5-2004

The Effects of Habitat Alterations on Growth and Vitality of *Torreya taxifolia* Arn. in Northern Florida, U.S.A.: a Dendroecological Study

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Recommended Citation

Atchley, Elizabeth A., "The Effects of Habitat Alterations on Growth and Vitality of *Torreya taxifolia* Arn. in Northern Florida, U.S.A.: a Dendroecological Study. " Master's Thesis, University of Tennessee, 2004.
https://trace.tennessee.edu/utk_gradthes/4660

To the Graduate Council:

I am submitting herewith a thesis written by Elizabeth A. Atchley entitled "The Effects of Habitat Alterations on Growth and Vitality of *Torreya taxifolia* Arn. in Northern Florida, U.S.A.: a Dendroecological Study." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Geography.

Henri D. Grissino-Mayer, Major Professor

We have read this thesis and recommend its acceptance:

Sally P. Horn, Kenneth H. Orvis

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Sally P. Horn

Sally P. Horn, Thesis Committee Member

Kenneth H. Orvis, Thesis Committee Member

Acceptance for the Council:

Vice Provost and Dean of Graduate Studies

The Effects of Habitat Alterations on Growth and Vitality of *Torreya taxifolia* Arn. in Northern Florida, U.S.A: a Dendroecological Study

A Thesis
Presented for the
Master of Science Degree
The University of Tennessee, Knoxville

Elizabeth A. Atchley
May 2004

Dedication

This thesis is dedicated to the memory of my Mother,
Lavern D. Atchley,
for a lifetime of love and support.

Acknowledgements

Many people assisted me with this project. I would like to express my deepest gratitude to my major professor, Dr. Henri D. Grissino-Mayer, for his guidance and support in the field and lab. I have learned so much from him, not only about the science of dendrochronology, but also about patience, persistence, and dedication to learning. I am also very grateful to my other committee members, Dr. Ken Orvis for his intellect and support, and Dr. Sally Horn for her experience and wisdom from which she has provided immense guidance and support during my years in the program. I am deeply grateful to the staff, faculty, and my fellow graduate students of the Department of Geography for their support throughout the whole process.

I am grateful to the Department of Geography and the McCroskey Memorial Fund for the financial support that was necessary to conduct my fieldwork in Florida. I would like to thank the Florida Nature Conservancy and Greg Seamon at the Apalachicola Bluffs and Ravines Preserve for their support and generosity, the staff of Torreya State Park for their flexibility and for granting me permission to sample on their land, and the Army Corps of Engineers for granting sampling permission at the Jim Woodruff Dam site in Chattahoochee, Georgia. I would also like to thank Sharon Hermann for her guidance during the early stages of my study when I needed it most.

I am grateful to my fellow graduate students in the Department of Geography at the University of Tennessee for their support and enthusiasm. I would like to thank Daniel Lewis and Jake Cseke for their support in the field and lab. I would like to thank Georgina Wight, Saskia van de Gevel-Edinin, and Alison Miller for great peer reviews. I thank David Mann, Evan Larson, Lisa Boulton, and Martin LaFrenz for their moral support.

I am grateful to my father, Billy R. Atchley, for being very proud and supportive, and to my sisters, Tammy and Lisa, for their great moral support. I am deeply grateful to Heather Leigh Harvey for her support and assistance in the field as well her patience and moral support during the long writing process. I would also like to thank her parents, Debby and Howard Harvey, for their support during the past four years. I am forever grateful to my best friends Shawn Arthur, Stephanie Martin, and Karen and Doug Velliquette for years of support.

Finally, I would like to thank my "kids" Domino, the Border Collie and cats, Dymphna and Gipsy, for their unconditional love.

Abstract

Torreya taxifolia has thrived in the bluffs and moist hammocks along the Apalachicola River in northern Florida and southern Georgia for thousands of years. This species underwent a drastic decline in the mid-1950s. A stem and needle blight, similar to that which destroyed the American chestnut, has resulted in widespread mortality and a virtual halt in sexual reproduction in *Torreya* throughout its natural range. Because no single invasive, lethal pathogen has been isolated, possible environmental factors that would cause decreased growth and resistance to disease are being examined. Among these factors are changes in local climate and land use regimes. A study of the climate history within the habitat of *T. taxifolia* may identify the change(s) that have initiated and are currently causing the decline of this species. In addition a climate/growth model for this species should benefit restoration and reintroduction programs.

Increment cores and cross sections were taken throughout the range of *T. taxifolia*. Because *T. taxifolia* is an endangered species, no samples were taken from live trees. Cross sections were cut from remnant logs of *Torreya*, and increment cores were extracted from nearby pines. A total of 29 *Torreya* cross sections and 150 pine increment cores were taken from the collection sites at Woodruff Dam, Torreya State Park, and the Apalachicola Bluffs and Ravines Preserve (ARBP). The samples were prepared and measured using standard dendrochronological techniques. Correlation analyses were conducted using local climate data, including precipitation, temperature, and drought (PHDI) for the purpose of modeling tree-growth response to local climate. Early period and late period growth patterns were compared to determine if a certain mechanism in the local environment weakened these trees making them more susceptible to the stem and needle blight. Historical accounts of changes in the habitat and surrounding area were also reviewed to determine if anthropogenic habitat changes, such as the construction of Woodruff Dam near Chattahoochee or local clear-cutting operations, contributed to the increase in mortality of *T. taxifolia*.

