Dendroclimatological Analysis of Oak Species in the Southern Appalachian Mountains

A Bachelor's Honors Thesis

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Abstract

A dendroclimatological study was performed on oak species from three sites in the southern Appalachian Mountains. Tree-ring chronologies were developed for Griffith Knob and Little Walker Mountain in the Jefferson National Forest, Virginia, and for Gold Mine Trail in the Great Smoky Mountains National Park, Tennessee. The longest of these chronologies extended from 1836 to 2005, and the oldest tree sampled had a minimum age of 170 years. We statistically compared the three chronologies with monthly precipitation, temperature, PDSI, and PHDI data from local NCDC climatic divisions for the years 1930 to 2005. Oak tree growth correlated significantly and positively (highest $r = 0.50$, $p < 0.0001$) with precipitation for each site during one or more summer months (May–July). Temperature correlated significantly and negatively (lowest $r = -0.36$, $p < 0.002$) at each site during the same period. PDSI and PHDI each correlated positively and significantly (highest $r = 0.57$, $p < 0.0001$) with growth throughout the growing season, with correlations extending into the previous fall at lower elevation sites. Macroclimate factors were similar at each site, yet microclimate differences influenced the duration of the climate signal. The results of this study suggest that oak species in southern Appalachia require a cool, moist summer for maximum growth to occur, while fall moisture availability is important for oaks in a warmer and drier climate. These climatic analyses yield valuable information for the feasibility of climate reconstruction from forest interior trees and the assessment of oak forest health.

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Chapter 1

Introduction

1.1 Introduction

Climatic variables such as precipitation, air temperature, and drought often define the amount of annual radial growth in trees located in temperate regions. The climate-tree growth relationship provides important data that can be used to model past climatic conditions. Thus, the nature of future climate can be inferred from tree-ring records from the past (Fritts 1976). The purpose of this study is to use dendroclimatological techniques to analyze the climatic responses of three mixed-oak (*Quercus* spp.) chronologies from sites located in the southern Appalachian Mountains. The trees sampled for this study are located in mixed pine-oak forests at the Griffith Knob (GK) and Little Walker Mountain (LW) sites in the Jefferson National Forest, Virginia, USA, and the Gold Mine Trail (GMT) site in the Great Smoky Mountains National Park, Tennessee, USA.

Oak is a proven species for dendroclimatological studies, and has been used extensively in locations throughout North America (Fritts 1962; Pan *et al.*. 1997; D'Arrigo *et al.*. 2001). This study incorporates several different species within the *Quercus* genera including white oak (*Quercus alba* L.), black oak (*Quercus velutina* Lam.), scarlet oak (*Quercus coccinea* Muenchh.), northern red oak (*Quercus rubra* L.), chestnut oak (*Quercus montana*), and blackjack oak (*Quercus marilandica* Muenchh.). Oak is a ring porous wood type, with large, prominent pores in the earlywood clearly marking the ring boundary (White 1980). The nature of oak ring formation makes this type of wood a very good choice for dendrochronological research because it had clear ring boundaries and rarely produces false or locally absent rings (McCarthy and Bailey 1996).

1.2 Dendrochronology

The science of dendrochronology studies the annual growth rings of wood to analyze the ecological and environmental factors that influence tree growth (Fritts 1976). The growth patterns found in tree rings are recognized as reliable indicators of climate dynamics. Researchers have applied dendrochronology to several subfields, including dendroclimatology (Schulman 1942), dendroarchaeology (Douglass 1929), and dendrogeomorphology (Smith *et al.* 1994). The subfield of dendroecology investigates stand dynamics (Abrams *et al.*. 1997), disturbances such as wildfire and insect outbreak (Speer *et al.* 2001; DeWeese 2007), and masting periods (Speer 2001). Dendroclimatology is perhaps the most important subfield of dendrochronology today because of widespread concern over rising global temperatures.

Dendrochronological research is far from complete in the southern Appalachian Mountains. More tree-ring studies have taken place in the southwestern United States because the trees are considered more sensitive. However, trees in southern Appalachia have proven to be limited by precipitation and temperature (Grissino-Mayer and Butler 1993; DeWeese 2007), making dendrochronological studies possible. Because few dendroclimatological studies in the region have analyzed oak, a greater knowledge of the climatic factors that affect the genera is desirable. Out of all species of oak in the southern Appalachians, dendrochronologists have studied white oak most often, leaving many analyses still to be done on the remaining species. This research looks at climate response on a genera-wide scale within the region, incorporating multiple species into single chronologies.

1.3 Objectives

The two primary objectives of this research are:

- To develop interspecies oak tree-ring chronologies for three study sites in the southern Appalachian Mountains.
- To statistically analyze the climate-tree growth relationship in various oak species and investigate the presence of a clear climatic signal.

Chapter 2

Literature Review

2.1 Biogeography and Ecology of Oak Species in Appalachia

Oak trees are abundant across the eastern United States, particularly in the Appalachian Mountains, and the disturbance history and successional trends of the eastern oak community type have been extensively studied (Stephenson and Adams 1989; Abrams and Copenheaver 1999; Abrams 2005). Natural disturbances such as wildfire and the chestnut blight (*Cryphonectria parasitica* (Murr.) Carr) have affected oak species both adversely and advantageously in the Appalachian Mountains and eastern United States (Abrams 2003). Anthropogenic disturbances have been wide-spread in the region for centuries as well, and human-related disturbance intensified after European settlement (Delcourt and Delcourt 2000).

2.1.1 Stephenson and Adams (1989)

Red oak was studied in the mountains of western Virginia to obtain a greater understanding of the high-elevation oak community type. Red oaks at 13 sites in the Ridge and Valley and Blue Ridge provinces of Appalachia were cored and quantitatively analyzed. The study was conducted obtain data on composition and structure of red oak forests, and to assess red oak forest successional dynamics and present status (Stephenson and Adams 1989).

Stephenson and Adams surveyed soils of the 13 sites, and found red oak forests in middle-Appalachia to consist generally of highly acidic sandy loams and sandy clay loams. They determined red oak to be a very gap-opportunistic species. In their analysis, the chestnut blight was found to be the most important factor in the advancement of red oak into the canopy. Stephenson and Adams determined that the species has replaced the chestnut's role in the forest, and other species are not likely to displace it. Furthermore, red oak-dominated uplands have recently become even more extensively populated by the tree. The understory at each site was also dominated by red oak, signifying a continued prominence in the coming century (Stephenson and Adams 1989).

2.1.2 Biocca *et al.* (1993)

Biocca *et al.* investigated the decline of individual oak trees by contrasting them with nearby healthy oak trees in the mountains of western North Carolina. In 1979, the Wayah Ranger District of the Nantahala National Forest previously categorized the trees studied as "declined" or "healthy." Each tree was sampled and separate tree-ring chronologies were developed for both categories. Using dendroecological analysis techniques, Biocca *et al.* (1993)determined the periods of stress on both healthy and declined individuals.

The unhealthy trees entered into a perpetual state of decline after a stress in the year 1971, though they experienced several stresses leading up to that point. The trees endured stress periods in 1911, 1925–1928, 1930–1933, 1952–1954, and 1964. A severe regional drought exacerbated the trees' declines in 1984–1985. The healthy trees also endured these stresses, yet contrastingly, did not enter into a state of permanent decline. Biocca *et al*. determined a likely cause of the distinction to be a result of differing ages. The healthy tree group proved to be the older of the two groups of trees, thus indicating that the stresses apparently occurred at a time when the older trees were not as vulnerable as the younger, now declining trees. The healthy trees were also found to be in locations favorable to light competition. The study concluded that the site may not be suitable to a high density oak forest (Biocca *et al*. 1993).

2.1.3 Abrams *et al.* (1997)

This study examined the successional status of two oak forests in the Jefferson National Forest of western Virginia. A northern red oak-dominated old growth forest was contrasted with another old growth forest dominated by chestnut oak. The study objective was to gain a better understanding of the dendroecology of the two stands by analyzing their composition, age structure, and successional development. Though the two forests studied were in close proximity to each other, one was located on a mesic site (northern red oak), while the other was located in a xeric location (chestnut oak). The old growth status of the forests provided a special opportunity to study the successional dynamics of contrasting European settlement oak forests (Abrams *et al.* 1997).

Northern red oak proved to be an important species in both forests. Though not the dominant canopy species in the chestnut oak stand, northern red oak was the second most prevalent species here. However, chestnut oak did not exist at all in the northern red oak stand. Northern red oak was also the most dominant seedling and sapling in the understory of both forests, indicating a future dominance. The chestnut oak forest exhibited less species diversity than the northern red forest as well (Abrams *et al.* 1997).

The northern red oak chronology extended back 275 years in time, and the chestnut oak chronology spanned 311 years. The most notable declines in the northern red oak forest occurred in the 1930s and 1940s, likely a result of storm damage. The stand experienced major release periods in the 1820s and 1830s and again in the 1930s, the latter likely a result of chestnut blight and widespread fire suppression (northern red oak is a fire intolerant species). The chestnut oak stand experienced periodic declines throughout the 1700s, exempting a favorable climatic period from 1740–1745 when a release was experienced. Northern red oak recruitment in the chestnut oak forest increased greatly in the 1930s, verifying that chestnut blight and fire suppression are beneficial to northern red oak. Abrams *et al.* concluded that the differences of the two forests could largely be attributed to the varying edaphic and topographic qualities of the two sites. Due to the rarity and advanced age of old growth oak forests, further studies were recommended to be carried out in the near future before they disappear (Abrams *et al.*. 1997).

2.1.4 Abrams (2003)

Abrams conducted a broad-scale biogeographical study of white oak. The study examines the decline of white oak since European settlement in the eastern United States. Abrams explains that white oak was the most dominant species in the eastern United States prior to settlement, and it is arguably the most valuable hardwood in North America. Extensive logging of the species has led to a dramatic decline in white oak recruitment during the 20th century, and much of the human-caused damage to the forest is irreversible. The objectives of this study were to determine why white oak dominated and red oak was restricted during the pre-settlement period, to outline the human role in white oak decline, and to find out what makes white oak vulnerable to the changes humans fostered (Abrams 2003).

Abrams attributes the vast pre-settlement distribution of white oak largely to common understory fire. Several studies in Appalachia show declines of white oak of up to 38% from the pre-settlement forest to present-day (McCormick and Platt 1980; Orwig and Abrams 1994; Abrams and McCay 1996; Black and Abrams 2001). The rise of red oak and red maple (*Acer rubrum* L.) in the eastern forest is attributed to large-scale logging of white oak in the late 19th century, widespread fire-suppression, and the chestnut blight. As white oaks compartmentalize fire injuries much more effectively than red oaks, lack of fire neutralizes the white oak advantage over red oak. Chestnut blight also opened up more gaps in the forest, allowing red oak to advance rapidly into the canopy during the 20th century. Following intense logging, white oak is slower to regenerate and less opportunistic than other oak species as well. Abrams concludes that humans have altered the appearance of today's oak forests much faster than any natural process is capable of achieving. Unfortunately, the decline of white oak is likely permanent (Abrams 2003).

2.2 Oak Dendroclimatology in Appalachia

Oak tree rings are a proven and reliable source for dendroclimatological analysis, and have been used extensively in Appalachia and around the world (Estes 1970; Bitvinskas and Kairaitis, 1975; Orwig and Abrams 1995; Bonn 2000; D'Arrigo *et al*. 2001). Oaks are highly sensitive to summer temperature and precipitation, benefitting most from a cool, moist summer. Because the genera records drought and above average temperature events exceptionally, oaks offer a high-resolution indicator of climate trends (McCarthy and Bailey 1996; Bortolot *et al*. 1997; McClenahen *et al*. 1997; Hart, *et al*. 2004).

2.2.1 McClenahen *et al*. (1997)

Much concern exists for the health of natural ecosystems and the effects of pollution on forests. The study by McClenahen *et al*. focused on the interacting relationship of climate and industrial pollution on annual growth of northern red oak. Chronologies were developed from sites located in close proximity of Johnstown, Pennsylvania, a town historically known for its industrial emissions. McClenahen *et al*. established control sites upwind of the pollution source for comparison purposes (McClenahen *et al*. 1997).

Using statistical analyses, McClenahen *et al.* found a clear climatic signal at the control sites, while the polluted sites showed a very weak climatic signal and low growth rates overall. For the control samples, a positive relationship was found between temperature and growing season. The most consistent and significant variable proved to be a positive relationship between precipitation and the month of July, meaning that summer moisture availability is the most important factor in northern red oak growth in central Pennsylvania. The study concluded that historical industrial emissions from nearby Johnstown, Pennsylvania proved to cause a long-term decline in growth rates of local northern red oaks (McClenahen *et al*. 1997).

