ended at the end of the 19$^{th}$ century. The records at Carvers Creek do no extend into the turpentining era as they do at Weymouth Woods. Likewise, the chronologies at Salters Lake begin after the turpentining industry had largely left the area.

The similarity between turpentined and non-turpentined chronologies gives evidence to the resilience of longleaf pines to the damages of the turpentining industry. It was longleaf pine's ability to withstand heavy and chronic abuse that made it such a successful species for turpentining. Slash pine yielded more oleoresin than longleaf but could not withstand the damage to the cambium inflicted with the box cut method

(Wahlenberg, 1946). If the longleaf had not been so resistant to abuse, the more conservative French facing method may have been employed much earlier, possibly reducing the damage inflicted to the longleaf savanna ecosystem by the naval stores industry.

### *5.3.2 IC and MS*

Turpentined trees experienced different levels of chipping and boxing for different lengths of time at each site (Ashe, 1894; Wahlenberg, 1946), which led me to expect that the IC for the turpentined chronology would be weaker than the IC for the non-turpentined chronology. This was largely the case (Table 5). The exception was the Salters Lake site, where the turpentined IC was higher than the non-turpentined IC (.512–.478).

There was no overall pattern in MS (Table 5). The non-turpentined chronologies at Nichols Tract and Carvers Creek had higher MS than the turpentined chronologies. MS was equal at Weymouth Woods and nearly equal at Salters Lake (Table 5). There was no statistical difference between either IC or MS for turpentined and non-turpentined chronologies for any site. The similarities between turpentined and non-turpentined chronologies attest to the resilience of the remaining turpentined longleaf pine and its ability to resume normal growth and development post-turpentining.

### *5.3.3 Differences in BAI*

Living turpentined longleaf face increased risk from insects, fire, and wind when compared with non-turpentined longleaf; but both populations have a similar response to site variables. To test for differences in longer-term radial-growth trends, I subtracted turpentined BAI from non-turpentined BAI and graphed the difference over time (Figures 18–21). All turpentined chronologies, except Weymouth Woods, are experiencing a decrease in BAI over time when compared with the non-turpentined chronologies. Two sites, Nichols Tract and Carvers (Figures 18, 20), show a distinct shift at 1940, where the turpentined chronologies lose vigor in comparison to the non-turpentined chronologies. There is an overall downward trend at Salters Lake, and a slight upward trend at Weymouth Woods. There is an apparent oscillation in the Weymouth Woods data (Figure 15), which is absent during the turpentining era during the years 1850–1900.

As a group, the turpentined trees show no overall trends. At all sites except Weymouth Woods, turpentined and non-turpentined chronologies appear to be inter-annually stable in the recent record (1940–2010). Since 2008, the turpentined chronologies at all sites have added less growth than the non-turpentined trees. The four growing seasons from 2007–2010 were drought years, 2007 being a pronounced drought year (May–October PDSI = -2.76). The year 1940 was also a pronounced drought year (PDSI = -2.34). Longleaf pine trees react negatively to high temperatures, which can severely restrict latewood growth (Lodewick, 1930; Meldhal, 1999). PDSI is not the best measure of short-term (< 12 month) climate variation (Dai & NCAR, 2013). It is possible that a period of high temperatures or dry weather has some pronounced effect on the turpentined longleaf pine and that the PDSI is not sensitive enough on a weekly basis to register the phenomenon.

*5.3.4 Regime Shift*

When analyzed at five-year minimum intervals, the turpentined chronologies all showed more regime shifts than did non-turpentined cores with the Weymouth Woods tract showing the greatest disparity between the two chronologies (Figures 22–25). At the Nichols Tract and Carvers Creek, both chronologies' regimes move in unison post-1950 (Figures 22, 24). A possible post-turpentining rebound is evident in the Nichols Tract from 1900-1905 (Figure 22) and from 1888–1904 at Carver Creek (Figure 24). Regime shifts do not follow a set pattern at Weymouth Woods or Salters Lake. At Weymouth Woods, the turpentining era is evident from 1890–1900, as is the subsequent rebound (Figure 23). The Salters Lake shows the most stability over time, with non-turpentined trees approaching turpentined trees but the average BAI remaining approximately 15 $cm^2$/yr. The regime shift analysis revealed no common pattern amongst sites; however, at all sites except Weymouth Woods, non-turpentined chronologies showed gains over turpentined chronologies.