A master chronology extending back to 1869 was established using 125 pine cores. Twenty of the *T. taxifolia* cross sections were successfully dated, extending the chronology back to 1814. I found a significant positive relationship between growth and spring precipitation and an inverse relationship between growth and summer drought severity and summer temperature. The climate-growth response of *T. taxifolia* mirrored that of the pines, but was not as intense, possibly because of the protected understory habitat.

The correlation between tree growth and precipitation suggests that moisture is the strongest determining factor of growth in this area. The inverse relationship with temperature illustrates the effect of higher temperatures on available moisture. A drought and warm period occurred simultaneously during the mid-1950s in combination with heightened clear-cutting practices and the construction of Woodruff Dam. It is my conclusion that habitat destruction occurring as early as the turn of the 20th century began weakening the *Torreya*. The unfavorable climate conditions and rapid degradation of the habitat that occurred during the mid-1950s further weakened the *Torreya* and allowed them to succumb to terminal infection by the blight.

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Chapter 1

The Plight of *Torreya taxifolia* Arn.

1.1 Introduction

In 1875, prominent Harvard botanist Asa Gray traveled to the bluffs of the Apalachicola River in northwest Florida to study the rare conifer, *Torreya taxifolia* Arn. After pushing through dense thickets of bald cypress, palmetto, bamboo, and tupelo, he found a shining example of what he came to study. He described the *Torreya* as "A beautiful shaggy pyramid, some fifty feet high and cloaked with glossy evergreen needles" (Nicholson, 1990). Gray also noted the restricted range of this species, making this cryptic prediction: "So this species may be expected to endure, unless these bluffs should be wantonly deforested–against which their distance from the river and the steepness of the ground offer some protection. But any species of a very restricted range may be said to hold its existence by a precarious tenure" (Nicholson, 1990).

In just under 100 years, that dark prediction is proving true for the *T. taxifolia* in Florida. In 1958, Vaughn McCowan of the Florida Forest Service found dead *Torreya* on the higher slopes of the Apalachicola bluffs. At that time, the blame was placed on several successive drought years experienced throughout the Florida Panhandle. By 1962, botanist Herman Kurtz of Florida State University and a colleague, R.K. Godfrey, reported many dead trees with a few sending up basal sprouts. They also found evidence of disease, brown blotches, on all of the vegetation and basal sprouts (Toops, 1981). Since then, the *Torreya* population has steadily declined. Currently, no large trees are left in the wild. A blight, similar to that which destroyed the American chestnut, is attacking the limited population, killing the adults and basal sprouts and saplings upon reaching sexual maturity (Toops, 1981).

1.2 Problem Statement

Some of the fungi possibly responsible for the blight are common natives that have never been serious problems in the past. There is now much speculation about multiple factors within the environment causing the decline of the *T. taxifolia* population. Several successive drought years that occurred in the mid-1950s were blamed for the initial decline, but this population is believed to have occupied the area since the last glacial period (Toops, 1981). A population established since then is likely to have survived more severe climatic shifts. Just prior to the decline of *Torreya,* part of the uplands above the Apalachicola bluffs were cleared and planted with slash pine (Nicholson, 1990). It is believed that the clearing of the area may have changed the hydrology of the ravines, or the reduction of canopy cover may have increased ambient temperature as more heat radiated off the unshaded soil. These factors could have weakened the trees to the point that they were more likely to exhibit pathologic symptoms of the fungus (Nicholson, 1990).

Schwartz *et al.* (1995) believed that fire suppression might be the culprit. Lightning-ignited ground fires have long been a feature in Florida's longleaf pine forests (Nicholson, 1990). Smoke from these fires possibly drifted and settled into the ravines, acting as a natural fungicide, keeping the fungal spores in control (Nicholson, 1990). The suppression of fire in these forests may have caused the fungal spore load to reach a critical level in the area.

Many local residents believe that the construction of a dam near Chattahoochee changed the local climate in the ravines by causing the water to be warmed in Lake Seminole before being released into the Apalachicola River (Toops, 1981). Schwartz *et al.* (1995) noted that outflow temperatures averaged 1.2°C higher in the Apalachicola River than its tributary streams. It is uncertain whether or not this local water temperature change is responsible for the decline of the species (Schwartz *et al.*, 1995). Schwartz and Hermann (1999) suggested that the current low growth rates of *T. taxifolia* may be attributed to changing forest management practices in the bluffs. They state that a combination of fire suppression and the cessation of selective timbering in the ravines since the 1950s has allowed a dense, young forest canopy to overshadow any *Torreya* juveniles growing in the understory. They believed that lower light levels, not a fungal agent, may be responsible for the decline.

One or all of these factors could be playing a role in the demise of *Torreya taxifolia* in its natural range. A study of climate history within the habitat of *T. taxifolia* may identify the change(s) that initially caused and are currently causing the decline of this species.

1.3 Objectives

It is unknown how long remaining trees will continue producing basal sprouts or if any will outlast the blight. Most who study this species believe that extinction is imminent if aggressive conservation actions are not taken (Toops, 1981). My hypothesis is that some change(s) in the local environment, possibly combined with the outbreak of the stem and needle blight, are responsible for the ongoing extinction of *Torreya taxifolia* in its natural range.

The specific objectives of my study are:

- To build a tree-ring chronology using increment cores from living *Pinus* species throughout the habitat of *T. taxifolia* for the purpose of analyzing changes in tree growth in response to changes in local and regional climate.
- To examine and analyze tree-ring patterns from samples of *Torreya taxifolia* taken from downed logs dating back to the beginning of the decline to find evidence of changes in tree growth rates which might suggest initial changes of light, temperature, and/or moisture that may have contributed to the population decline.
- To compare environmental and climatic conditions at the time of the initial decline to those currently present to determine whether or not some of the mechanisms responsible for the initial decline of *T. taxifolia* are present now.
- To provide information that will help others formulate a management plan to improve habitat conditions where possible to aid in the growth and recovery of *T. taxifolia* in its natural range.