2.2.2 Pan *et al.* (1997)

Pan *et al.* conducted a dendroclimatological study of the major forest species of central Appalachia. The study took place at Fernow Experimental Forest near Parsons, West Virginia. The dominant species in the forest were northern red oak, black cherry (*Prunus serotina* Ehrh.), white ash (*Fraxinus americana* L.), and tulip poplar (*Liriodendron tulipifera* L.) The objectives of the study were to obtain dendrochronological data for selected hardwood species and to identify the growth response functions of these species. Statistical analysis was used to determine the climate-growth relationships (Pan *et al*. 1997).

The study determined that the most important factor that influence northern red oak growth is precipitation. Statistical analyses showed precipitation coefficients were positive for most months except April, which had a negative and significant relationship. Coefficients for temperature were significant and negative in summer, while prior September and November and current May were significant and positive. These results verified that, at this location, northern red oak prefers above average temperature in autumn and May and below average temperatures in summer. Pan *et al*. inferred from these results that above average temperature and moisture in May results in rapid growth in northern red oak (Pan *et al.* 1997).

2.2.3 Bortolot *et al*. (2001)

Bortolot *et al*. developed a white oak chronology to identify the cutting dates of white oak logs used in the construction of a log cabin at the Reynolds Homestead Research Center in south-central Virginia. Along with archaeological samples from the log cabin, 20 white oak trees were cored at a nearby stand to be used to date the Abraham Reynolds cabin. However, the chronology developed only dated back to 1821, and the cabin cores did not crossdate. Therefore, the cabin samples were dated using a preexisting white oak chronology obtained from the International Tree-Ring Data Bank. Using this chronology, Bortolot *et al.* established the years of 1875 and 1876 as cutting dates for the cabin logs (Bortolot *et al.* 2001).

The cabin cores were then combined with the white oak cores to extend the newly developed chronology back 280 years (1720–2000). Statistical analyses were then carried out on the chronology. The results showed that precipitation has the greatest effect on white oak growth in south-central Virginia. Precipitation from current April and June and the previous September proved to have the most significant positive relationship, indicating that spring and summer rainfall produces more growth. The only significant relationship with temperature found was a negative relationship with the month of November. Bortolot *et al*. concluded that white oak may be more useful in precipitation reconstruction than in temperature reconstruction (Bortolot *et al*. 2001).

2.2.4 D’Arrigo *et al***.** (2001)

Six chronologies were developed from the highlands of southeastern New York by D’Arrigo *et al.* to study the climate-growth relationship in chestnut oak and eastern hemlock (*Tsuga canadensis* (L.) Carr.). Three chestnut oak and three eastern hemlock chronologies were built from sites located within the Black Rock Forest in Cornwall, New York. The objectives of this study were to develop the first ever tree-ring chronologies for the Black Rock Forest and examine their climate-growth relationships. The longest chestnut oak chronology developed for this study extends from 1806 to 1994 while the longest hemlock chronology dates from 1780–1992 (D'Arrigo *et al*. 2001).

Statistical analyses found that summer moisture availability is of considerable importance for chestnut oak. In all three oak chronologies, a significant positive relationship exists between tree growth during of June and July and precipitation. A significant negative relationship between June and July tree growth and temperature also exists, indicating that high temperature and low precipitation conditions are conducive of a poor growing season. The Palmer Drought Severity Index also correlated positively with the previous September and October and the current summer, confirming the importance of summer moisture availability. D'Arrigo *et al.* elaborated that this condition is exacerbated by the fact that chestnut oaks often grow on rocky upland slopes with shallow soils, making it a very drought sensitive species (D'Arrigo *et al.* 2001).

Chapter 3

Study Areas

3.1 Geographical Overview

3.1.1 Geography and Climate

Orogenesis of the Appalachian Mountains took place about 250–300 million years ago (Christopherson 2006). The southern Appalachians extend from north Georgia to West Virginia in a southwest to northeast trend. The southern Appalachians fall within the range of the humid subtropical climate of the southeastern United States. Cold winters and hot summers characterize this climate type (Bailey 1978). Subregions within the Appalachian chain include the Ridge and Valley Province, the Blue Ridge Province, and the Allegheny plateau Province (Rehder 2004). The Griffith Knob (GK) and Little Walker Mountain (LW) study sites are located in the Jefferson National Forest within the Ridge and Valley Province. The Gold Mine Trail (GMT) site lies in the Great Smoky Mountains National Park, part of the Blue Ridge Province.

3.1.2 JNF and GSMNP

The Jefferson National Forest (JNF) and the Great Smoky Mountains National Park share similar history and climate. The U.S.D.A Forest Service created the Jefferson National Forest in 1936 from lands formerly located within the Unaka and Natural Bridge National Forests, as well as other lands obtained by the Clinch and Mountain Lake Purchase Units. Before the National Forest's creation, much of the area's forests were clear-cut for agriculture and mining operations. The Jefferson National Forest, located in the Blue Ridge Mountains of southwest Virginia, receives an average of 96.5 cm of precipitation annually. The average daily temperatures range from –6 ºC in January to 30 ºC in July (United States Forest Service 2007). Congress established

The Great Smoky Mountains National Park (GSMNP) in 1934. The park is located on the border of Tennessee and North Carolina. GSMNP receives 140–216 cm of precipitation annually. Daily temperatures in the park's lowlands average from 4 ºC in January to 23 ºC in July. The GSMNP was the first park chosen in a location encompassing large areas of privately owned land (Campbell 1960). Though logging no longer occurs in GSMNP, large areas of the park were logged before its establishment, causing immense degradation of the forest. The National Park Service states that 95% of the park is forested today, one-third of which is considered old-growth forest (National Park Service 2007).

3.2 Site Descriptions

3.2.1 Griffith Knob

The study area (37º01'N, 81º13'W) is located on the west face of Griffith Knob (GK), adjacent to the Reed Creek Valley in Bland County, Virginia (Figure 3.1). The site is between Little Walker and Brushy Mountains in the Ridge and Valley Province in Jefferson National Forest. Elevation at GK ranges between 1100 and 1150 m. The understory of the GK study sites is dominated by black gum (*Nyssa sylvatica* Marsh.), Virginia pine (*Pinus virginiana* Mill.), Table Mountain pine (*Pinus pungens* Lamb.), bear oak (*Quercus ilicifolia* Wangenh.), mountain laurel (*Kalmia latifolia* L.), and blueberry (*Vaccinium* spp.). Table Mountain pine dominates the canopy. Scarlet oak, northern red oak, white oak, chestnut oak, and black gum appears in the canopy less frequently (Table 3.1) (DeWeese 2007).

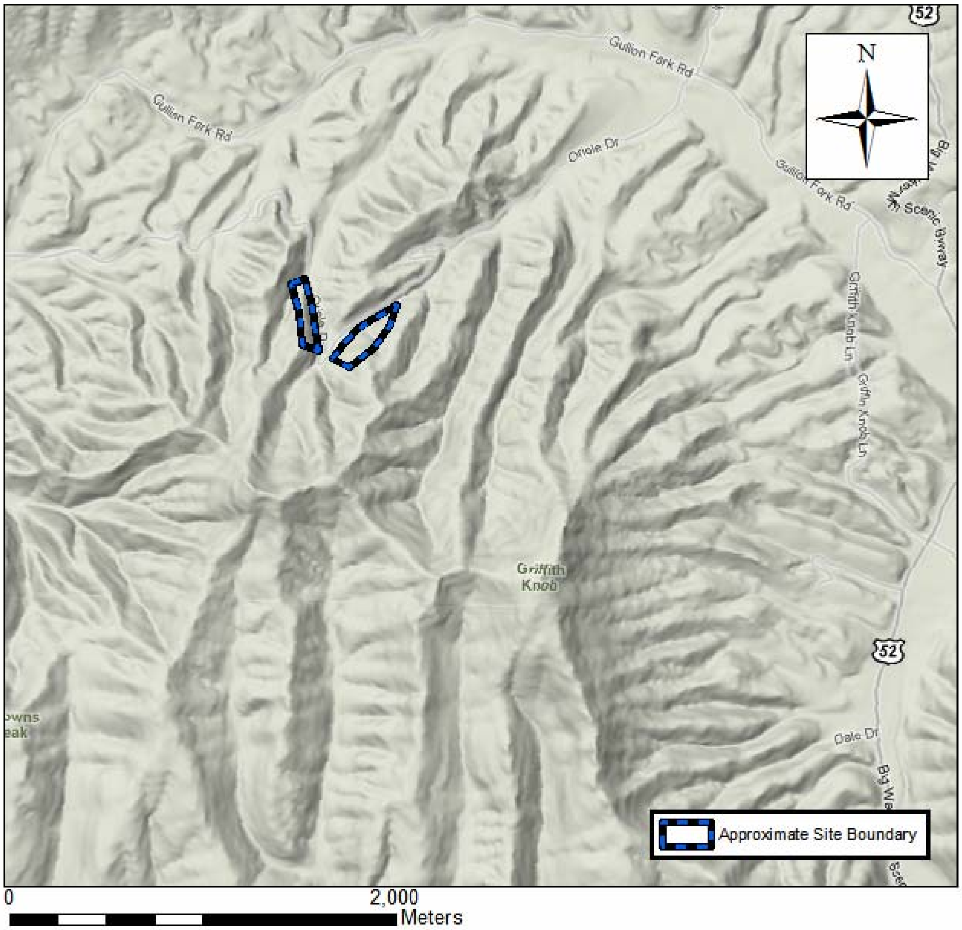

Figure 3.1 Topographic map of the Griffith Knob study area, Jefferson National Forest, Virginia. This map was created using Google Maps.

Table 3.1 Details of the research sites used in this study.

Site	Location	Elevation	Aspect	Oak species
Griffith Knob	37º01'N 81º13'W	1100–1150m	West	*Q. alba* *Q. coccinea* *Q. montana* *Q. rubra* *Q. velutina*
Little Walker	37º03'N 80º56'W	800–920m	North	*Q. alba* *Q. coccinea* *Q. montana* *Q. rubra,*
Gold Mine Trail	35º38'N 83º54'W	460–600m	Southeast	*Q. alba* *Q. coccinea* *Q. marilandica* *Q. montana* *Q. rubra* *Q. velutina*

3.2.2 Little Walker Mountain

Little Walker Mountain (LW) is located in the Ridge and Valley Province in Jefferson National Forest at 37º03'N, 80º56'W (Figure 3.2). The sample site is on the north face of the mountain in Bland County, Virginia. The site lies adjacent to Little Walker Creek, a tributary to the North Holston River. The elevation range for the site area is approximately 800 to 920 m. Understory vegetation at LW consists primarily of oak and American chestnut (*Castanea dentata* Marsh.) seedlings. Striped maple (*Acer pensylvanicum* L.), mountain laurel, and rhododendron (*Rhododendron catawbiense* Michx.) are the dominant species in the forest's midstory. Chestnut oak and Table Mountain pine are dominant in the upper canopy, though black gum, white pine (*Pinus strobus* L.), red maple, scarlet oak, and northern red oak are also common canopy species (Table 3.1) (DeWeese 2007).

3.2.3 Gold Mine Trail

The Gold Mine Trail (GMT) study site is located in the far western edge of the Great Smoky Mountains National Park, Blount County, Tennessee. The site is between the park boundary and the Cooper Road Trail. The elevational range of the study area is between 460 and 600 m. The understory consists predominately of white pine, red maple, while rhododendron and mountain laurel also exist less prominently. Recent southern pine beetle outbreak has damaged the yellow pine dominated canopy. The dominant canopy species at the GMT study area are shortleaf pine (*Pinus echinata* Mill.), Virginia pine, pitch pine (*Pinus rigida* Mill.), white oak, black oak, blackjack oak, chestnut oak, northern red oak, and scarlet oak, and eastern hemlock (Table 3.1) (Laforest 2007).