The Weymouth Woods BAI chronologies show the two chronologies converging in 2011 (Figure 15). The strength of using regime shift analysis is for assessing stability of turpentined versus non-turpentined chronologies. I conclude, for the sites in this study, the turpentined chronologies show a greater sensitivity to site dynamics than the non-turpentined chronologies.

*5.3.5 Drought Response*

Basal Area Increment growth was not statistically different between turpentined and non-turpentined chronologies for the drought periods analyzed (Figures 26–29). For all sites, the response of turpentined BAI varied more between drought periods than did non-turpentined BAI, although, as noted above, the relationships between turpentined and non-turpentined chronologies were not significantly different.

Nichols Tract and Carvers Creek exhibited the same pattern for drought response as in other areas of this research with turpentined trees losing vigor over time in comparison to the non-turpentined trees (Figures 26, 28). At Weymouth Woods, the non-turpentined trees grew at roughly 80 percent of their average over all drought periods analyzed while turpentined trees varied considerably more over the same periods (Figure 27). For sites in this study, box cuts and cat face scars did not slow the growth of turpentined trees as compared to growth of non-turpentined trees during selected drought periods.

## 5.4 Site Observations

*5.4.1 Nichols Tract*

The turpentining years were not readily apparent from the Nichols Tract data. Interviews with family members and local historians and historical records documenting the arrival of the railroad in the 1890s, point to the beginning of turpentining and heavy logging in the early 20$^{th}$ century (Ashe, 1894; Allen, 2012; Chesson, 2012). A release event in the early 1900s is evident in the both turpentined and non-turpentined tree-ring records (Figure 31). It was common practice to chip trees for turpentine prior to logging by five or more years, and the removal of some of these turpentined trees could explain the apparent vigor of the turpentined chronology early in the record. All logging activities stopped in the early 1930s when Margret Nichols convinced her father to stop harvesting longleaf (Allen, 2012). The actions of Margret Nichols likely preserved the turpentined and non-turpentined trees found today at the Nichols Tract.

The vigor of both turpentined and non-turpentined trees reached a peak in the 1940s and early 1950s (Figure 14). Subsequent fire suppression in addition to reduced logging suppressed BAI in the following decades (Figure 32).

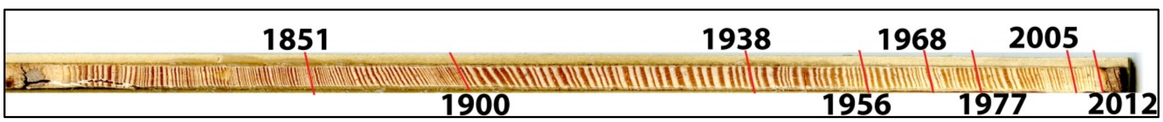


Figure 31. A non-turpentined core from Nichols Tract. Years in black refer to release events, historical events, or correspond to the photographs in Figure 32. There is a noticeable, sustained release after 1900, presumably from logging. Notice the reduction in ring widths after 1977. Notice also the difference in growth in the roughly equal periods of 1900–1938 and 1977–2012, presumably due in part to a reduction in open canopy.