Further studies of the changes in local climate and habitat are necessary to determine causes for the decline of *T. taxifolia* in its natural range. Conservation and reintroduction programs must take these habitat changes into consideration before successful management practices can be enacted. A dendroecological study of *T. taxifolia* could assist in determining what habitat changes have occurred, as well as the precise timing of these changes and how they may have contributed to the decline in growth of this species.

Chapter 2

The Ecology of *Torreya taxifolia*

2.1 Physiology of *Torreya taxifolia*

Torreya taxifolia is a dioecious evergreen tree in the *Taxaceae* family that typically grows from 9–12 m tall with a diameter at breast height of 30–50 cm (Figure 2.1). *T. taxifolia* mainly grow on steep, shaded limestone bluffs and ravines along the Apalachicola River in northwestern Florida and extreme southern Georgia. Although it is often found in dense shade in its natural environment, some cultivated specimens seem to fare better in full sunlight (Schwartz and Hermann, 1999).

The trees of the *Torreya* genus vaguely resemble their cousins, the yews (*Taxus* spp.). They are small to moderately sized evergreen trees with flattened glossy green needles (Judd *et al.*, 1999). The leaves are sharply pointed, two-ranked, and are dark green above and paler underneath. When the vegetation is crushed or broken, a pungent odor is emitted, giving this species its common name, stinking cedar (Toops, 1981). The bark is about 1 cm thick on mature trees and is irregularly divided by shallow fissures (Statler, 1990).

The ovules are arils that are 3-4 cm long (Statler, 1990). They are fleshy, turning leathery at maturity and contain a single woody seed. The male trees bear their microsporophylls within stroboli that begin growth a year before flowering. Reproductive structures emerge in March and April. The seeds ripen from August to October and are released from September to November. *T. taxifolia* produce male and female cones at 20

Figure 2.1 *T. taxifolia* seedling at Torreya State Park.

years of age, and are wind-pollinated. Viable seeds are rock hard at maturity and require after-ripening for germination. Vegetative reproduction occurs through sprouts from the roots or trunk following damage to the aboveground portion of the tree (Statler, 1990).

2.1.1 Stem and Needle Blight

Trees infected with the stem and needle blight rarely reach heights over 2 m (Nicholson, 1990). Brown blotches appear on the leaves and stems of infected trees, and the seeds from diseased trees, which should be rock hard, are soft and easy to crumble (Toops, 1981). Infected trees seldom bear reproductive structures (Schwartz and Hermann, 1993). The blight has virtually stopped sexual reproduction in this species (Schwartz and Hermann, 1993).

Fungi possibly responsible for the blight have been identified as members of the genera *Physalospora* and *Macrophoma* (Statler and Dial, 1984). The primary disease agent has yet to be discovered and the origins of the infection are still unclear (Schwartz *et al.*, 1995). It is possible that it may begin with the fungi attacking the tree while the fungi are still in their sexual reproductive cycle (Statler, 1990).

Lee *et al.* (1995) found the fungus *Pestalotiopsis microspora* associated with diseased and healthy trees, suggesting an endophytic-pathologic relationship. The fungi may thrive within the bark of the tree for many years with no negative effect on health or growth. If the host becomes stressed due to changing environmental factors, these same fungi may terminally infect the host, limiting growth and eventually causing the death of the host. *P. microspora* produces phytotoxins, pestalpyrone, hydroxypestalopyrone, and pestaloside (Lee *et al.*, 1995). Pestaloside was proven to have antifungal properties against other fungal endophytes of *Torreya taxifolia*, perhaps as a mechanism to reduce competition within the host (Lee *et al*., 1995).

2.2 Biogeography of *Torreya taxifolia*

The genus *Torreya*, named for botanist John Torrey, has one of the longest periods of existence of any woody plant species on Earth (Nicholson, 1990). This genus consists of five species living in the northern hemisphere. Three species grow in Asia while the other two, including *T. taxifolia*, are found in North America. Current fossil data dates the origin of *Torreya* at approximately 160 million years ago during the early Jurassic. The complete evolutionary history and past distribution have not yet been revealed. There can only be speculation about why the five species of this genus are scattered so widely across the northern hemisphere and why there ranges are so limited. Further study must be conducted to learn about the ecology, as well as the past, present, and future trends in evolution and distribution of this genus.

2.2.1 Phylogeny of *Torreya taxifolia*

While confusion surrounds the direct ancestors of *Torreya,* fossil evidence suggests that the origin of the genus may have occurred sometime during the early to mid-Jurassic. The confusion surrounding the evolutionary history could be attributed to the fact that there were considerably more conifers during the Mesozoic than are present today. Some are similar to living forms and appear to be ancestors of modern species while others combine features of several different taxa (Miller, 1977). Data from rbcL DNA sequences, morphology, anatomy, and alkaloid chemistry divide the *Taxaceae* family into two clades, one consisting of *Torreya* and *Amenotaxus* and the other consisting of *Taxus, Austrotaxus*, and *Pseudotaxus* (Judd *et al*., 1999). *Amenotaxus* was reported for the first time in the Late Cretaceous. An early Cretaceous seed found in Belgium was typed as *Vesquia*, an extinct genus of *Taxaceae*. The morphology of the seed is like that of *Torreya* while the megaspore membrane is more similar to that of *Taxus* and *Amenotaxus* (Miller, 1977). There is also speculation that a fossil of *Cephelotaxospermum* from the late Cretaceous of Alabama may actually be the fruit of *Torreya* (Miller, 1977). Fossilized wood of *Torreyoxylon* from the lower Cretaceous of Hungary is more like the wood of modern *Torreya* (Miller, 1977). The task of clarifying evolutionary pathways of these Mesozoic conifers with the abundance of fossil species on record has been described as being like a jigsaw puzzle with too many pieces (Miller, 1977).