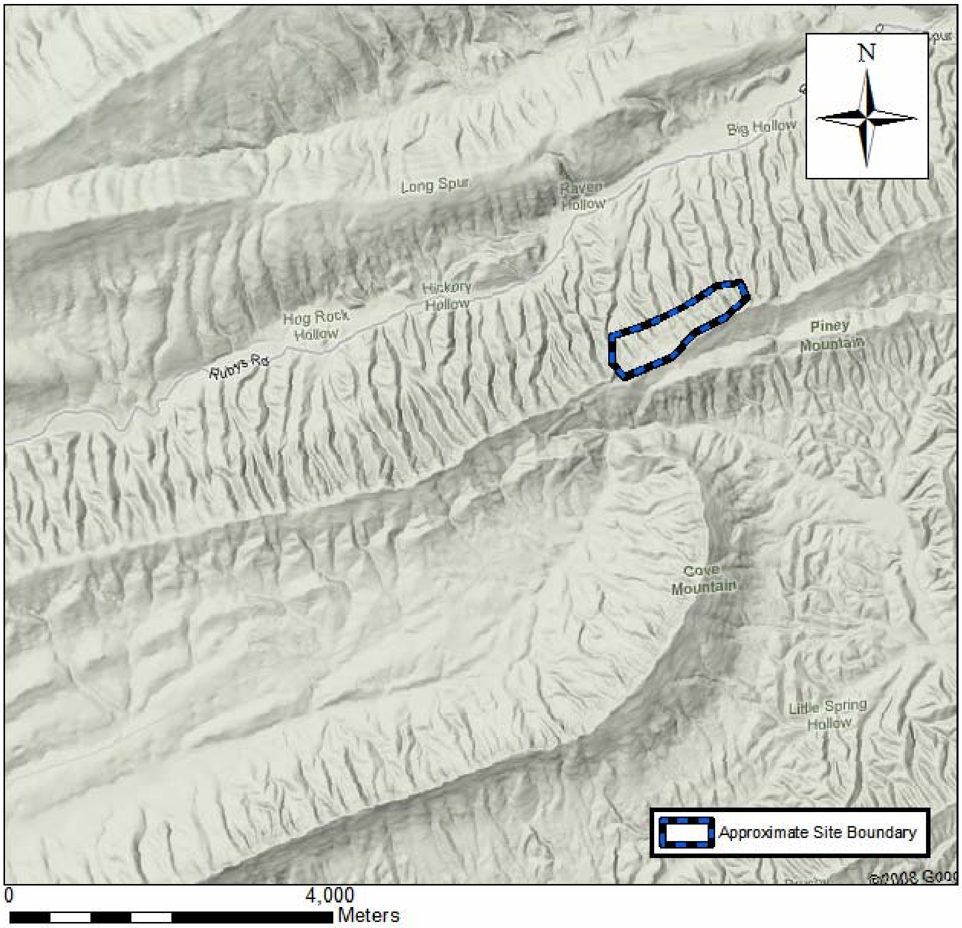

Figure 3.2 Topographic map of the Little Walker Mountain study area, Jefferson National Forest, Virginia. This map was created using Google Maps.

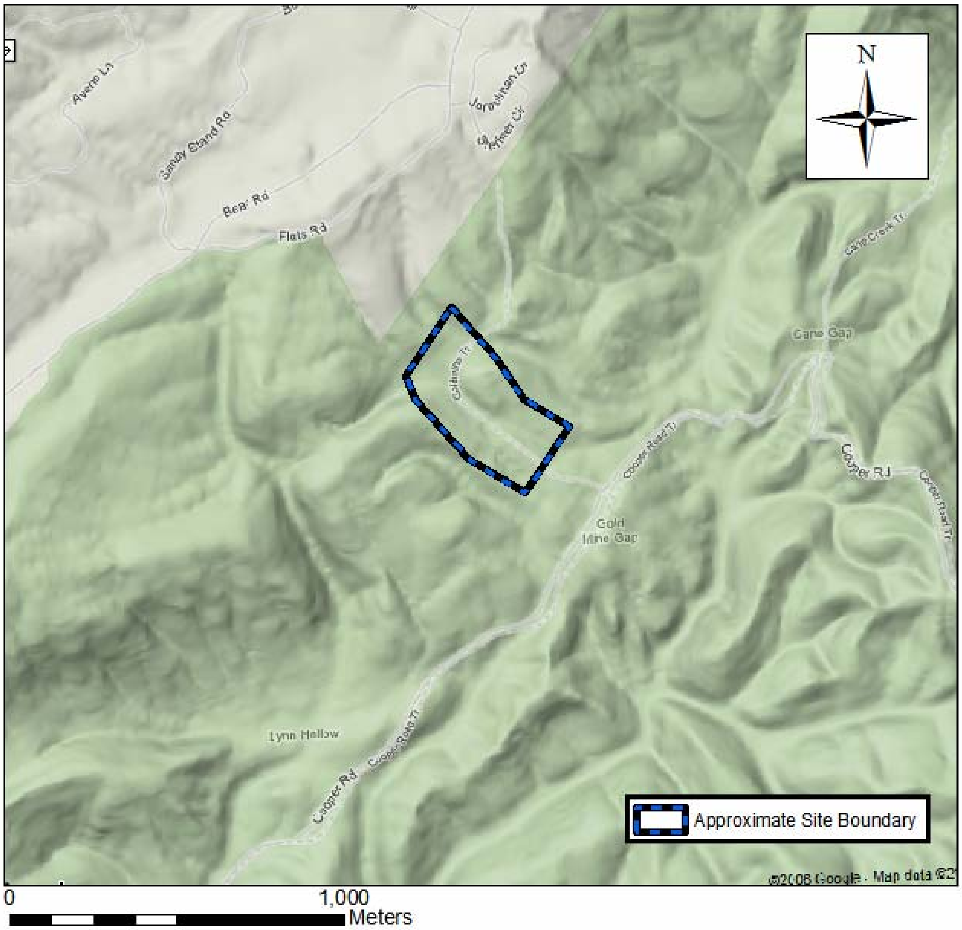

Figure 3.3 Topographic map of the Gold Mine Trail study area, Great Smoky Mountains National Park, Tennessee. This map was created using Google Maps.

Chapter 4

Methods

4.1 Field Methods

The field methods used were not intended specifically as a dendroclimatic analysis of oak because this study was a secondary feature of a larger research project designed to evaluate the fire regimes of mixed hardwood and yellow pine stands. Yellow pines were used to determine past fire occurrences and to analyze climate. Separate studies outline the results of the yellow pine analyses (DeWeese 2007; LaForest 2007). The study sites selected showed minimal effects of human-related disturbance to more accurately evaluate fire history and climatic response. I set up three 50 by 20 m macroplots at each site to determine forest age structure and to perform further climate analyses on oak species (DeWeese 2007; LaForest 2007).

Increment borers were used to extract two core radii from each living tree ≥ 5 cm DBH located within each macroplot (Figure 4.1) (DeWeese 2007; LaForest 2007). I extracted the cores approximately 30 cm above the ground, parallel to the slope contour. The core samples were either the entire length of the trunk or were extracted from opposite sides of the trunk to show a full diameter of the tree because growth patterns can differ across different radii of the tree (Fritts 1976; Cleaveland 1980). I used at least 30 cores from living oak trees at each site to establish chronologies.

Figure 4.1 An increment borer is used to extract a core sample from a black oak.

4.2 Laboratory Methods

Upon extraction, the cores were placed in paper straws for temporary storage and drying. The dried cores were then mounted using wood glue on wooden core mounts. The tracheids were aligned vertically so that the transverse plane of the core would be visible after sanding, thus optimizing the clarity of the ring boundaries (Stokes and Smiley 1996). I sanded all of the cores progressively using a belt sander beginning with ANSI 40-grit (500–595 µm) and ending with ANSI 400-grit (20.6–23.6 µm) sanding belts (Orvis and Grissino-Mayer 2002).

The macroplot cores were dotted on every decadal ring (e.g. 1900, 1910, etc.) from the outermost to the innermost ring (Figure 4.2) (Stokes and Smiley 1996). I measured the oak core rings to the nearest 0.001 mm using a Velmex measuring system, coupled with Measure J2X measurement software, for chronology development. After measurement, the measurement files were combined into one master file per site. The remaining non-oak/yellow pine cores remained unmeasured and were used solely for macroplot age structure analysis.

I then crossdated the cores visually and evaluated for crossdating quality using COFECHA tree-ring software. The computer program COFECHA is used by dendrochronologists to evaluate the quality of crossdating and measurement accuracy of tree-ring series (Grissino-Mayer 2001). Tree-ring series were analyzed using 40-year segments lagged successively by 20 years. Not all increment cores were included in the chronology because some segments had correlations falling below the critical correlation coefficient of 0.37 ($p > 0.01$). Low correlations such as this are likely caused by irregular growth patterns.

Figure 4.2 Oak increment cores were mounted, sanded, and dotted before measurement.

4.3 Chronology Development

Researchers typically develop oak chronologies from a single species or a grouping of similar species (e.g. white oaks or red oaks). Due to the field limitations of this study, the three chronologies were developed from a variety of oak species. I developed a mixed oak master tree-ring chronology for each individual site by using the computer program ARSTAN (Cook 1985). Standardization corrects ring widths to accommodate the changing age and geometry of a living tree specimen (Fritts 1976). In this study, standardization was obtained by dividing the ring width measurements for each year by the value obtained from a negative exponential curve fit to the series (Cook and Kairiukstis 1992). Standardization creates a new time series and generates a mean and variance more uniform by removing age-related trends (Matalas 1962; Fritts 1976). Once standardized, the ring-width indices have no positive or negative linear trend and their mean value is 1.0. Additionally, the variability shown in juvenile growth is made comparable to slower mature growth (Fritts 1976). Standardization also minimizes potential “noise” influences such as tree size, stand density, and competition (Friend and Hafley 1989).

Mean sensitivity, year-to-year variability, standard deviation, overall variability, and first-order autocorrelation are the descriptive statistics used to characterize tree-ring chronologies. It is desirable for a chronology to have low first-order autocorrelation and high mean sensitivity and standard deviation (Dewitt and Ames 1978; Grissino-Mayer and Butler 1993). Mean sensitivity values ≥ 0.3 represent a sensitive measurement series (Grissino-Mayer 2001). The average interseries correlation is the most important indicator of the validity of the chronology’s crossdating accuracy and strength of climate signal. Interseries correlation measures the strength of crossdating among all series for a site, and values above 0.50 are generally desirable (Grissino-Mayer 2001).

4.4 Climate Analyses

In this study, I analyzed the relationships between oak tree growth and local monthly data for precipitation, temperature, and drought. Regional precipitation and temperature data were obtained from the National Climatic Data Center website (NCDC 2007). For the Griffith Knob and Little Walker Mountain sites, temperature and precipitation data came from Virginia's Southwestern Mountain climate division (zone 4406). For Gold Mine Trail, the data came from Tennessee's Eastern climate division (zone 4001). I also obtained drought data in the form of Palmer Drought Severity Index (PDSI) and Palmer Hydrological Drought Index (PHDI) from the NCDC website. PDSI is a monthly meteorological index that describes the severity of wet and dry phases and estimates soil moisture availability incorporating soil type, precipitation, temperature, and evapotranspiration (Palmer 1965). Tree-ring chronologies often correlate strongly with PDSI in the eastern United States (Stahle *et al.*. 1985; Jenkins and Pallardy 1995; Lafon 2000). PHDI is an adaptation of PDSI that responds more slowly to changing weather conditions than PDSI. PHDI approximates true subsurface hydrologic characteristics and is therefore used to assess long-term moisture supply (Grissino-Mayer and Butler 2003).

Climatic influence on oak tree growth was assessed using correlation analyses on the years of 1930–2003 for GK and LW and 1930–2005 for GMT. Correlation analysis uses Pearson correlation coefficients as a measure of the strength of the relationship between two variables. I used Pearson's product-moment correlations to determine the months that are most influential in determining the annual tree growth (Fritts 1976; Grissino-Mayer and Butler 1993). Each study site was analyzed individually for its relationships with temperature, precipitation, PDSI, and PHDI using SAS software (Schotzhauer and Littell 1987). I also lagged the climate variables to determine if the conditions of the previous growing season affected growth during the current season. The lagging of climate variables is necessary because tree growth during the current year is in part dependent upon the carbon uptake that occurs during the previous growing and dormant seasons (Fritts 1976; Waring 1983; Grissino-Mayer and Butler 1993). Finally, SAS was used to seasonalize the precipitation, temperature, PDSI, and PHDI variables to isolate the longer series of months most important to tree growth.

Chapter 5

Results

5.1 Griffith Knob Results

5.1.1 Chronology

The Griffith Knob chronology spanned A.D. 1889 to 2003 (Figure 5.1). The 115-year tree-ring chronology consisted of 43 measured series. Of these, only four exceeded 100 years in length (sample GKD005 being the oldest at 115 years). The average series length was 79 years. The chronology consisted of 3,399 rings in total. Narrow rings that assisted in crossdating included the years 1894, 1895, 1903, 1914, 1930, 1947, 1966, 1988, and 1999. COFECHA descriptive statistics reported an overall average interseries correlation of 0.67 (Table 5.1). The chronology included black oak, chestnut oak, northern red oak, scarlet oak, and white oak.