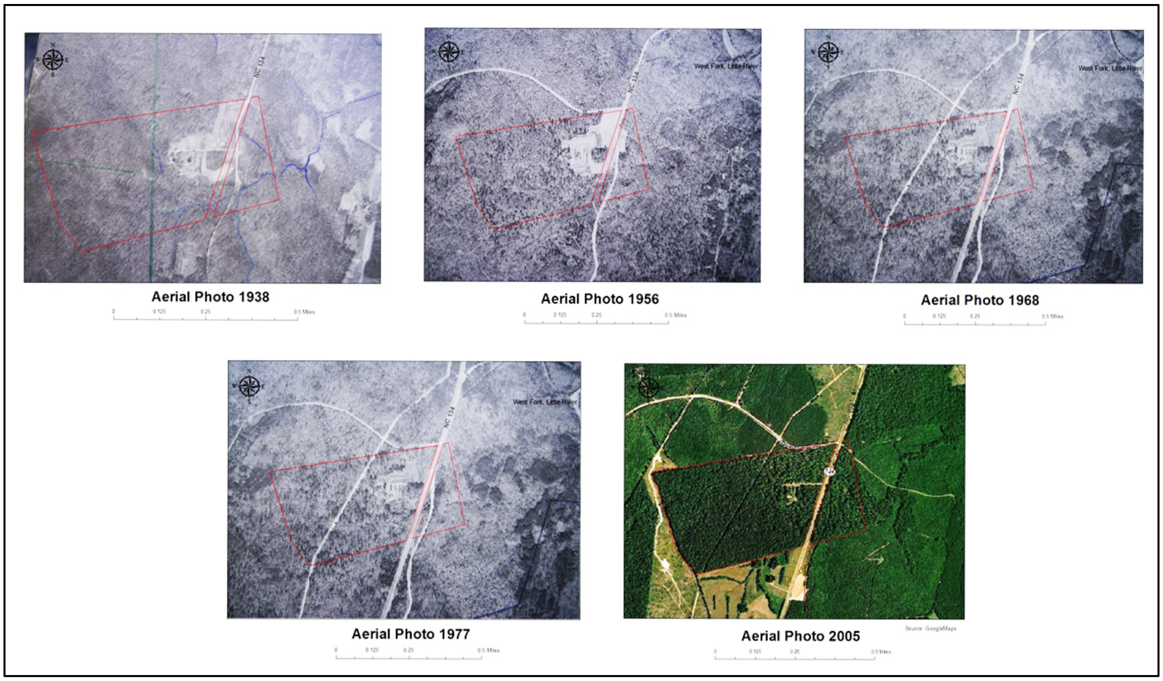


Figure 32. Aerial photographs of Nichols Tract show forest-canopy cover from 1938–2005. Logging had ceased by 1938, and there were no major fires reported post- 1930s. Notice the increase in canopy cover from 1977 to 2005, hardwood trees growing after fire and logging suppression would have matured and reached the upper canopy by this time.

Turpentined trees' BAI values are markedly less after 2000. The reduction in BAI could signify a problem for these trees when coupled with the re-introduction of fire at the Nichols Tract in 2013. Turpentined trees are more damage susceptible with fire than non-turpentined trees, and the re-introduction of fire can have mortal consequences for old-growth trees, as roots growing into the accumulated humus layer formed when fire is suppressed are killed and damaged with the return of fire (Varner *et al.* 2005). The Nichols Tract managers have attempted to protect the remaining turpentined longleaf pine, but fire remains a threat to the continued health of the turpentined trees (Figure 33).

Turpentined stumps were lost in the first controlled fire, and it remains to be seen how living turpentined longleaf react to the re-appearance of fire.

Figure 33. The photo on the left shows the pit created after a turpentined stump burned during a prescribed burn at Nichols Tract. The photo on the right shows juvenile longleaf pine (in the bottlebrush stage) at Nichols Tract sprouting new leaves post burn. Photos by Lindsay Cummings.

*5.4.2 Weymouth Woods*

With respect to sample depth, historical records, and consistent, documented land management, Weymouth Woods was superior to other sites in this study. The Shaw's Ridge farm, which formed a major portion of downtown Southern Pines and part of Weymouth Woods, was a working farm and naval stores operation run by Charles C.

Shaw from 1781–1852 (Lindau, 1987). The railroad came to the Shaw property in 1877, which led to a rapid increase in production of turpentine. The land was divided amongst Shaw's children, and a portion of Shaw's Ridge was bought by a naval stores company that turpentined the site before selling 160 ha to John T. Patrick in 1883. Patrick established Vineland in 1887, the name of which was later changed to Southern Pines. The Boyd purchase in 1904 of the Shaw's Ridge Tract, which is the field site Weymouth Woods, signaled the end of turpentining operations on the property (Figure 34).