2.2.2 Distribution of *Torreya*

The genus *Torreya* has a disjunct modern distribution. Three species, *T. grandis*, *T. nucifera*, and *T. jackii*, are found in southeast Asia while the other two species, *T. californica* and *T. taxifolia*, have limited ranges in North America. This widely separated distribution could be achieved several ways. It is possible that existing populations are evolutionary relicts. Current fossil evidence seems to indicate that *Torreya* once had a more continuous distribution. *Torreya* fossils that are dated 100–160 million years old have been found in Europe and eastern North America (Nicholson, 1990). It is possible that past fluctuations in climate drove *Torreya* to extinction in much of its range, leaving scattered populations in sheltered areas like river bluffs and certain mountain slopes.

Torreya grows very slowly and most individuals do not reach sexual maturity until they are 20 years old (Statler, 1990). This would make it almost impossible for effective mass migration to a more suitable habitat. Slow growth and reproduction also make it easy for *Torreya* to be out-competed by faster growing trees that would adapt more quickly to favor the change in climate.

It is also possible that current populations are climatic relicts that once had a more northerly range, but during the last glacial the advancing ice pushed them south where they mixed with the temperate deciduous forest species. It is possible that when the ice retreated, the *Torreya* did not reoccupy their northern range and could only survive in cool, moist refuges such as evergreen mountain forests, ravines, and some riverbanks. This is believed to be the case for *Torreya taxifolia.* One theory suggests that *T. taxifolia* was pushed south by the glaciers that covered the northeastern U.S. where it adapted to particular climate or soil conditions in the Apalachicola River system. This topographically unique area likely prevented the expansion of this species northward after the ice retreated (Toops, 1981). This theory is supported by the presence of other remnants of Appalachian vegetation found in the same area of the Florida Panhandle.

Vicariance events could have possibly separated a once continuous population. Perhaps, before the Cretaceous, *Torreya* had a continuous range in the southern Laurasian landmass. Epicontinental seas developed between Asiamerica and Euramerica during the middle and late Cretaceous (Cox and Moore, 1988). In addition, continental drift separated the landmasses by the late Eocene. These events would have served as significant barriers widely separating the population, leading to the disjunct distribution and variety of species seen today. The lack of fossil evidence for this genus makes it difficult to form concrete conclusions about ancestry and historical distribution.

2.3 Economic Importance

Because this species is endangered, no products from the wood or fruits are currently marketed. However, shortly after its discovery in the mid-1800s, many *Torreya* were cut and used as fuel for steamboats running on the Apalachicola River (Gray, 1889). Because *Torreya* was valued for its rot-resistant wood, many of the largest trees were harvested and used for making shingles, fence posts, and cabinets (Burke, 1975). Because *Torreya* is locally believed to be the "gopherwood" used to build Noah's arc, it was used to build pulpits in several of the local churches. Some other species of *Torreya* are used as ornamentals. The wood, edible seed, and seed oil are widely used and valued in Asia (Judd *et al*., 1999). The compound taxol, contained within the trees of this genus, has also proven to be a promising anti-cancer compound (Judd *et al.*, 1999).

Chapter 3

Literature Review

3.1 Biogeography and Ecology

The specific causes of terminal infection and subsequent decline of *Torreya taxifolia* remain unknown. Several studies have investigated possible ecological factors within the habitat that may have weakened *Torreya taxifolia* prior to terminal infection.

3.1.1 Toops (1981)

Connie Toops (1981) provided a timeline of events as well as local perspective concerning the decline of *Torreya* in her article, "The 'Stinking Cedar' is in Big Trouble." Prior to the mid-1950s decline, Dr. Herman Kurz, a botanist at Florida State University, led tours around the bluffs of the Apalachicola River to view healthy populations of *T. taxifolia*. In 1958, dead *Torreya* were found along upper slopes of the bluffs by Vaughn McCowan of the Florida Forest Service. By 1962 Kurz and a colleague noted many more dead trees and evidence of disease (Toops, 1981).

While the cause of the sudden decline is unknown, many local residents blame drought and the construction of Woodruff Dam and Lake Seminole. They thought the dam blocked the tributaries of the Apalachicola, causing the water to back up and warm in the lake before release. They believed that the resulting increase in temperature would negatively impact the trees growing on the bluffs along the river (Toops, 1981).

At the time of Toop's (1981) review, several programs were underway to rescue the *Torreya*. Botanists and horticulturists were attempting to cultivate disease-free seedlings for possible re-introduction. Many of the seedlings re-introduced at that time were soon exhibiting the effects of the stem and needle blight. The work to conserve and propagate this species continues today despite the difficulty of producing healthy cultivars.