5.1.2 Climatic Analyses

Correlation analyses showed a clear climatic signal in the oaks of Griffith Knob. A significant (June $r = 0.49$, $p < 0.05$) positive relationship existed between precipitation and growth during May and June of the current year (Figure 5.2). When the precipitation variable was seasonalized, a strong correlation ($r = 0.54$, $p < 0.0001$) occurred from May to July (Table 5.2). I found a significant negative relationship between growth and temperature during the current year's July ($r = -0.26$, $p < 0.05$) (Figure 5.2), however, seasonalized temperature variable showed no significant correlations. I found a significant positive relationship between PDSI and growth for the current months of May to August (June and July $r = 0.48$, $p < 0.0001$) (Figure 5.3). The period of May to July proved strongly significant ($r = 0.47$, $p < 0.0001$) when PDSI was seasonalized (Table 5.3). For PHDI, a significant positive relationship existed from May to

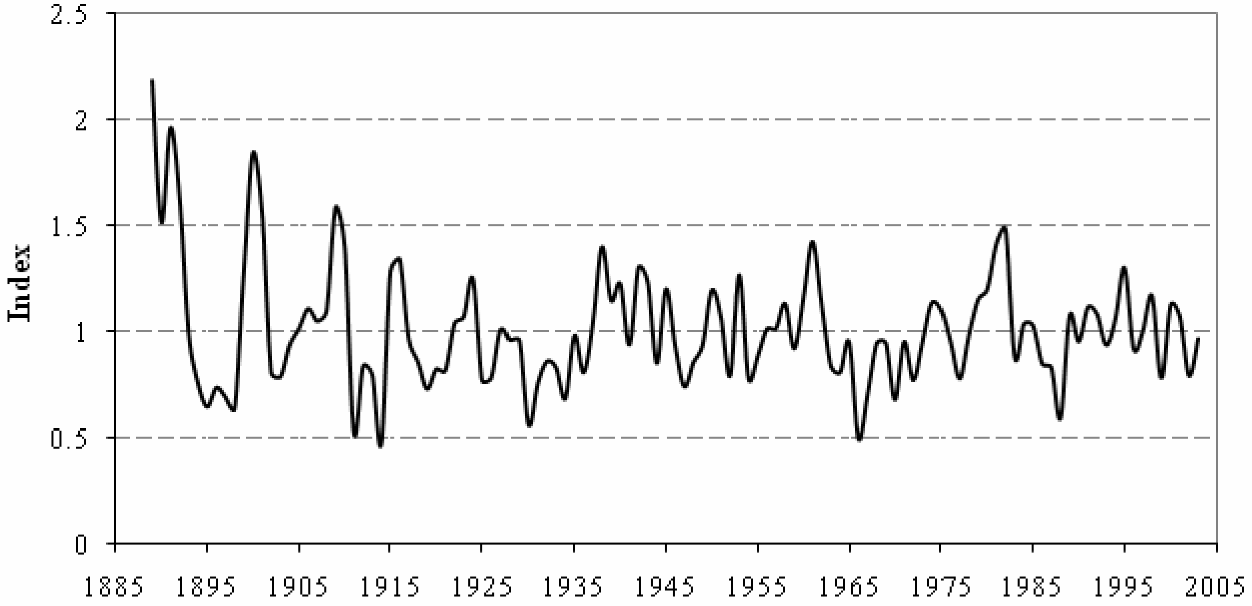

Figure 5.1 Griffith Knob chronology ring-width index, Jefferson National Forest, Virginia.

Table 5.1 Descriptive statistics of the oak chronologies developed for this study.

Sites	Number of Series	Range of Years	Interseries Correlation	Mean Sensitivity	Standard Deviation	Auto-correlation
Griffith Knob	43	1889–2003	0.67	0.277	0.484	–0.026
Little Walker Mountain	40	1889–2004	0.66	0.268	0.491	–0.033
Gold Mine Trail	37	1836–2005	0.57	0.224	0.466	–0.029

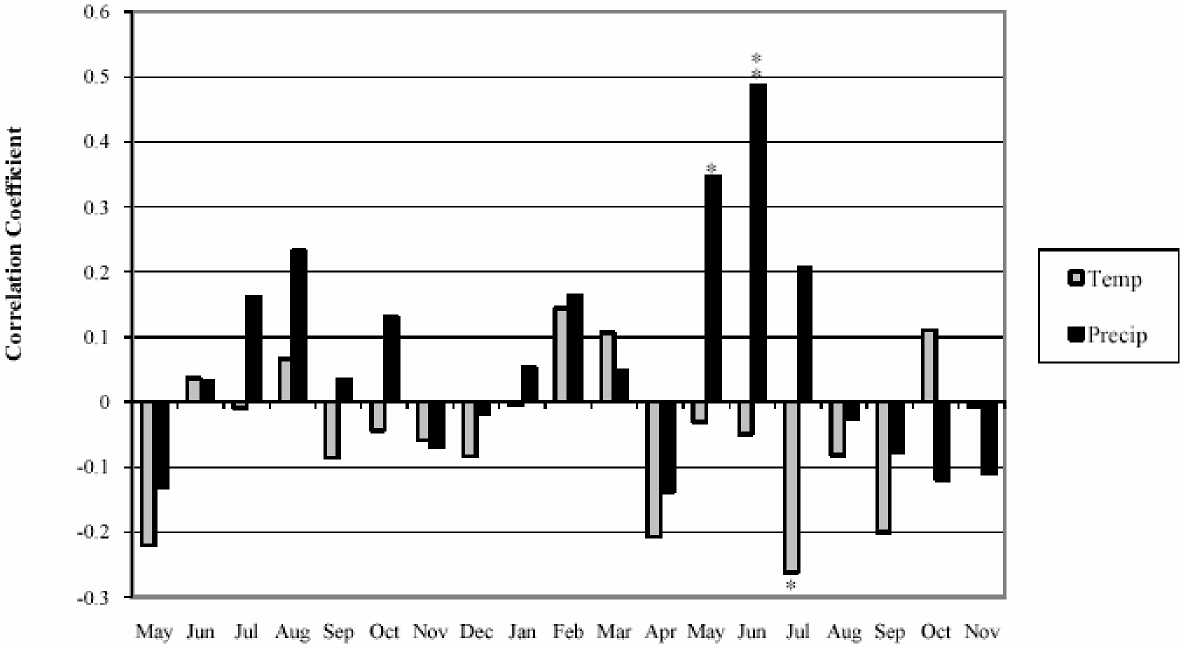

Figure 5.2 Monthly correlation coefficients between growth and temperature and precipitation at Griffith Knob. Statistically significant relationships are denoted by * ($p < 0.05$) and ** ($p < 0.0001$).

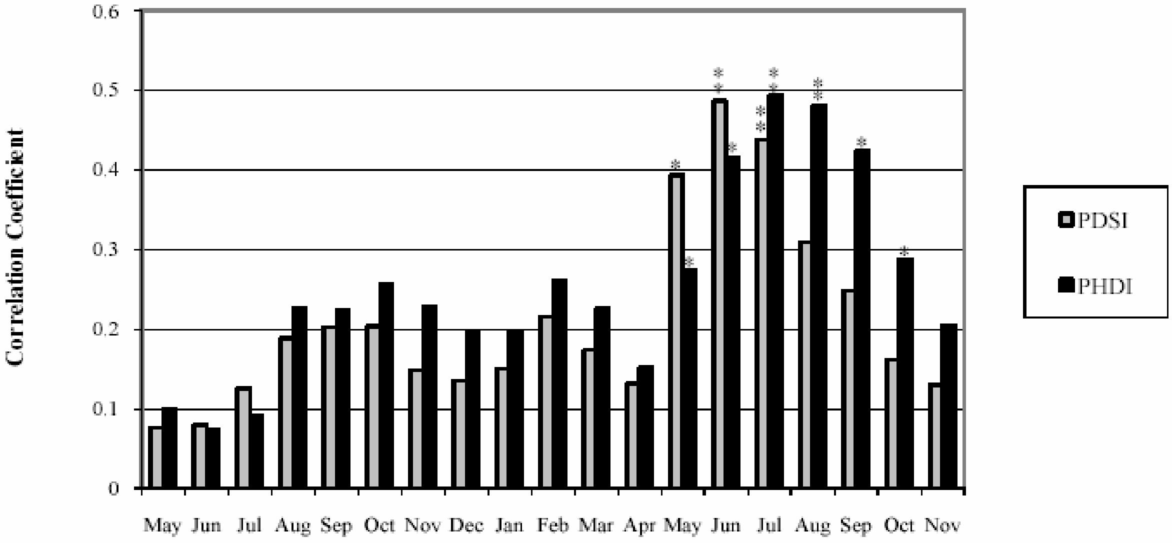

Figure 5.3 Monthly correlation coefficients between growth and PDSI and PHDI at Griffith Knob. Statistically significant relationships are denoted by * ($p < 0.05$) and ** ($p < 0.0001$).

Table 5.2 Correlation coefficients between the GK chronology and seasonalized precipitation.

Season	**Correlations**
April–June	0.42**
April–July	0.44***
May–June	0.53***
May–July	**0.54*** **
June–July	0.49***

*p < 0.05, **p < 0.01, ***p < 0.0001.

Table 5.3 Correlation coefficients between the GK chronology and seasonalized PDSI.

Season	**Correlations**
May–June	0.45***
May–July	**0.47***
June–July	**0.48***
May–August	0.45***
June–August	0.44***
May–September	0.42**
June–September	0.41**
May–October	0.38**
June–October	0.37**
May–November	0.35**
June–November	0.33**

*$p < 0.05$, **$p < 0.01$, ***$p < 0.0001$.

September (up to $r = 0.49$, $p < 0.0001$) (Figure 5.3). The seasonalized PHDI variable was most significant from July to August ($r = 0.51$, $p < 0.0001$) (Table 5.4).

5.2 Little Walker Mountain Results

5.2.1 Chronology

The Little Walker chronology extended 116 years from A.D. 1889–2004. The chronology consisted of 40 series. Two series extended over 100 years (LWC055A is the oldest at 116) while the mean series length was 78.9 years. A total of 3,155 rings were measured across all series. The overall series average interseries correlation was 0.659 (Table 5.1). Marker years that assisted in crossdating of the Little Walker chronology are 1896, 1914, 1930, 1941, 1955, 1966–1967, 1988, and 1999 (Figure 5.4). The species included in the LW chronology are chestnut oak, northern red oak, and scarlet oak.

5.2.2 Climate Analyses

Statistical analyses showed a strong climate signal in the Little Walker oak chronology. Precipitation correlated positively and significantly to ring production during the months of May and June ($r = 0.49$, $p < 0.0001$) of the current year. May to June growth correlated most significantly with seasonalized precipitation ($r = 0.61$, $p < 0.0001$) (Table 5.5). A significant inverse relationship existed most significantly between growth and temperature during the current month of April ($r = -0.36$, $p < 0.01$) (Figure 5.5). When seasonalized, growth during the months of April through July negatively correlated most significantly with temperature ($r = -0.25$, $p < 0.05$) (Table 5.6). PDSI and growth exhibited a positive and significant relationship

Table 5.4 Correlation coefficients between the GK chronology and seasonalized PHDI.

Season	Correlations
May–August	0.46***
June–August	**0.50*****
July–August	**0.51*****
May–September	0.47***
June–September	0.49***
July–September	0.49***
May–October	0.46***
June–October	0.47***
July–October	0.45***
May–November	0.43***
June–November	0.43***
July–November	0.41***

*p < 0.05, **p < 0.01, ***p < 0.0001.

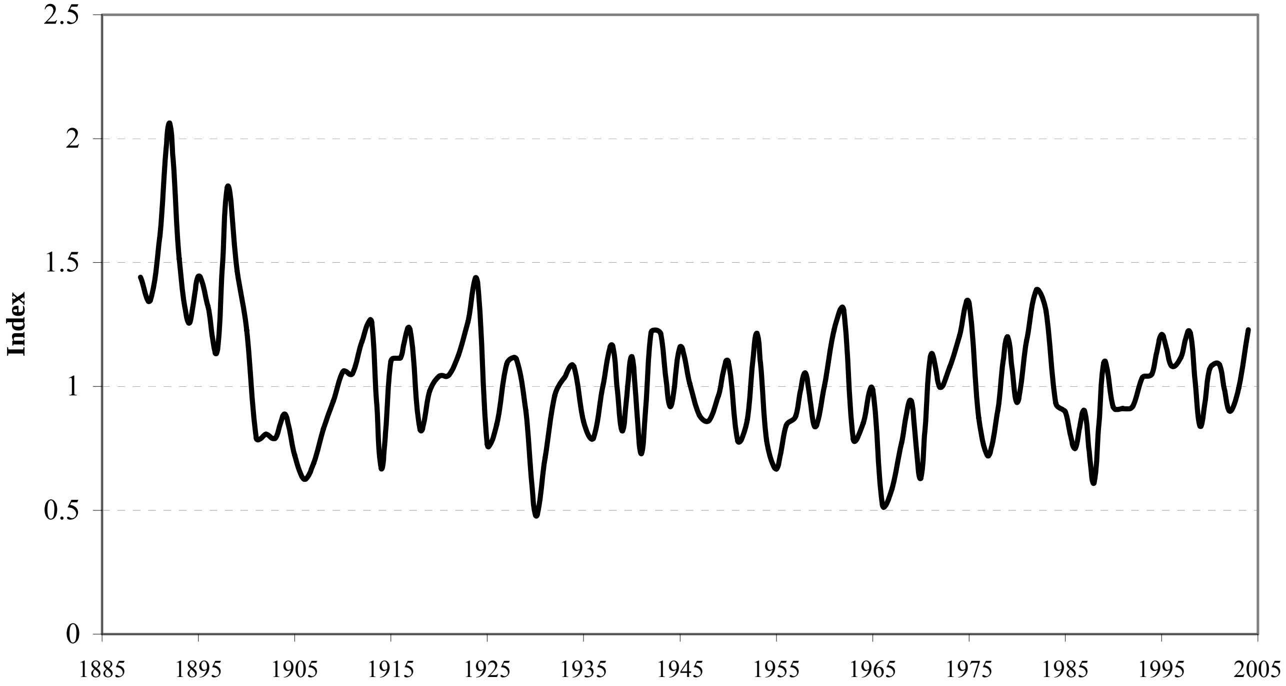

Figure 5.4 Little Walker Mountain chronology ring-width index, Jefferson National Forest, Virginia.