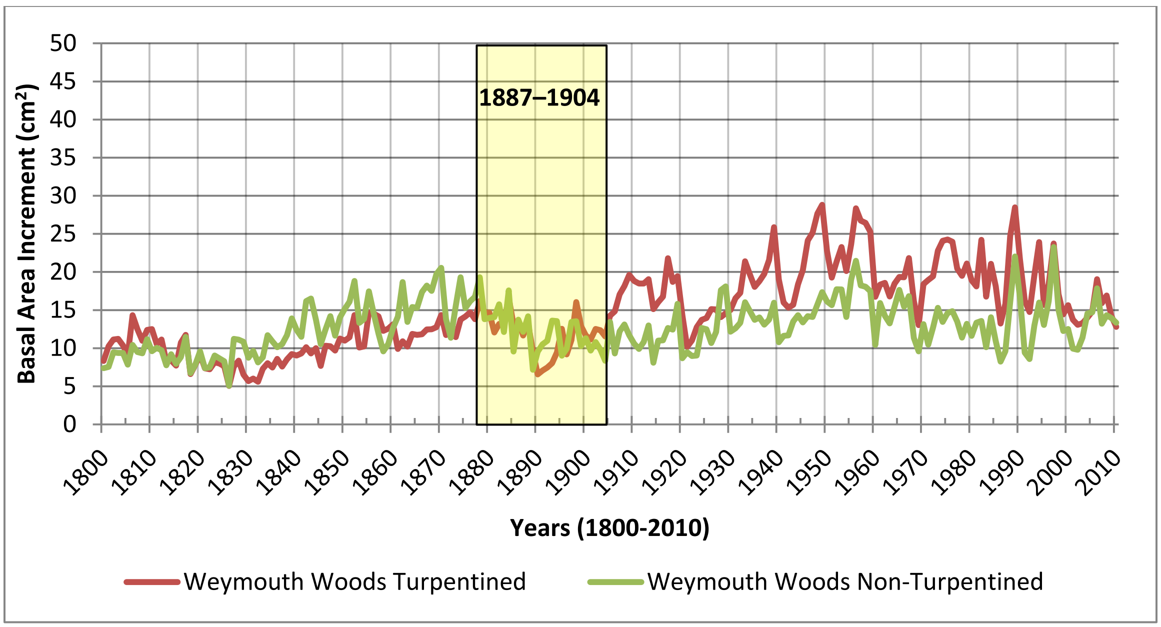


Figure 34. The highlighted years (1887–1904) mark the period of intensive turpentining at the Weymouth Woods field site. Notice the rebound of the turpentined chronology (red) after turpentine production ceased in 1904.

A sample depth of 22 cores from 1800 and increasing to 56 cores by 2011 ensured tree-ring records from Weymouth Woods spanned the entire turpentining era (approximately 1850–1900 for the Sandhills and Piedmont sites). While not all trees in the Weymouth

Woods estate were turpentined, many of the old-growth trees on the property have box cuts and cat faces. A number of the larger trees on the property show only a small scar at the base of the tree, while many smaller trees on the upland portion of the site show scars over ten feet tall (Figure 35) .

Figure 35. A typical cat face from Weymouth Woods (left) and a close-up view of a box cut (right). Notice the v-shaped cuts made in the face in the photos, which led to the cat face or chevron moniker. Photos by Lindsay Cummings.

Figure 36 shows the signs of resinosis and trauma rings (between arrows) during the period of heavy turpentining (1887–1904).

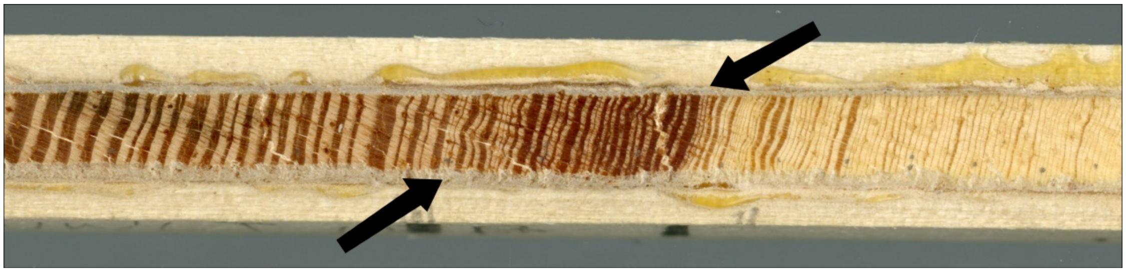

Figure 36. Tree-ring sample taken from a turpentined longleaf at Weymouth Woods. Discoloration between the arrows is due to resinosis from trauma experienced during the turpentining process.

Figure 37 shows the enlarged oleoresin ducts formed by the trauma of chipping into the xylem of the tree (arrows). The years of known active turpentining are marked in red in the following figures. Also visible in Figure 37 is the discoloration due to resinosis after turpentining. These indicators are not evidence of turpentining on their own. However, when combined with historic data and visual confirmation of scarring, tree-ring evidence can be attributed to turpentining activity and not to some other form of disturbance.