3.1.2 Nicholson (1990)

Rob Nicholson (1990) described the pathology and possible causes behind the decline of *T. taxifolia* in his article, "Chasing Ghosts." Pathologists identified fungi collected from infected *Torreya* as common, native species. This finding raised many questions about the role of environmental factors in the terminal infection of this population. Nicholson described several possible culprits including a serious drought that occurred in the mid-1950s, global warming, and clear-cutting of the upland forests by the timber industry. He also discussed the possible effects of fire suppression with biologist Mark Schwartz, who believed the smoke from frequent fires in the upland pine forests acted as a fungicide keeping spore levels in control. Nicholson accompanied Schwartz on several survey trips in 1989. He discussed the mortality of this population, noting the disappearance of several individuals in just a few month's time.

Nicholson (1990) also described a genetic propagation project. More than 2,500 cuttings were collected and sterilized and treated with rooting hormones. Many of these cuttings rooted, and were saved for future re-introduction. The cuttings were tagged with location information. This information will ensure future planting in their original location for the purpose of preserving genetic variability.

3.1.3 Schwartz and Hermann (1993)

Mark Schwartz and Sharon Hermann (1993) completed a survey of the number and health of *T. taxifolia* at five sites in southern Georgia and northern Florida. The 1988 survey of the ravines within the southern section of the Apalachicola Bluffs and Ravines Preserve resulted in the addition of 75 trees to the existing inventory of 25 individuals (Schwartz and Hermann, 1993). Six additional individuals were added to the inventory after a 1991 survey in the same area (Schwartz and Hermann, 1993).

In the northern part of the range, the 1988 survey recorded 25 trees on U.S. Army Corps of Engineers land in Decatur County, Georgia near Lake Seminole (Schwartz and Hermann, 1993). An additional two individuals were added to the count in 1992. Just south of that location within the Flat Creek Drainage, 25 trees were surveyed and measured. An additional six individuals were found in 1992. Census information was obtained for 27 individuals just north of the Apalachicola Bluffs and Ravines Preserve within three ravines along Big Sweetwater Creek in 1991 (Schwartz and Hermann, 1993). After a 1992 survey, 16 trees were added to the count for this population (Schwartz and Hermann, 1993).

Tree size, vigor, and habitat were also assessed during the surveys. The tallest tree surveyed was 3.25 m high, but most individuals were less than one meter tall. The average tree height was 87.8 cm (Schwartz and Hermann, 1993). The tallest trees seemed to be concentrated in the northern portion of the survey area, possibly because of more favorable soil conditions compared to the more sandy soils underlying the southern area of the range. Tree height and stem number had a positive relationship, indicating a greater density of stems among the taller trees in the northern area (Schwartz and Hermann, 1993).

Because *T. taxifolia* do not expand apical buds each year, an age correction factor was introduced using the relationship between the lateral internodes of each branch and the number of terminal internodes above the branches (Schwartz and Hermann, 1993). Using this correction factor, it was determined that the stems expanded apical buds every other year. Schwartz and Hermann also determined that the mean age for the surveyed trees was 12 years, and the maximum age was 31 years. There was a mixture of trees with primary stems dating from the time of the initial decline and trees with primary stems sprouting from other stems that had since died (Schwartz and Hermann, 1993).

Habitat was categorized based on three characteristics: 1) relative elevation above the ravines, determined by slope and distance measurements; 2) the slope aspect of an occurrence, which was determined with the use of a compass; and 3) canopy cover, determined by the measurement of light levels and analyses of photographs of the overhead canopy (Schwartz and Hermann, 1993). The largest numbers of *T. taxifolia* were found less than six meters above the base of the ravines where the lowest light levels were recorded. The relationship between locations of *T. taxifolia* and low light levels did not seem to indicate a preference for low light. Schwartz and Hermann determined that the most likely reason for this distribution of trees along the lower portions of the slope was due to the higher nutrient and moisture content of the soil.

Variations in disease symptoms were also observed within the range of *T. taxifolia*. Needle spots and needle necrosis were more frequent in the southern portions of the range, and stem cankers were more frequent in the northern areas (Schwartz and

Hermann, 1993). This was possibly due to the fact that only larger stems will produce visible disease cankers while smaller stems mainly express foliar symptoms. Therefore, the larger trees in the northern areas were more likely to have more noticeable cankers.

The growth data from this survey indicate an overall decline in the growth and health of the current population of *T. taxifolia*. From 1988-1992, 10% of the surveyed trees died (Schwartz and Hermann, 1993). Ten percent of the population showed reduced growth each year through the loss of the primary stem. Only 20% of the population expanded apical buds and elongated stems each year. Schwartz and Hermann (1993) also determined that most of the population has, at least once, experienced primary stem mortality within the past 30 years.

Schwartz and Hermann (1993) concluded that following the infection and mortality of the primary stem, the plants were left with several smaller stems of which the largest became the primary stem. The continuing death of the primary stems strongly inhibited growth leaving the plants small and stressed. Eventually these stressed plants would deplete their reserves and die.

The hope for sustaining the population of *T. taxifolia* in their native range lies with several larger, relatively healthy individuals. Schwartz and Hermann (1993) noted that these individuals are not growing any faster than the others, but the lack of disease symptoms is promising for the possibility of establishing a mature, sexually reproductive population.