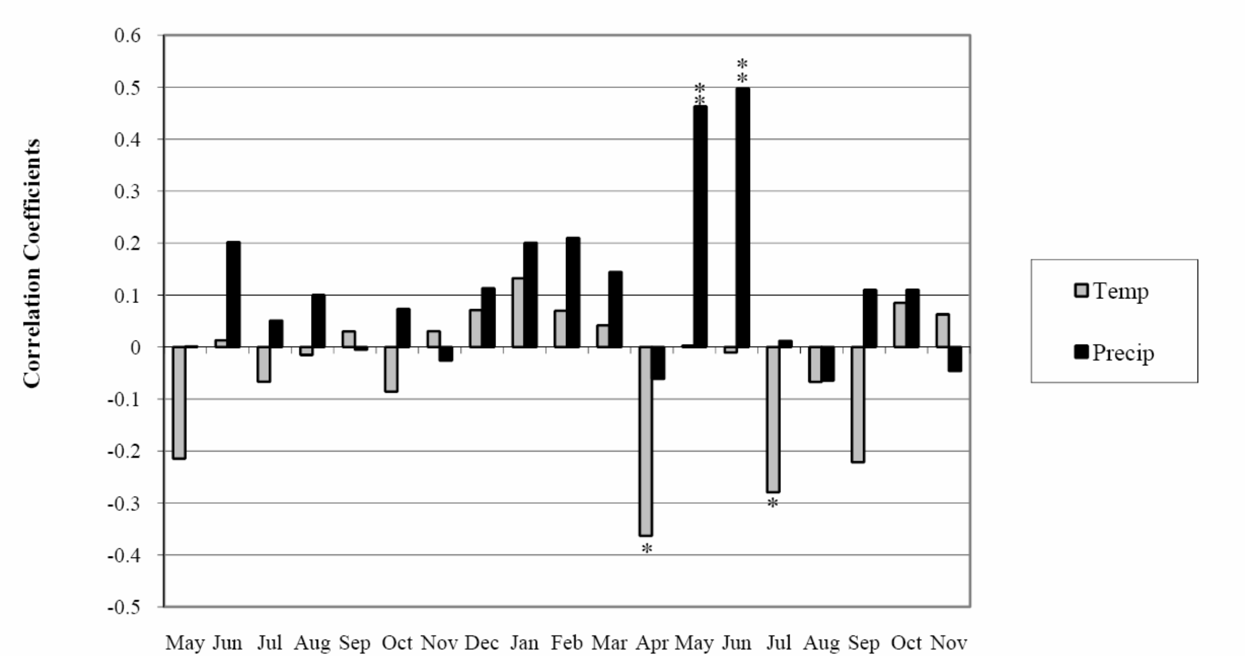

Figure 5.5 Monthly correlation coefficients between growth and temperature and precipitation at Little Walker Mountain. Statistically significant relationships are denoted by * ($p < 0.05$) and ** ($p < 0.0001$).

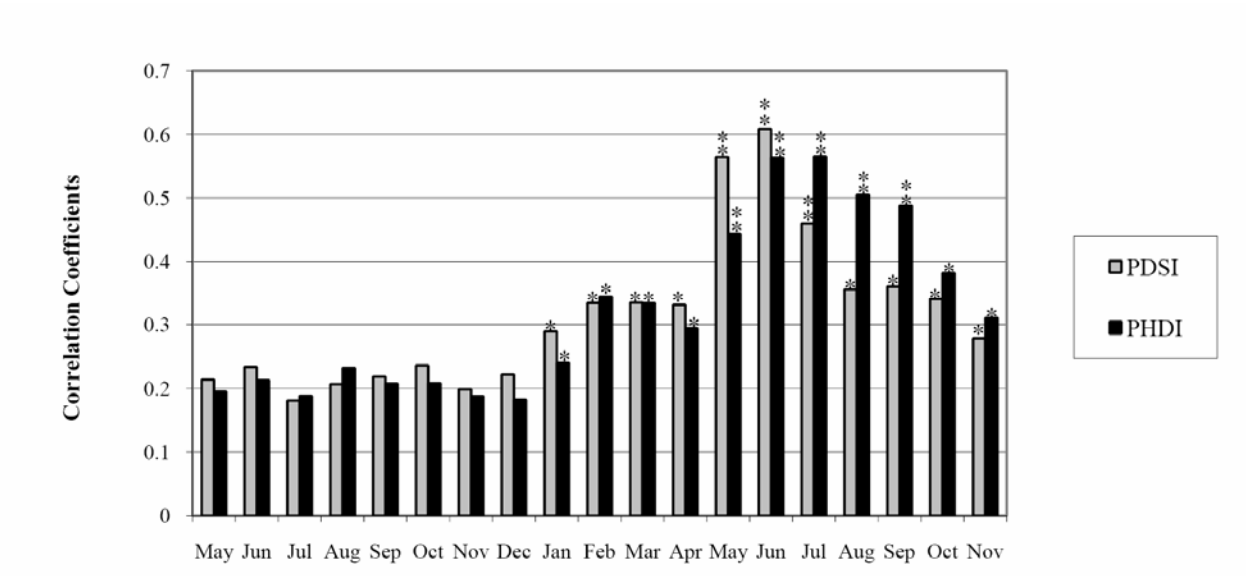

Figure 5.6 Monthly correlation coefficients between growth and PDSI and PHDI at Little Walker Mountain. Statistically significant relationships are denoted by * ($p < 0.05$) and ** ($p < 0.0001$).

Table 5.5 Correlation coefficients between the LW chronology and seasonalized precipitation.

Season	Correlations
April–June	0.53***
April–July	0.45***
May–June	**0.61*** **
May–July	0.52***
June–July	0.38**

*p < 0.05, **p < 0.01, ***p < 0.0001.

Table 5.6 Correlation coefficients between the LW chronology and seasonalized temperature.

Season	Correlations
April–May	–0.23*
April–June	–0.19
April–July	–0.25*
May–June	–0.00
May–July	–0.10
June–July	–0.16

*p < 0.05, **p < 0.01, ***p < 0.0001.

during June ($r = 0.23$, $p < 0.05$) and October ($r = 0.24$, $p < 0.05$) of the previous year, and March through November (up to $r = 0.61$, $p < 0.0001$) of the current year. Seasonalized PDSI correlated most significantly during May through July ($r = 0.57$, $p < 0.0001$) (Table 5.7). PHDI correlated positively and significantly during the previous August ($r = 0.23$, $p < 0.05$) and January through November of the current year (up to $r = 0.56$, $p < 0.0001$) (Figure 5.6). May through September correlated most significantly with seasonalized PHDI ($r = 0.58$, $p < 0.0001$) (Table 5.8).

5.3 Gold Mine Trail Results

5.3.1 Chronology

The Gold Mine Trail chronology spanned 170 years from 1836 to 2005 (Figure 5.7). The chronology was consists of 37 series with an average series length of 86.2 years. The chronology contained eight series that extended beyond 100 years (the oldest were GMB026 and GMB085 at 170). I dated 3,191 rings with an overall average interseries correlation of 0.57 (Table 5.1). The years 1838–1839, 1846, 1850, 1872, 1879, 1898, 1911, 1914, 1925, 1936, 1956, 1964, and 1985 served as narrow marker rings (Figure 5.7). The chronology consisted of black oak, blackjack oak, chestnut oak, northern red oak, scarlet oak, and white oak.

5.3.2 Climate Analyses

A climate signal at Gold Mine Trail was verified by strong statistical correlations between radial growth and climatic variables. Oaks at Gold Mine Trail had a positive significant relationship with precipitation during September ($r = 0.25$, $p < 0.05$) and October ($r = 0.34$, $p < 0.01$) of the previous year, and May ($r = 0.4$, $p < 0.001$) and June ($r = 0.31$, $p < 0.01$) of the current year (Figure 5.8). Seasonalized precipitation correlation showed a significant relationship from May to June ($r = 0.49$, $p < 0.0001$) (Table 5.9). Temperature again exhibited a negative significant

Table 5.7 Correlation coefficients between the LW chronology and seasonalized PDSI.

Season	**Correlations**
April–June	0.56***
May–June	0.60***
April–July	0.55***
May–July	**0.57*** **
June–July	0.56***
May–August	0.55***
June–August	0.51***
July–August	0.42***
May–September	0.53***
June–September	0.49***
July–September	0.42***

$*p < 0.05$, $**p < 0.01$, $***p < 0.0001$.

Table 5.8 Correlation coefficients between the LW chronology and seasonalized PHDI.

Season	**Correlations**
May–August	0.57***
June–August	0.58***
July–August	0.55***
May–September	**0.58*** **
June–September	0.58***
July–September	0.55***
May–October	0.56***
June–October	0.56***
July–October	0.52***
May–November	0.54***
June–November	0.53***
July–November	0.49***

*p < 0.05, **p < 0.01, ***p < 0.0001.

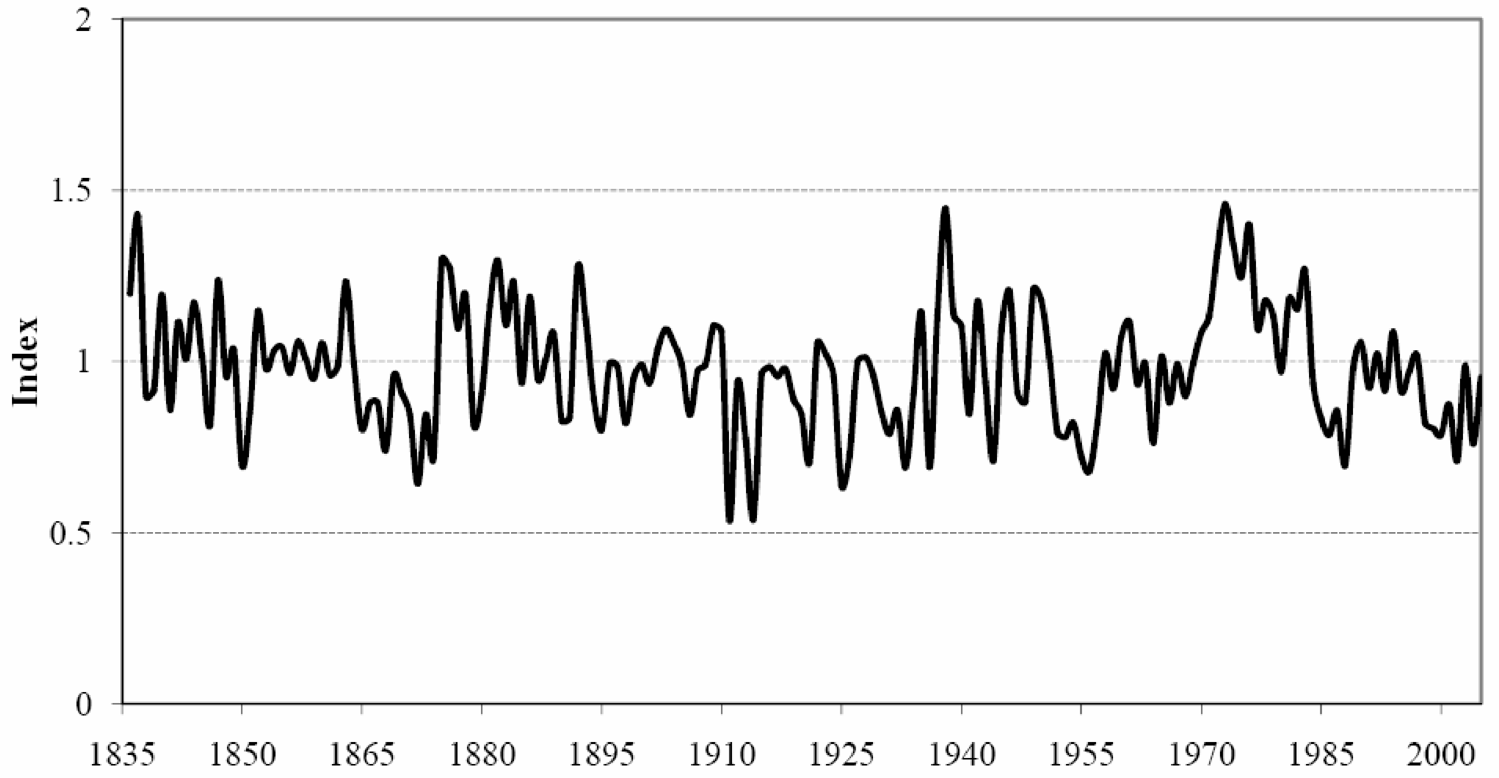

Figure 5.7 Gold Mine Trail tree-ring chronology, Great Smoky Mountains National Park, Tennessee.