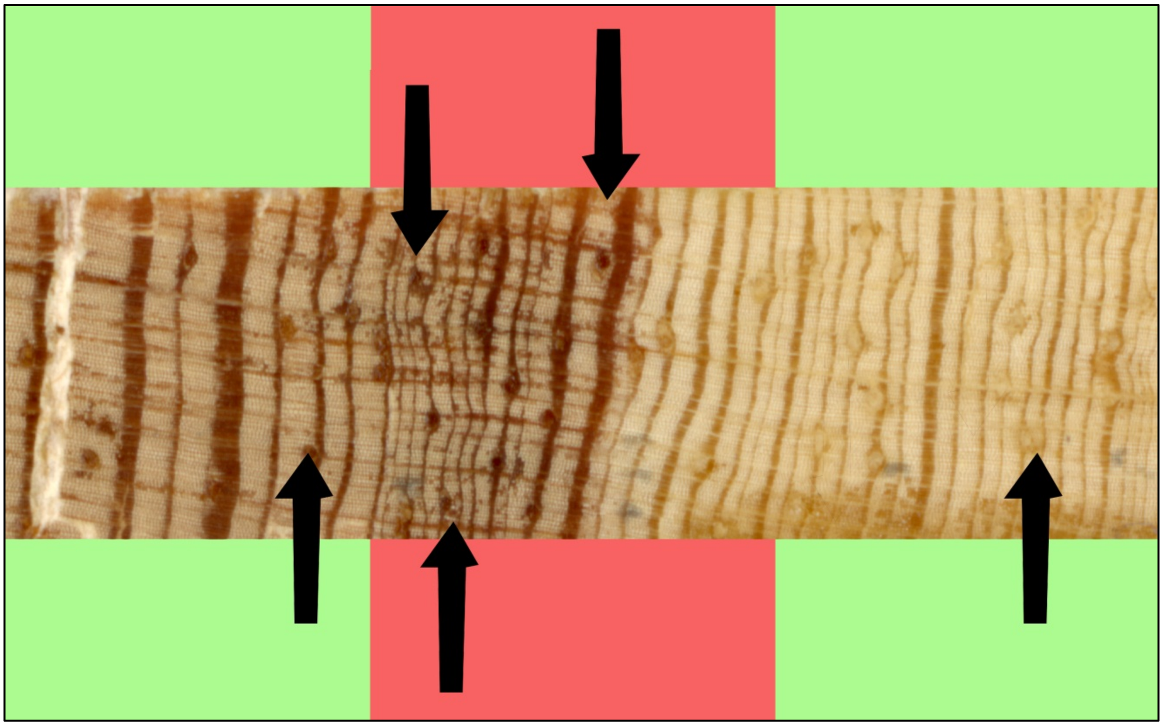

Figure 37. Trauma such as turpentining causes oleoresin ducts to expand and multiply. Notice the oleoresin ducts (arrows) during the turpentining period (red) and the discoloration of the wood. Trauma rings are also present during turpentining.

A plot of means for the Weymouth Woods site showed turpentined and non-turpentined annual BAI diverging most noticeably between the years 1850 and 1905 (Figure 38). Further analysis with the multi-ANOVA procedure showed the turpentined and non-turpentined chronologies to be statistically significantly different from the period 1800–2010 (one-sided $p$ value $<.001$) (Table 8).

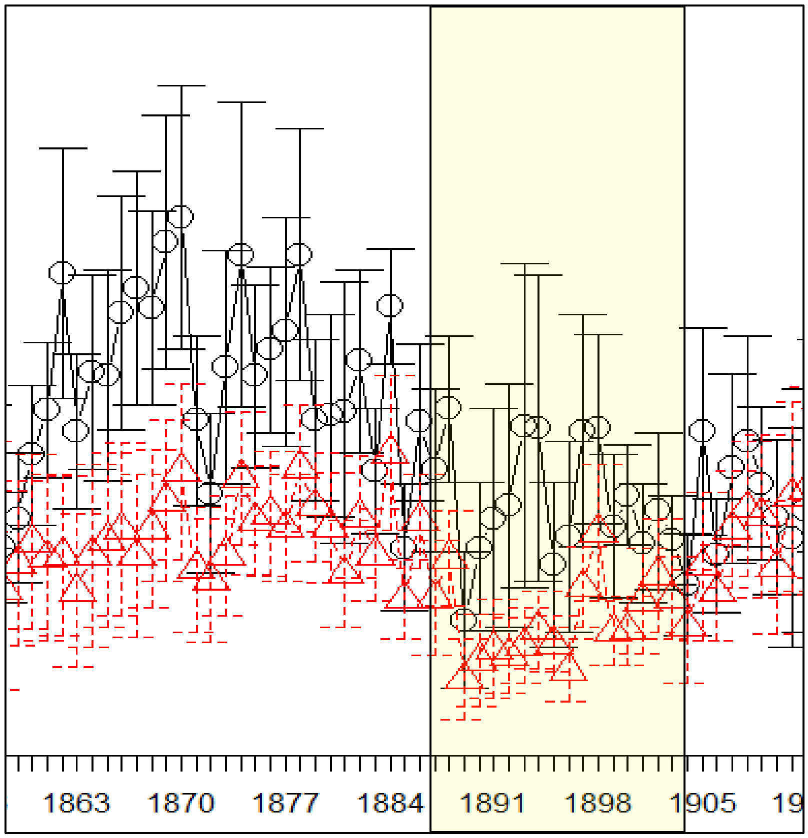


Figure 38. A portion of the plot-of-means chart showing the range of BAI growth for turpentined (red) and non-turpentined (black) chronologies during the period of turpentining activities. The Y-axis (not shown) ranges from 0–50 $cm^2$. Notice the wide range of non-turpentined BAI in relation to the narrower range of the turpentined BAI from 1887–1904 (yellow).