3.1.4 Schwartz *et al.* (1995)

Schwartz *et al.* (1995) examined the effect of environmental stresses on the growth and health of *Torreya.* The factors examined included moisture and temperature stress, changes in soil chemistry and hydrology, and fire suppression. Local fire suppression could affect the growth and health of *T. taxifolia* in two ways. Reduced light levels could result from increased vegetation density and resource competition in and above the ravine system. Fire suppression may also result in increased fungus/pathogen levels on the foliage of *T. taxifolia* due to the reduction of smoke, which may act as a fungicide, within the ravines. The stress imposed by these factors was determined by measuring changes in the net photosynthesis rate of *T. taxifolia* and four other closely related species including *Torreya californica*, *Torreya grandis*, *Torreya nucifera*, and *Taxus floridana*. *Taxus floridana* was chosen because it shares the same habitat within the bluffs and ravines of the Apalachicola River (Schwartz *et al.*, 1995).

Seedlings of *T. californica* and *Taxus floridana* were cultivated and grown outdoors in full sun for 2–3 years (Schwartz *et al.*, 1995). Cuttings from *T. taxifolia*, *T. nucifera*, and *T. grandis* were cultivated in a greenhouse and allowed to grow for two years. The effect of increased temperature on photosynthesis and respiration was assessed by measuring rates at 5°C intervals from 5–40°C. All species in the study expressed the highest photosynthesis rates at temperatures of approximately 20°C (Schwartz *et al.*, 1995). *T. taxifolia* seemed to have the most resistance to increased temperatures, possessing the highest rate of photosynthesis over the broadest range of temperatures compared to the other species. These results disagree with the theory that increased temperatures alone would stress the trees, causing a breakdown of the native population.

The effects of water stress were assessed by the examination of photosynthesis under conditions of decreased soil moisture and relative humidity. The effects of decreased soil moisture were determined by saturating the soil in the pots containing the seedlings then withholding water until they showed carbon gain rates of less than 50% maximum. The photosynthesis response to changes in relative humidity was measured in leaf chambers with humidity levels of 20%, 50%, and 90% (Schwartz *et al*., 1995).

Changes in levels of relative humidity resulted in slight changes in the photosynthesis rates for all species. The rate of photosynthesis was 6% higher at 50% relative humidity than at 20% or 90% relative humidity. The biggest difference in respiration rates for *T. taxifolia* and *T. floridana* occurred between 15% and 50% relative humidity. *T. taxifolia* fared the best during the water stress experiment, maintaining the highest rate of photosynthesis compared to the other species tested. These results suggest that *T. taxifolia* is not significantly affected by short-term water stress.

Before conducting the greenhouse experiment for soil nutrient stress, soil samples were collected from different elevations of the ravines within the habitat of *T. taxifolia* in Florida. No significant difference in nutrient levels was found for the soils collected at the differing elevations. The lowest nutrient class contained lower nutrient levels than the most infertile ravine soils while the higher class contained 10× the nutrients of the low class soils. The seedlings were grown in a pure silica medium and fertilized with weekly water treatments (Schwartz *et al.*, 1995).

There were no significant differences in growth of the seedlings with the different nutrient treatments. All seedlings involved in the growth trial increased net biomass by more than 50% showing that the range of nutrient availabilities encountered in the wild is not a limiting factor of growth (Schwartz *et al.*, 1995).

Schwartz *et al.* (1995) used three levels of water treatments to determine the effect of water stress on growth. The pots containing the seedlings were saturated either once, twice, or three times a week. The seedlings receiving water 2–3 times a week had a greater increase in biomass than those watered once a week (Schwartz *et al.*, 1995). These results, coupled with those from the water stress response test, suggest that *T. taxifolia* may resist short-term water stress, but struggles to recover and grow during longer dry periods (Schwartz *et al.*, 1995).

Schwartz *et al.* also used field data and growth trials to determine the effects of light stress on the growth of *T. taxifolia*. Recent growth measurements from 165 surveyed trees were used to correlate recent growth with canopy cover. Percent of canopy coverage was calculated using photographic slides of the canopy projected on a screen containing 100 randomly selected points. The percentage of points coinciding with vegetation determined percentage canopy cover for that location. No significant correlation was found between canopy cover and growth at that time (Schwartz *et al.*, 1995).

Canopy gaps were opened up above 12 randomly selected trees growing in the Apalachicola Bluffs Preserve. Terminal bud expansion and stem elongation were measured over two years to determine growth response to increased light in the field. Other trees in the survey growing in low light conditions were used as a control group. There was no significant release or increase in growth of the trees in the study plot compared to the rest of the population. Stem elongation did not exceed the mean when compared to the rest of the population (Schwartz *et al.*, 1995).

During the greenhouse growth trials, *T. taxifolia* seedlings were exposed to three levels of light (Schwartz *et al.*, 1995). The seedlings were grown in 0%, 50%, and 70% shade with natural light, which was supplemented by high intensity lamps. In this case, the plants in lower light did experience a decline in growth. The seedlings in 50% shade averaged 77% of the growth of those in high light. The seedlings in the lowest light level averaged 48% of the growth of the high light plants and 63% of the growth of the seedlings exposed to 50% shade. These results conflicted with those found in the field growth trials. The fact that the trees grown in the greenhouse responded favorably to increased light while those in the field did not suggested that factors other than low light may have been limiting the growth of *T. taxifolia* in its environment. The occurrence of disease symptoms in different light levels was also noted in the field surveys. There was no correlation between low light and the occurrence of disease symptoms in *T. taxifolia* (Schwartz *et al.*, 1995). Schwartz *et al.* (1995) determined that healthy needles of *T. taxifolia* could have photosynthesis rates 20% higher than those with disease symptoms. They also noted that healthy needles had respiration rates 40% lower than diseased needles, suggesting that the disease affects the internal functions of the leaf.