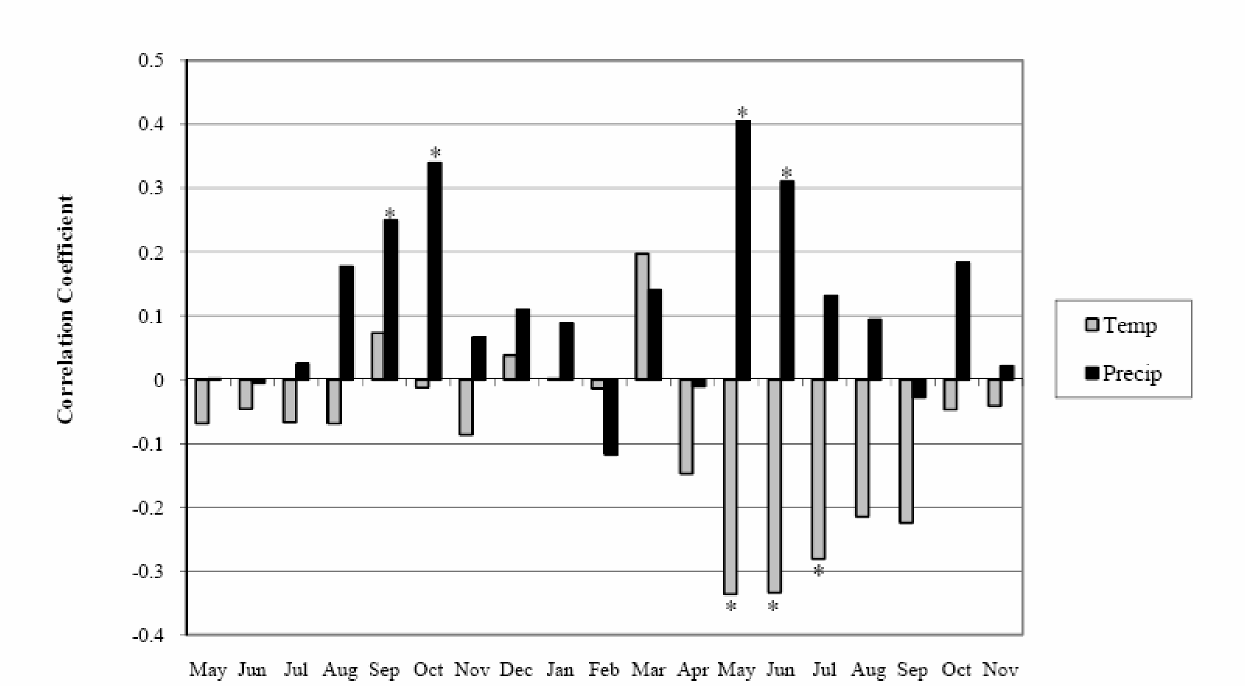

Figure 5.8 Monthly correlation coefficients between growth and temperature and precipitation at Gold Mine Trail. Statistically significant relationships are denoted by * ($p < 0.05$) and ** ($p < 0.0001$).

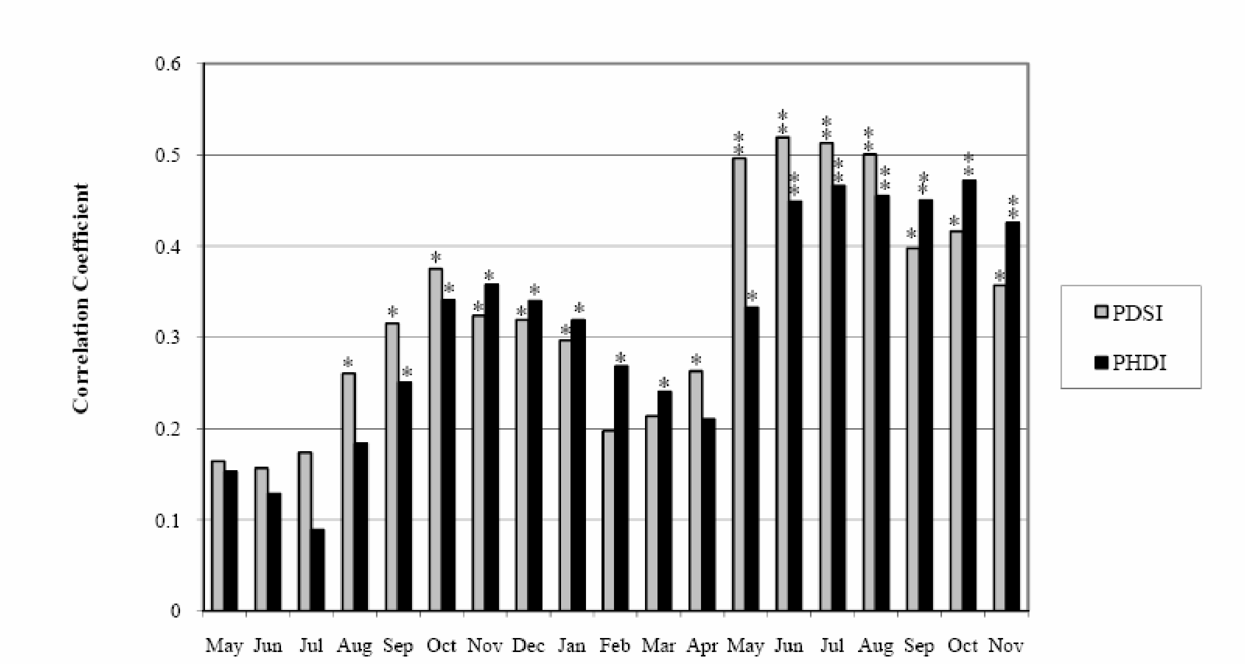

Figure 5.9 Monthly correlation coefficients between growth and PDSI and PHDI at Gold Mine Trail. Statistically significant relationships are denoted by * ($p < 0.05$) and ** ($p < 0.0001$).

Table 5.9 Correlation coefficients between the GMT chronology and seasonalized precipitation.

Season	**Correlations**
April–June	0.39**
April–July	0.37**
May–June	**0.49*** **
May–July	0.43***
June–July	0.29*

$^*p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.0001$.

relationship during the current year's May through July (as low as $r = -0.33$, $p < 0.01$) (Figure 5.8) with a strong seasonalized relationship lasting from April to July ($r = -0.46$, $p < 0.0001$) (Table 5.10). Significant positive relationships existed between PDSI and growth during the previous August through current January (as high as $r = 0.37$, $p < 0.001$), as well as current April through November (as high as $r = 0.52$, $p < 0.0001$) (Figure 5.9). Seasonalized PDSI correlated most significantly from May to August ($r = 0.53$, $p < 0.0001$) (Table 5.11). PHDI and growth correlated most significantly (as high as $r = 0.47$, $p < 0.0001$) during June through November of the current year. When Seasonalized, PHDI correlated most significantly from June to November ($r = 0.50$, $p < 0.0001$) (Table 5.12).

Table 5.10 Correlation coefficients between the GMT chronology and seasonalized temperature.

Season	**Correlations**
April–May	–0.37**
April–June	–0.45***
April–July	**–0.46***
May–June	–0.42**
May–July	–0.44***
June–July	–0.37*

*p < 0.05, **p < 0.01, ***p < 0.0001.

Table 5.11 Correlation coefficients between the GMT chronology and seasonalized PDSI.

Season	**Correlations**
May–June	0.52***
May–July	0.53***
June–July	0.53***
May–August	**0.53*** **
June–August	0.53***
May–September	0.52***
June–September	0.51***
May–October	0.51***
June–October	0.50***
May–November	0.50***
June–November	0.49***

*p < 0.05, **p < 0.01, ***p < 0.0001.

Table 5.12 Correlation coefficients between the GMT chronology and seasonalized PHDI.

Season	Correlations
May–August	0.45***
June–August	0.48***
July–August	0.47***
May–September	0.47***
June–September	0.48***
July–September	0.47***
May–October	0.48***
June–October	0.49***
July–October	0.49***
May–November	0.49***
June–November	**0.50*** **
July–November	0.49***

*p < 0.05, **p < 0.01, ***p < 0.0001.

Chapter 6

Discussion and Conclusions

6.1 Chronologies

The three oak chronologies developed for this study had several corresponding narrow marker years (e.g. 1914, 1930, 1954, 1988), indicating a macroclimate response to regional climate conditions. The GK chronology had the greatest interseries correlation (r = 0.67) and mean sensitivity (0.277). Greater sensitivity and correlation at GK was likely because tree growth here was limited more singularly by precipitation, whereas the temperature and drought variables had greater influences on growth at LW and GMT.

The GMT chronology was the longest at 170 years (1836–2005), followed by the LW chronology at 116 years (1889–2004), and GK at 115 years (1889–2003). The oak trees used in these chronologies (GK and LW especially) do not extend significantly beyond the period of modern climate records (1895–present). Because modern records are used to calibrate climate reconstruction (Fritts 1976), older trees should be targeted for sampling at these sites to extend these chronologies further in time beyond the calibration period. I did not include all increment core samples from each site in the chronologies due to time constraints. Additionally, some cores did not date well because of irregular growth patterns. I targeted the cores with the most annual rings to extend each chronology as far back in time as possible. In the future, the remaining cores should be measured and crossdated to in order to improve the sample depth of the existing chronologies.

6.2 Climate Analyses

The climatic factors that influenced the oaks of this study were similar to those found in previous dendroclimatological oak studies (McClenahen *et al.* 1997; Bortolot *et al.* 2001; D'Arrigo *et al.* 2001). Statistical correlation analyses showed that oak trees increase radial growth during cool, moist summers. Fall moisture availability also preconditions tree growth for cell production in the following spring. High correlations between tree growth and precipitation at each site indicated moisture availability to be important to southern Appalachian oak species. Inverse relationships between growth and temperature in the same months indicated that cooler temperatures promote cell production. PDSI and PHDI correlated strongly at all three sites across more months than did precipitation and temperature variables, signifying the importance of long-term moisture availability. Narrow rings at the LW, GK, and GMT chronologies corresponded to PDSI indicated drought conditions at the Virginia Southwest Mountain and Tennessee Eastern climatic divisions in the years 1914, 1925, 1931, 1953–54, 1970, and 1985–1988 (NCDC 2007), signifying large regional droughts.

Monthly and seasonalized precipitation correlation results showed that the months of May through July of the current growing season were most important in regulating oak radial tree growth. These months significantly correlated with growth at each study site. At GK and LW, precipitation during the previous growing season was not an important limiting factor. Available moisture during late spring and summer months proved to be a vital factor of oak xylem production because these months make up the bulk of the growing season, when trees need moisture the most. At GMT, the lowest in elevation and the site that was farthest south, precipitation during the previous September and October influenced ring width during the current year . Precipitation during this time of year allows for moisture storage and increased growth in the following growing season (Bortolot *et al.* 2001). These results suggest that wet conditions during the previous fall are more beneficial to oak species at lower elevations and latitudes.

GK, LW, and GMT all correlated negatively with temperature during the current summer. This inverse relationship indicated that high summer temperatures restrict tree growth because trees subjected to high temperatures and low moisture produce a narrower annual ring (Fritts 1976). Conversely, cooler than average summer temperatures formed a wide ring at our research sites. The temperature signal was stronger at lower elevations. An inverse relationship with temperature and growth exists at GK (highest elevation) during July, at LW during April and July, and at GMT (lowest elevation) during May, June, and July. Furthermore, the seasonalized temperature variable correlated significantly stronger at GMT ($r = -0.46$, $p < 0.0001$; April–July) than at LW ($r = -0.25$, $p < 0.05$; April–July) and GK (no significant seasonalized correlation).