When combined into a single chronology (Table 7), the Weymouth Woods trees—both turpentined and non-turpentined—have a stronger IC (.520) than the Weymouth Woods turpentined chronology (.502) and other field sites in this study. The IC correlation of the turpentined chronologies was expected to be lower due to the random nature of the turpentining industry's chipping, facing, and boxing of trees from year-to-year. Multiple faces and different rates of chipping can drastically alter the growth rate of a tree over a longer period of time (Figure 39). Periods of resting, in which trees were not turpentined, further hinders correlation for periods of turpentining.

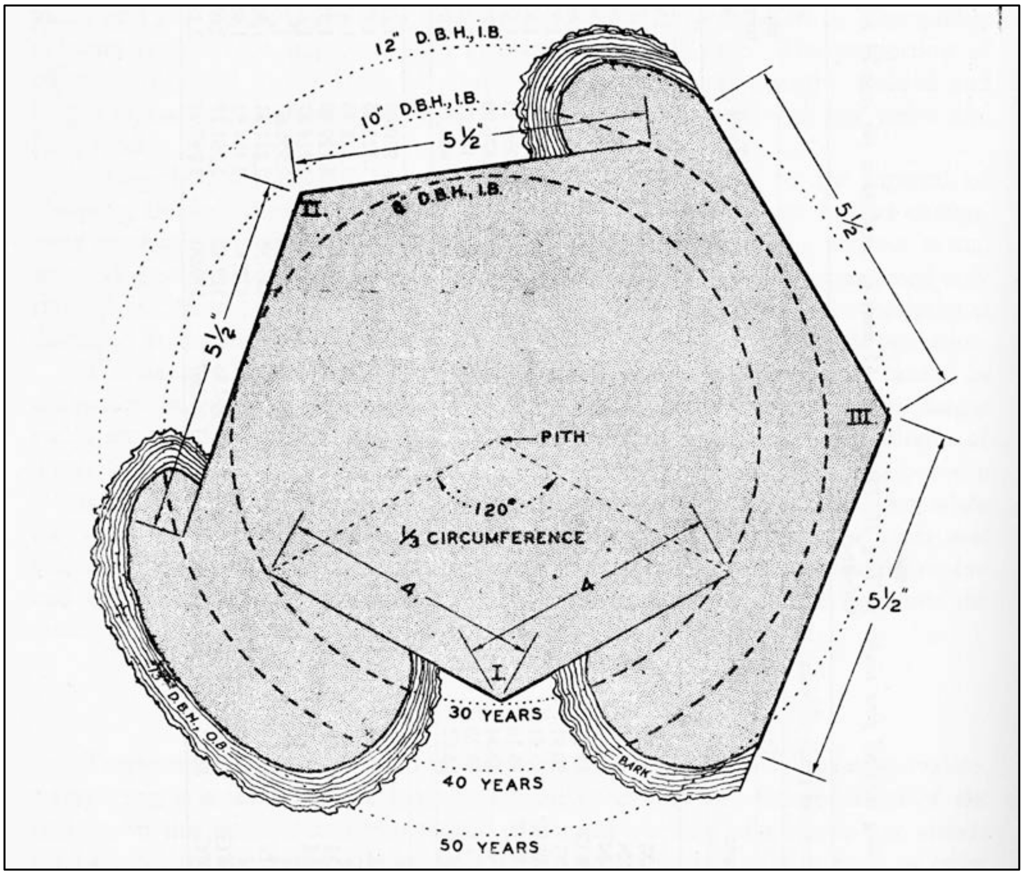


Figure 39. This figure depicts one method for turpentining a longleaf pine. The tree was fist chipped when it was 30-years-old and continued to be chipped periodically until it was 50-years-old. Different widths of chipping, periods of rest, and multiple faces all contribute to weakening IC in the turpentined chronologies. Reprinted from Wahlenberg (1946).