The effect of smoke on the pathogens infecting the *T. taxifolia* was also assessed during this study. .Associate fungi were isolated and cultivated in the lab to test the effect of smoke on the pathogens (Schwartz *et al.*, 1995). The fungi *Pestalotia natans* and *Acremonium* sp. were the primary candidates for the test because they occurred with the highest frequency on the diseased needles of *T. taxifolia*. Smoke from fires fueled by a mixture of longleaf pine needles and grasses collected from areas above the ravines was funneled through a duct into a smoke chamber. The fungal cultures were allowed to grow for one day before being exposed to the smoke treatments of 0, 1, 3, 5, 10, or 20 minutes. The fungi exposed to the smoke did experience a reduction in growth. The effect was significantly greater on the fungus *P. natans* than on *Acremonium* (Schwartz *et al.*, 1995).

The effect of smoke on mycelia growth was also tested. Five culture plates were exposed to the smoke treatments before mycelium blocks were placed on them. The authors then monitored the growth of the mycelium for six days. There was a reduction in mycelia growth in both *Pestalotia natans* and *Acremonium*. Again, the effect of the smoke on *Pestalotia natans* was greater than that on *Acremonium* (Schwartz *et al.*, 1995).

The effect of smoke on spore germination of *Pestalotia natans* was also assessed in this experiment (Schwartz *et al.*, 1995). Five culture plates were exposed to smoke treatments of 0, 1, 3, and 5 minutes before having spore mixtures spread onto them. Spore germination and degradation was monitored for a 12-hour period on the exposed and control plates, which were not exposed to the smoke treatments. The spores on the exposed plates did experience higher mortality and lower germination and mycelia growth rates than those on the control plates.

The results of this study suggest that smoke does reduce growth and increase the mortality of associate fungi. However, the effect of the smoke on germination and growth was not strong enough to suggest that reduced exposure is a major cause of the infection and subsequent decline of *T. taxifolia* (Schwartz *et al.*, 1995).

3.1.5 Schwartz and Hermann (1999)

Schwartz and Hermann (1999) tried to determine pre-decline growth rates for *T. taxifolia* through comparison with *T. californica*, a closely related species, and tree-ring analysis. Because *T. californica* is the closest relative of *T. taxifolia*, has similar growth habits, and grows in similar conditions, it was a prime candidate for determining pre-decline growth trends of *T. taxifolia.* They also tested the possibility that low light could be a primary factor in the current decrease in growth of *T. taxifolia* in its natural environment.

Growth measurements from a 1989–1998 population census of *T. taxifolia* were compared to those from 65 *Torreya californica* surveyed in the coast range in California. To determine growth rates for *T. californica*, measurements of internode length for the past 3–5 years, tree height, basal diameter of the primary stem, and number of internodes were conducted. This information was used to calculate the rate of growth for this species and to compare with that of *T. taxifolia.*

Schwartz and Hermann (1999) found that growth habits of *T. californica* were very similar to those of *T. taxifolia.* Forty-four percent of the *T. californica* surveyed expanded a terminal bud compared to 48% of surveyed *T. taxifolia.* When comparing the number of internodes above the oldest lateral branch, they found that the frequency of terminal bud expansion was higher in *T. taxifolia* than *T. californica. T. taxifolia* was also found to possess greater height with increased age while *T. californica* generally had a greater basal diameter with age (Schwartz and Hermann, 1999).

To determine the effect of light on growth in the field, three growth plots were created in high and low light environments. The canopy was cleared over the high light growth plots. Each growth plot was planted with 10 *T. taxifolia* seedlings. The plants were grown from cuttings and averaged 15–50 cm tall (Schwartz and Hermann, 1999). Because of a dry spring following the plantings, several of the trees were dead by the following June (Schwartz and Hermann, 1999). Only six trees survived in the high light plots and 11 trees survived in the low light plots.

The trees grown in the high light plots possessed higher growth frequencies than those in the low light plots (Schwartz and Hermann, 1999). All six of the trees in the high light plots expanded a terminal bud during the growing season compared to 36% of the trees in the low light plots, illustrating the importance of light on initial growth rates in the field. These results do, however contradict those from the 1995 Schwartz *et al.* study in which the canopy was cleared over 12 individuals. Only three of the 12 trees expanded a terminal bud during the year of that study (Schwartz *et al.*, 1995). It is possible that increased light only results in a significant growth release in very young individuals.

Schwartz and Hermann (1999) obtained tree-ring samples from dead and downed *T. taxifolia* logs to determine historical growth rates. Five cross sections and 13 increment cores were analyzed. The rings from the resulting series were standardized dividing each ring width by the mean for that series. If three or more years of growth exceeded the mean, they were considered to be a period of release for that individual. All but one of the tree-ring samples expressed suppression and release in growth. Most individuals had 1–3 periods of release averaging 7–8 years.

After comparing the growth of *T. taxifolia* with that of *T. californica* and examining historical growth habits via tree ring analysis, Schwartz and Hermann (1999) suggested that slow growth rates may be the norm for *T. taxifolia* in a natural, low light environment. They suggested that opening canopy gaps in the habitat could be the only way to increase growth in extant populations.

3.1.6 Schwartz and Hermann (2000)

Schwartz and Hermann (2000) utilized the 1988–1992 survey data for constructing growth models for *Torreya taxifolia* in their natural range to determine persistence of this species. The initial data were modified using data from concurrent surveys. Two growth models were tested.