A strong positive relationship with growth and PDSI existed at all sites, signifying a clear dependence upon soil moisture. The results showed that as with the other climate variables, weakening signal strength occurred as elevation increased. Soil moisture at GK was most important to tree growth during summer months. This relationship was apparent at LW from late winter to autumn of the current year, indicating a need for soil moisture throughout most of the current year. PDSI correlated with ring width most strongly at GMT, where a signal was evident from August of the previous year through the current November. At GMT, the amount of soil moisture in the fall preconditioned ring width for the following year. This available soil moisture indicated that growth regulators produced during the current year are affected by the amount of available moisture the previous year, an example of biological persistence (Pan *et al.* 1997).

Oak radial tree growth responded similarly to PHDI and PDSI at all three sites, further emphasizing the importance of available soil moisture. PHDI reacts more slowly to climatic conditions than PDSI (Grissino-Mayer and Butler 2003), as the analyses of this study confirmed. At each site, PHDI consistently correlated more significantly later during the year than PDSI. This was a reflection of the long-term nature of PHDI. The elevational difference between the three sites was also seen in the PHDI correlations. As with PDSI, the PHDI signal existed from the previous fall through the current fall at GMT, from the previous winter through the current November at LW, and the current summer at GK. The lack of a temperature preconditioning signal and the presence of a PDSI and PHDI preconditioning signal suggests that moisture availability is somewhat more important than temperature to growth. Though cool temperatures are important for maximum growth in summer, moisture availability is important across multiple seasons, especially at lower elevations.

6.3 Site to Site Response Variance and Microclimate Conditions

Oak trees at GMT were more responsive to the climate variables tested than both GK and LW. Though each site responded similarly, all but one climatic variable was significant in more months at GMT than the two other sites in Virginia. Two months (September and October) of the previous season showed significant relationships ($p < 0.05$) with precipitation in addition to the current season's relationships, whereas GK and LW were only significant in the current May and June. Temperature was significantly negatively correlated from May to July at GMT, while only May and June were significant at LW. A significant inverse relationship with temperature at GK existed solely in July. Further, seasonalized temperature correlations were stronger, more significant, and longer lasting at GMT than GK and LW. The PDSI and growth relationship at GMT was significant ($p < 0.001$) in seven months spanning across the previous and current growing season. Only three months were significant ($p < 0.001$) at both GK and LW. The relationship between PHDI and growth were similar between GMT and LW. Both sites have six months in the current growing season with significant relationships ($p < 0.001$) (though it should be noted that the six months at GMT were significant to $p < 0.0001$, whereas LW has fewer months significant to that level). The GK site had only four months with a significant PHDI relationship ($p < 0.001$).

Though a macroclimate signal is evident between all three sites, microsite conditions influence the strength of each site's climate response. GMT, the most responsive of the sites to precipitation, is located on a southeast-facing slope while LW and GK are located on north and west-facing slopes, respectively. In the Northern Hemisphere, south-facing slopes are much drier due to increased sun exposure, and a rain shadow exists over east-facing slopes (Christopherson 2006). The September and October precipitation response at GMT is a result of these drier conditions. Moisture availability during the previous fall preconditions tree growth and promotes the winter storage of carbohydrates, which in turn, initiates cell production in spring (Fritts 1976). The dry conditions at the south-facing GMT site created greater sensitivity to precipitation. The absence of these dry conditions accounts for the lack of fall precipitation response at GK and LW.

The temperature variable correlated with ring width notably stronger and more often at GMT than at GK and LW. Greater temperature sensitivity at GMT was likely due to its latitudinal differences from the other two sites. GMT was 280 kilometers southwest of the other two study sites, indicating that GMT was subjected to a greater amount of sunlight on a daily and yearly basis, creating a significantly warmer climate overall. Summer temperatures were 2.6 ºC warmer on average during the month of July. Temperatures from 1930–2006 averaged 21.9 ºC in July at Virginia's Southwestern Mountain climate division compared to 24.5 ºC at Tennessee's Eastern climate division (NCDC 2007). Increased elevation also diminished the relationship between growth and temperature. The GMT site was 595 and 330 m lower than GK and LW, respectively. GMT, which had the most significant relationship to temperature, had the lowest elevation of the three. On the other hand, GK, the highest of the three sites, had the least significant temperature relationship. As expected, LW, the median of the three sites in elevation, fell between the others in responsiveness. The warmer climate of GMT offered a clear explanation to its more prominent inverse relationship with temperature.

As elevation and latitude decrease, warmer temperatures accelerate evapotranspiration rates and oak trees become more sensitive to drought (Fritts 1976). Lower average air temperature at the increased elevation of GK equated to a slower evapotranspiration rate, which allowed soil moisture to remain available for more months of the year. Inversely, warmer average air temperature at GMT caused a higher evapotranspiration rate, resulting in less residual soil moisture. Less available moisture coupled with increased air temperature leads to water stress within the tree (Fritts 1976). Oaks exposed to these conditions are inherently more sensitive to drought because soil moisture is not as readily available. In the southern Appalachians, higher elevation oaks (like those of GK) are less vulnerable to drought conditions due to a cooler climate. Conversely, lower elevation oaks (like those of GMT), are more sensitive to drought.

6.4 Conclusions

The goal of this study was to explore the climatic factors that limit growth in oak trees from three sites in southern Appalachia. Oak radial tree growth is highest during cool, moist summers. Moisture availability during the previous fall also preconditions tree growth and promotes the winter storage of carbohydrates, which in turn, initiate cell production in spring (Fritts 1976). Oak climate response increases in Appalachia across north to south and high to low gradients. Warmer temperatures at lower elevation and latitudes increase evapotranspiration rates. As a result, oak trees become more sensitive to drought.

The trees sampled for this study exhibited significant correlations with all of the variables tested, which indicated that these species are suitable for climate reconstruction. Oak species are a reliable medium of precipitation and drought reconstruction (Cleaveland and Duvick 1992; Fritts 1962) but some researchers have deemed oaks as less suitable for temperature reconstruction (Bortolot *et al*. 2001). However, the high sensitivity at GMT suggested temperature reconstruction may be possible with oak trees in this particular climate type. Though white oak is the most commonly used oak for climate reconstruction in the eastern United States (Speer 2001), high mean sensitivities at each site suggested interspecies oak chronologies could also be used for climate reconstruction. Future studies should seek to extend oak chronologies further back in time so long-term temperature or precipitation construction can occur.

Silviculturists, foresters, and wildlife management officials can utilize the knowledge gained from this study. Knowing the time of year when oak species are most susceptible to dry conditions will allow land managers to determine when fire hazard potential is at its greatest. Further, fire ecologists can better coordinate prescribed burning periods in mixed oak forests around drought periods. Climate conditions can also affect masting periods of oak specimens. This information is important to land managers, especially park wildlife and game officials, because many wildlife populations are dependent upon acorns as a food source. Officials can predict food availability and hence, the health of animal populations, if they understand the relationship between climate and tree growth (Speer 2001). Further studies should seek to determine whether low elevation or low latitude has a greater influence on the climate signal in oak. If global temperatures continue to rise as predicted (Mann *et al*. 1998), the potential frequency of drought may increase, resulting in a decrease in wood productivity (Orwig and Abrams 1997). The results of this study show the potential of oak tree rings as a proxy record capable of climate reconstruction. Further development of oak chronologies from other sites should take place to improve knowledge of the dynamics of Earth's past environments.

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APPENDIX

Appendix A-1 Details of the series in the Griffith Knob chronology. QUAL: *Quercus alba*; QUCO: *Quercus coccinea*; QUMO: *Quercus montana*; QURU: *Quercus rubra*; QUVE: *Quercus velutina*.

	Series	Species	Interval		No. of Years	Correlation with master	Mean Sensitivity
1	GKA004A	QUMO	1915	2003	89	0.843	0.363
2	GKA004B	QUMO	1915	2003	89	0.843	0.326
3	GKA006A	QUMO	1949	2003	55	0.510	0.349
4	GKA006B	QUMO	1949	2003	55	0.539	0.378
5	GKA020A	QUMO	1939	2003	65	0.696	0.285
6	GKA020B	QUMO	1939	2003	65	0.692	0.292
7	GKA033A	QUMO	1955	2003	49	0.706	0.274
8	GKA033B	QUMO	1916	2003	88	0.602	0.310
9	GKA034A	QUMO	1922	2003	82	0.739	0.251
10	GKA045A	QUCO	1916	2003	88	0.704	0.266
11	GKA056B	QUMO	1899	2003	105	0.674	0.288
12	GKC066A	QUMO	1939	2003	65	0.743	0.205
13	GKC066B	QUMO	1937	2003	67	0.721	0.233
14	GKA075A	QUCO	1917	2003	87	0.737	0.305
15	GKA075B	QUCO	1916	2003	88	0.686	0.314
16	GKC084A	QUCO	1942	2003	62	0.644	0.263
17	GKC090A	QUMO	1932	2003	72	0.657	0.266
18	GKC092B	QUMO	1949	2003	55	0.796	0.212
19	GKC120A	QUCO	1935	2003	69	0.529	0.269
20	GKC127A	QUMO	1927	2003	77	0.650	0.237
21	GKC127B	QUMO	1927	2003	77	0.628	0.224
22	GKD001A	QUMO	1938	2003	66	0.769	0.281
23	GKD001B	QUMO	1938	2003	66	0.772	0.315
24	GKD005A	QUMO	1899	2003	105	0.506	0.200
25	GKD005B	QUMO	1889	2003	115	0.785	0.232
26	GKD010A	QUCO	1915	2003	89	0.582	0.279
27	GKD028B	QUVE	1928	2003	76	0.779	0.315
28	GKD031A	QUMO	1946	2003	58	0.590	0.226
29	GKD031B	QUMO	1928	2002	75	0.612	0.237
30	GKD032A	QUMO	1901	2003	103	0.717	0.277
31	GKD033A	QUMO	1910	2003	94	0.701	0.285
32	GKD033B	QUMO	1910	2003	94	0.669	0.302
33	GKD041B	QURU	1909	2003	95	0.696	0.301
34	GKD045A	QUAL	1923	2003	81	0.665	0.341
35	GKD054A	QUMO	1938	2003	66	0.576	0.263
36	GKD057A	QUMO	1917	2003	87	0.648	0.327
37	GKD057B	QUMO	1917	2003	87	0.557	0.287
38	GKD058A	QUMO	1921	2003	83	0.553	0.217
39	GKD058B	QUMO	1921	2003	83	0.667	0.236
40	GKD059A	QUMO	1920	2003	84	0.657	0.232
41	GKD059B	QUMO	1917	2002	86	0.707	0.287
42	GKD060B	QUMO	1927	2003	77	0.546	0.296

43	GKD061A	QUMO	1924	2003	80	0.626	0.274
	Total:		1889	2003	115	0.670	0.277

Appendix A-2 Details of the series in the Little Walker Mountain chronology. QUCO: *Quercus coccinea*; QUMO: *Quercus montana*; QURU: *Quercus rubra*.