In order to test the strength of the chronology during the 20th century, I removed years prior to 1901 and analyzed the resulting chronologies for turpentined and non-turpentined trees at Weymouth Woods (Table 7). The IC of the resulting chronologies from 1901–2012 show an increase in turpentined IC (from .502 to .538) and a decrease in non-turpentined IC (from .537 to .499). The discrepancy in the turpentined chronology was expected after removal of the turpentined years. The discrepancy in the non-turpentined chronology was not expected. The non-turpentined chronology had 6 out of 15 trees dated to pith after 1900. It is possible that young trees and older trees at Weymouth Woods show different growth responses to site conditions, which would explain the difference in IC for the period 1901–2011 for non-turpentined trees. Further research could test for a difference in younger versus older trees at Weymouth Woods. Further research could also test if turpentined trees differed from non-turpentined trees of the same age. As Weymouth Woods differed in BAI compared to the other sites, and as the site is of cultural and ecological importance, it would be worthwhile to investigate this matter further.

The Weymouth Woods site is unique amongst the sites in this study in that the turpentined trees there have sustained vigor over time in comparison to the non-turpentined trees. Considering the heavy scarring from box cutting, it is interesting that the trees at Weymouth Woods have outpaced the non-turpentined trees in growth over the last century. Since 2003, both chronologies have shown decreased growth, but there is no evidence that turpentined trees are faring worse than the non-turpentined trees. At least one of the turpentined samples had added no growth in 2012, a sign of a dying tree. Fire has been used sparingly at Weymouth Woods, especially in the sample area, because of the presence of turpentined longleaf trees. It is important that the caretakers of Weymouth Woods protect turpentined trees as they add aesthetic appeal and historical significance to the landscape. Whether from careful management or from ideal site dynamics, the turpentined trees at Weymouth Woods continue to grow and perform like their non-turpentined neighbors.

### *5.4.3 Carvers Creek*

The tree-ring record at Carvers Creek begins after the period of heavy turpentining in the area (Hood, 2006). The land at Carvers Creek, formerly Long Valley Farm, was most likely removed from turpentine production in 1892 when the land was sold to a timber company at auction. There is a period of rebounding growth for the turpentined trees the late 1880–1940s (Figure 15), which is likely a reaction to the end of turpentining. The turpentined trees lost vigor in comparison to the non-turpentined trees after 1940, when this pattern also occurred at Nichols Tract. There was a period of drought from 1940–1942 in the Piedmont region that impacted the chronologies at Nichols Tract, Weymouth Woods, and Carvers Creek. The turpentined trees at Carvers Creek did not return to their prior growth pattern post-1940s drought.

Carvers Creek showed few discernable differences between chronologies, with similar IC and MS between turpentined and non-turpentined trees. Regime shift analysis showed an increase in growth for turpentined trees around 1888 that might be evidence of a post-turpentine rebound (Figure 24). The two chronologies showed similar regime shifts around 1905 and 1968. Non-turpentined trees outperformed the turpentined trees since 1942 in all but one year (Figure 16). The turpentined longleaf pines at Carvers Creek showed more deformation than turpentined trees at other sites (Figure 40). Trees had sparse crowns and crooked, leaning trunks. The turpentining operations at Carvers

Creek began in 1847; it is likely the trees suffered chipping at an earlier date and over a longer period than turpentined longleaf at Nichols Tract or Weymouth Woods. The box cuts and cat faces on the trees at Carvers Creek were distinctly different from the markings on trees at Nichols Tract and Salters Lake, appearing most similar to the markings at Weymouth Woods.

Figure 40. Turpentined longleaf at Carvers Creek (left) displaying deformed crown common among turpentined trees at all sites. A cat face scar, or chevron, remains visible 100 years post-turpentining at Carvers Creek State Park (right). Notice fire charring on the trunk face in the photo to the right. Photos by Lindsay Cummings.

### *5.4.4 Salters Lake*

The Salters Lake site showed little variation between turpentined and non-turpentined trees. Located in the sandy soil of a Carolina bay, the Salters Lake site has a lower capacity for holding moisture than the loamier soils of the Sandhills or the clayey soils of the Piedmont (Lodewick, 1930; Henderson & Grissino-Mayer, 2008). Water in the porous, sandy soil quickly drains after a rain event; and trees cannot benefit from the overabundance of precipitation as the soil has little ability to retain moisture. This may explain why the turpentined trees and non-turpentined trees at Salters Lake behave in such a similar manner. MS was the lowest at Salters Lake for both turpentined and non-turpentined trees amongst all study sites, meaning the variation in growth from year-to-year was lower between wet and dry years. The Salters Lake site is in an edaphically harsh environment where non-turpentined longleaf pines are restricted in growth due to low soil moisture and nutrient content. Unlike the more favorable Piedmont site at Nichols Tract or the loamier sandy soil of Carvers Creek, the non-turpentined trees at Salters Lake cannot take advantage of good growing years any more than the turpentined trees (Figure 41).