	Series	Species	Interval		No. of Years	Correlation with Master	Mean Sensitivity
1	LWB005A	QUMO	1919	2004	86	0.710	0.271
2	LWB005B	QUMO	1896	2004	109	0.472	0.280
3	LWB033A	QURU	1955	2004	50	0.724	0.258
4	LWB033B	QURU	1955	2004	50	0.676	0.248
5	LWB044A	QUMO	1906	2004	99	0.698	0.201
6	LWB044B	QUMO	1924	2004	81	0.640	0.200
7	LWB046A	QUMO	1921	2004	84	0.529	0.241
8	LWB056A	QUMO	1919	2004	86	0.594	0.280
9	LWB056B	QUMO	1919	2004	86	0.601	0.268
10	LWB057A	QUMO	1917	2004	88	0.790	0.253
11	LWB057B	QUMO	1917	2004	88	0.693	0.237
12	LWB061A	QUMO	1915	2004	90	0.743	0.224
13	LWB061B	QUMO	1915	2004	90	0.653	0.221
14	LWC045A	QUMO	1935	2004	70	0.755	0.267
15	LWC045B	QUMO	1943	2004	62	0.811	0.276
16	LWC046A	QUMO	1918	2004	87	0.718	0.290
17	LWC046B	QUMO	1917	2004	88	0.540	0.278
18	LWC047A	QUMO	1936	2003	68	0.704	0.298
19	LWC048A	QUMO	1917	2004	88	0.599	0.249
20	LWC053A	QUMO	1933	2004	72	0.810	0.266
21	LWC054A	QUMO	1907	2004	98	0.648	0.275
22	LWC055A	QUMO	1889	2004	116	0.540	0.242
23	LWC055B	QUMO	1907	2004	98	0.636	0.290
24	LWC063A	QUMO	1936	2004	69	0.805	0.302
25	LWC063B	QUMO	1936	2004	69	0.714	0.350
26	LWC065A	QUMO	1935	2004	70	0.798	0.322
27	LWC071A	QUMO	1945	2004	60	0.438	0.266
28	LWC079A	QUMO	1923	2004	82	0.699	0.329
29	LWC079B	QUMO	1923	2004	82	0.755	0.312
30	LWC080A	QUMO	1925	2004	80	0.709	0.290
31	LWC080B	QUMO	1925	2004	80	0.683	0.312
32	LWC081A	QUMO	1936	2004	69	0.594	0.290
33	LWC081B	QUMO	1936	2004	69	0.720	0.262
34	LWD003B	QUMO	1944	2004	61	0.781	0.318
35	LWD056A	QURU	1947	2004	58	0.548	0.226
36	LWD056B	QUMO	1947	2004	58	0.501	0.247
37	LWC065B	QUMO	1940	2004	65	0.815	0.291
38	LWD071A	QUCO	1915	2004	90	0.549	0.280
39	LWD071B	QUCO	1915	2004	90	0.635	0.249
40	LWD100A	QUMO	1936	2004	69	0.514	0.223
	Total:		1889	2004	116	0.659	0.268

Appendix A-3 Details of the series in the Gold Mine Trail chronology. QUAL: *Quercus alba*; QUCO: *Quercus coccinea*; QUMA: *Quercus marilandica*; QUMO: *Quercus montana*; QURU: *Quercus rubra*; QUVE: *Quercus velutina*.

	Series	Species	Interval		No. of Years	Correlation with Master	Mean Sensitivity
1	GMA006A	QUCO	1860	2005	146	0.477	0.152
2	GMA019A	QUMO	1858	2005	148	0.689	0.209
3	GMA019B	QUMO	1913	2005	93	0.625	0.194
4	GMA027A	QUMO	1904	2005	102	0.630	0.228
5	GMA028A	QUMO	1942	2005	64	0.688	0.133
6	GMA043A	QUAL	1964	2005	42	0.533	0.235
7	GMA043B	QUAL	1952	2005	54	0.477	0.294
8	GMA050B	QUAL	1933	2005	73	0.527	0.369
9	GMA054A	QUCO	1935	2005	71	0.572	0.321
10	GMA054B	QUCO	1940	2005	66	0.461	0.239
11	GMA056A	QUAL	1901	2005	105	0.522	0.185
12	GMA057B	QUCO	1947	2005	59	0.485	0.221
13	GMA059B	QUCO	1955	2005	51	0.621	0.245
14	GMA063A	QUMA	1939	2005	67	0.540	0.258
15	GMA069A	QUVE	1935	2005	71	0.544	0.290
16	GMA069B	QUVE	1935	2005	71	0.548	0.245
17	GMA073A	QUAL	1934	2005	72	0.590	0.249
18	GMA073B	QUAL	1934	2005	72	0.586	0.238
19	GMA077A	QUCO	1953	2005	53	0.604	0.219
20	GMA077B	QUCO	1953	2005	53	0.631	0.171
21	GMA081B	QUAL	1864	2005	142	0.617	0.179
22	GMA088A	QUCO	1933	2005	73	0.450	0.261
23	GMA088B	QUCO	1933	2005	73	0.629	0.219
24	GMA090B	QUCO	1962	2005	44	0.547	0.195
25	GMA094A	QUAL	1946	2005	60	0.491	0.237
26	GMA094B	QUAL	1961	2005	45	0.481	0.205
27	GMA096A	QUCO	1964	2005	42	0.677	0.247
28	GMA096B	QUCO	1959	2005	47	0.586	0.201
29	GMA103A	QUCO	1958	2005	48	0.618	0.199
30	GMB018B	QUMO	1940	2005	66	0.417	0.345
31	GMB026A	QUAL	1836	2005	170	0.487	0.242
32	GMB026B	QUAL	1846	2005	160	0.559	0.227
33	GMB051B	QUAL	1846	2005	160	0.569	0.208
34	GMB065A	QUCO	1907	2005	99	0.588	0.187
35	GMB065B	QUCO	1890	2005	116	0.546	0.167
36	GMB085A	QUAL	1836	2005	170	0.597	0.224
37	GMB085B	QUAL	1863	2005	143	0.714	0.232
	Total:		1836	2005	170	0.570	0.224

Appendix B-1 Griffith Knob chronology ARSTAN output.

Year	Value
1889	2.1879
1890	1.5181
1891	1.9643
1892	1.6300
1893	0.9827
1894	0.7557
1895	0.6453
1896	0.7353
1897	0.6905
1898	0.6366
1899	1.2786
1900	1.8451
1901	1.5604
1902	0.8039
1903	0.7854
1904	0.9373
1905	1.0148
1906	1.1088
1907	1.0494
1908	1.0936
1909	1.5888
1910	1.4022
1911	0.5230
1912	0.8360
1913	0.7972
1914	0.4740
1915	1.2864
1916	1.3435
1917	0.9635
1918	0.8564
1919	0.7294
1920	0.8231
1921	0.8170
1922	1.0381
1923	1.0694
1924	1.2494
1925	0.7705
1926	0.7797
1927	1.0069
1928	0.9592
1929	0.9565
1930	0.5597
1931	0.7558
1932	0.8598
1933	0.8290
1934	0.6839
1935	0.9810
1936	0.8067
1937	1.0371
1938	1.3999
1939	1.1473
1940	1.2254
1941	0.9382
1942	1.3037
1943	1.2341
1944	0.8511
1945	1.2020
1946	0.9343
1947	0.7405
1948	0.8549
1949	0.9350
1950	1.1953
1951	1.0665
1952	0.7923
1953	1.2683
1954	0.7782
1955	0.8819
1956	1.0109
1957	1.0148
1958	1.1319
1959	0.9208
1960	1.1571
1961	1.4250
1962	1.1235
1963	0.8363
1964	0.8059
1965	0.9492
1966	0.4983
1967	0.7017
1968	0.9441
1969	0.9447
1970	0.6800
1971	0.9516
1972	0.7711
1973	0.9520
1974	1.1356
1975	1.1029
1976	0.9522
1977	0.7784
1978	0.9837
1979	1.1516
1980	1.2003
1981	1.4160
1982	1.4834
1983	0.8794
1984	1.0354
1985	1.0282
1986	0.8480
1987	0.8296
1988	0.5914
1989	1.0749
1990	0.9535
1991	1.1150
1992	1.0820
1993	0.9366
1994	1.0604
1995	1.3023
1996	0.9180
1997	1.0025
1998	1.1686
1999	0.7824
2000	1.1267
2001	1.0708
2002	0.7919
2003	0.9659

Appendix B-2 Little Walker Mountain chronology ARSTAN output.

Year	Value
1889	1.4411
1890	1.3479
1891	1.6102
1892	2.0628
1893	1.5155
1894	1.2552
1895	1.4445
1896	1.3230
1897	1.1505
1898	1.8019
1899	1.4668
1900	1.2260
1901	0.7910
1902	0.8072
1903	0.7915
1904	0.8872
1905	0.7217
1906	0.6254
1907	0.6920
1908	0.8279
1909	0.9407
1910	1.0588
1911	1.0513
1912	1.1819
1913	1.2599
1914	0.6679
1915	1.1027
1916	1.1152
1917	1.2289
1918	0.8268
1919	0.9802
1920	1.0411
1921	1.0446
1922	1.1254
1923	1.2607
1924	1.4205
1925	0.7671
1926	0.8478
1927	1.0906
1928	1.1111
1929	0.9004
1930	0.4806
1931	0.7113
1932	0.9623
1933	1.0349
1934	1.0807
1935	0.8591
1936	0.7909
1937	1.0042
1938	1.1635
1939	0.8201
1940	1.1200
1941	0.7287
1942	1.2172
1943	1.2143
1944	0.9186
1945	1.1604
1946	1.0111
1947	0.8842
1948	0.8620
1949	0.9642
1950	1.1024
1951	0.7801
1952	0.8670
1953	1.2149
1954	0.7834
1955	0.6673
1956	0.8416
1957	0.8798
1958	1.0541
1959	0.8371
1960	1.0021
1961	1.2278
1962	1.3094
1963	0.7864
1964	0.8510
1965	0.9860
1966	0.5221
1967	0.5863
1968	0.7731
1969	0.9414
1970	0.6291
1971	1.1200
1972	0.9962
1973	1.0798
1974	1.2038
1975	1.3357
1976	0.8737
1977	0.7191
1978	0.9062
1979	1.2005
1980	0.9359
1981	1.1850
1982	1.3900
1983	1.3041
1984	0.9336
1985	0.8985
1986	0.7496
1987	0.9015
1988	0.6117
1989	1.0949
1990	0.9164
1991	0.9112
1992	0.9195
1993	1.0360
1994	1.0508
1995	1.2096
1996	1.0846
1997	1.1161
1998	1.2142
1999	0.8401
2000	1.0696
2001	1.0882
2002	0.9022
2003	0.9935
2004	1.2287

Appendix B-3 Gold Mine Trail chronology ARSTAN output.

Year	Value
1836	1.1990
1837	1.4237
1838	0.8990
1839	0.9180
1840	1.1956
1841	0.8593
1842	1.1147
1843	1.0065
1844	1.1729
1845	1.0159
1846	0.8148
1847	1.2372
1848	0.9580
1849	1.0326
1850	0.6977
1851	0.8509
1852	1.1477
1853	0.9798
1854	1.0308
1855	1.0418
1856	0.9670
1857	1.0584
1858	1.0063
1859	0.9505
1860	1.0541
1861	0.9602
1862	0.9895
1863	1.2336
1864	0.9928
1865	0.8028
1866	0.8789
1867	0.8794
1868	0.7400
1869	0.9580
1870	0.9069
1871	0.8450
1872	0.6440
1873	0.8463
1874	0.7208
1875	1.2984
1876	1.2719
1877	1.0972
1878	1.1918
1879	0.8153
1880	0.9061
1881	1.1631
1882	1.2951
1883	1.1062
1884	1.2327
1885	0.9372
1886	1.1888
1887	0.9502
1888	1.0051
1889	1.0811
1890	0.8274
1891	0.8379
1892	1.2748
1893	1.1246
1894	0.8925
1895	0.8011
1896	0.9928
1897	0.9841
1898	0.8201
1899	0.9519
1900	0.9907
1901	0.9364
1902	1.0367
1903	1.0939
1904	1.0533
1905	0.9919
1906	0.8445
1907	0.9720
1908	0.9916
1909	1.1055
1910	1.0874
1911	0.5352
1912	0.9396
1913	0.7748
1914	0.5396
1915	0.9635
1916	0.9839
1917	0.9572
1918	0.9787
1919	0.8895
1920	0.8461
1921	0.7057
1922	1.0539
1923	1.0221
1924	0.9572
1925	0.6377
1926	0.7262
1927	0.9986
1928	1.0127
1929	0.9574
1930	0.8522
1931	0.7894
1932	0.8566
1933	0.6904
1934	0.9045
1935	1.1431
1936	0.6919
1937	1.1368
1938	1.4473
1939	1.1404
1940	1.1019
1941	0.8474
1942	1.1764
1943	0.9392
1944	0.7107
1945	1.0897
1946	1.2066
1947	0.9096
1948	0.8841
1949	1.2111
1950	1.1790
1951	1.0130
1952	0.7940
1953	0.7794
1954	0.8212
1955	0.7220
1956	0.6799
1957	0.8212
1958	1.0238
1959	0.9204
1960	1.0719
1961	1.1163
1962	0.9356
1963	0.9937
1964	0.7630
1965	1.0141
1966	0.8798
1967	0.9927
1968	0.8990
1969	0.9951
1970	1.0846
1971	1.1338
1972	1.3196
1973	1.4602
1974	1.3424
1975	1.2459

Year	Value
1976	1.3986
1977	1.0987
1978	1.1792
1979	1.1327
1980	0.9699
1981	1.1841
1982	1.1533
1983	1.2653
1984	0.9351
1985	0.8325
1986	0.7863
1987	0.8559
1988	0.6969
1989	0.9816
1990	1.0565
1991	0.9235
1992	1.0227
1993	0.9146
1994	1.0867
1995	0.9125
1996	0.9699
1997	1.0171
1998	0.8220
1999	0.8045
2000	0.7852
2001	0.8754
2002	0.7103
2003	0.9887
2004	0.7602
2005	0.9538