Figure 41. Stumps and a living tree showing signs of turpentining are actively protected from fire at Salters Lake. Notice the rake marks around the stump on the left. These photos highlight the different states of the turpentined stumps and trees at Salters Lake. Photos by Lindsay Cummings.

The naval stores industry had a long history in Bladen County that was concentrated around the Cape Fear River and the county seat of Elizabethtown, NC, six km south of Salters Lake (Powell, 1968). For a century after the town's founding in 1773, the longleaf pine forest provided turpentine, pitch, and tar to the markets in Wilmington. By the 1880s, Salters Lake was a "wasteland," devoid of trees or arable land (Ashe, 1894). In 1936, the land was re-forested by the Civilian Conservation Corps due to lack of productive timber; and in 1939, it became a state park. The turpentined trees that remained at Salters Lake were too marginal to be considered worthwhile for timber or turpentining in the 1880s, which is when my chronologies for the site start. These "wasteland" trees passed over for cutting in the 1880s have continued to survive and have provided vital ecosystems services for more than a century (Peet, 2006).

### 5.5 Conclusion

Turpentined longleaf pine provide a physical link to past land use. Living, turpentined trees serve as a reminder and a monument to the state's long and storied history of exploitation, both of people and of nature. This thesis aimed to raise awareness of the significance of turpentined longleaf pine trees in North Carolina and to examine the long-term effects of the naval stores industry on living, turpentined trees. The vast majority of turpentine longleaf pine have died. The turpentining process as it was practiced in the Southeast was unnecessarily destructive. The trees I sampled for my thesis represent the strongest, most robust turpentine longleaf pine. These trees do not reflect the damage done due to wind, fire, and disease. No conclusions should be drawn about the overall effect of climate and time on all living turpentine longleaf pine. The conclusions drawn here refer to living standing turpentined longleaf pine.

There were few morphological differences between turpentined and non-turpentined trees. Needle length was different for one site, Weymouth Woods. Turpentined trees had greater DBH, but significance varied between sites. There were no differences in height. From a morphological perspective, the living turpentined trees have fared equally in comparison to non-turpentined trees. The turpentined trees remain at a greater risk of wind throw, fire damage, and insect infestation, but aside from the physical damage caused by the scarring, they show no difference from non-turpentined trees.

Radial-growth data showed more variation than morphological data. The sites of Nichols Tract and Carvers Creek showed the most agreement between sites. At these two sites, turpentined trees showed a post-turpentine rebound period followed by substantial reductions in growth. The same overall pattern (post-turpentine rebound followed by growth reduction) is less pronounced but still evident at Salters Lake. The Weymouth Woods site provided the exception, where radial growth of turpentined trees was actually greater than non-turpentined trees even after the rebound period. Turpentined trees were no different in their susceptibility to drought from non-turpentined trees. However, shifts in BAI determined from regime shift analysis occurred during drought years for the turpentined chronologies, but generally was not detected in non-turpentined trees.

Weymouth Woods was the most informative of all the sites in this thesis. The chronologies from Weymouth Woods spanned the period of turpentining, and the historical records give insight into past land use, fire, and turpentining at the site. The chronologies at Weymouth Woods showed evidence of turpentining, and highlight the sensitivity of the turpentined trees post-turpentining. There is a large population of turpentined longleaf pine at Weymouth Woods, the majority of which were not used in this study. The results from this thesis justify further sampling and analysis from this site. A larger sampling of turpentined and non-turpentined trees would help confirm the results found in this study. It would be difficult to extend the study at other sites due to a lack of turpentined samples and presence of rot in the turpentined trees.

For more than a century the turpentined trees studied here have survived. Scarred but not stunted, overgrown cat faces and box cuts provide evidence of the past lives of turpentined trees. For the amount of abuse and mistreatment these trees endured, it is suprising to find such small differences between turpentined and non-turpentined trees.

Regardless of their robust rebound after chipping and their continued health, the window for experiencing turpentined trees is closing. Like other vestiges from the naval stores industry, old turpentined trees are disappearing from the landscape. While they remain, they offer a tool to inspire and connect the people of North Carolina to their past and their role in shaping its future.

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