A transition matrix model for a population consisting of 1000 individuals over a 100-year period was created using data from 187 surveyed trees. The population was divided into five size classes according to primary stem length. Growth rates for primary stems were calculated as 10 cm per year if growth occurred. Upward size transitions never exceeded one size class, and many individuals remained in the same size class for a number of years. If death of the primary stem occurred, a downward size transition resulted. Death of the primary stem was an uncommon occurrence and generally affected stems that were 50 cm tall or less. The projected population was calculated using data for all survey sites. Separate transition probabilities were calculated for the northern and southern survey sites using inter-annual variation from the pooled data set (Schwartz and Hermann, 2000).

The matrix model predicted a rapid decline of the population over the first 50-year segment followed by a slower decrease in numbers over the next 50 years. Schwartz and Hermann (2000) modified the model by increasing downward transition probabilities (main stem mortality). Increasing main stem mortality rates by 10% yielded a slight probability of extinction (>1%) over the next 30 years, a 33% probability of extinction over the next 50 years, and a high probability of extinction by 100 years (Schwartz and Hermann, 2000).

The separate site population projections yielded varied results. The northern areas of the range possessed the longest projected persistence times, possibly due to the higher number of stems in the larger size classes. The southern areas of the range consisted of a larger initial population, but most of the main stems were in the smaller size classes. This resulted in a more rapid decline and higher extinction rate than in the northern portion of the range (Schwartz and Hermann, 2000).

An individual based model was created for determining the effects of primary and secondary stem growth and mortality on population persistence (Schwartz and Hermann, 2000). Data from 187 surveyed trees were used to create the model, which projected populations of *T. taxifolia* 100 years into the future (Schwartz and Hermann, 2000). The stems were divided into four size classes of 50 cm intervals with the largest size class consisting of stems 200 cm or greater (Schwartz and Hermann, 2000). Random number draws determined the fate of individual stems. Each stem carried the probability of growing, not growing, or dying at each time interval (Schwartz and Hermann, 2000).

If a stem was assigned to grow, growth values were determined using a random number drawn from a Gaussian distribution based on the specific mean stem size (Schwartz and Hermann, 2000). Dead stems were removed from the population at each time interval. Individuals were considered dead when their stem count was equal to zero after each time interval. Random number draws were also used to determine whether or not new stems were to be added to individuals. Because sprouting usually follows the death of the main stem, the probability of sprouting new stems was based on the size and mortality of the longest stem. The lengths of new stems were also determined by Gaussian random number draws (Schwartz and Hermann, 2000).

The individual-based model predicted that, on average, only 33% of the 187 individuals were intact after 100 years (Schwartz and Hermann, 2000). Unlike the matrix model projection, the probability of extinction after 100 years was zero. The sensitivity of the model was checked by varying the growth parameters. Even after decreasing the probabilities of growth and sprouting, there was still a zero probability of extinction after 100 years. On the other hand, increasing stem mortality rates reduced population size and increased extinction probability to 33% over 100 years (Schwartz and Hermann, 2000).

Schwartz and Hermann (2000) determined that the individual-based model was more accurate after comparing the results to actual survey data. The model predicted an 88% survival rate after 10 years. Schwartz and Hermann found that 77.5% of the trees surveyed in 1988 remained alive in 1998. The matrix model predicted a 10-year survival rate of 55%. The higher accuracy of the individual-based model was explained by its ability to predict the growth of multi-stemmed individuals (Schwartz and Hermann, 2000).

The fact that neither model projects extinction within the next 50 years was promising for possible conservation efforts (Schwartz and Hermann, 2000). Because most of the habitat of *T. taxifolia* is protected, increasing the number of disease-free individuals should increase the probability of population growth and persistence for the next 50–100 years. The authors concluded that while changing environmental conditions within the habitat are possibly affecting the growth of this species, recovery was still possible.

3.2 Dendroecology in the Coastal Plain

The best mechanism for determining environmental changes within the *Torreya* habitat may be a dendroecological analysis of downed *Torreya* and its living associates. Dendrochronological studies have been successful in the southeastern coastal plain despite higher rainfall totals and lower seasonal precipitation variation than in locations in the western U.S. where tree-ring studies are more common. This final section of my literature review summarizes selected examples of dendrochronological studies conducted in the southeastern coastal plain.

3.2.1 Friend and Hafley (1989)

Friend and Hafley (1989) conducted a dendroclimatological study of shortleaf (*Pinus echinata* Mill.) and loblolly pines (*Pinus taeda*) in central North Carolina. Their main objectives were to find the strongest parameters determining growth for these species, and to determine whether or not these parameters could be predicted using a combination of physiological species responses and climate information.

Friend and Hafley (1989) sampled loblolly and shortleaf pines at two sites in North Carolina. These sites were former agricultural fields abandoned at the beginning of the 20th century. Both shortleaf and loblolly pine are naturally occurring successional species in this area. Thirty samples from each species were sampled at each site, with two cores extracted from opposite sides of each tree at 1.37 m above the ground. All rings from 1932–1982 were measured and the dates for all narrow rings in the series were verified via crossdating.

The climate variables analyzed included mean monthly air temperature, monthly precipitation, monthly rain days, and estimated soil moisture content. Friend and Hafley (1989) developed a model that related temperature and soil moisture with radial growth of the pines. This model contained climate conditions that were categorized as optimal, intermediate, and minimal for tree growth. These conditions were based on the monthly climate data for this area. The optimum temperature for growth was estimated to be 20°C and the optimum soil moisture level was set at –0.2Mpa. This level of moisture is equivalent to approximately 50% saturation for the silt loams found at the study sites. The projected growing seasons lasted from March through September for this area. The influence of the previous year's climate was taken into consideration because of the potential for increased carbohydrate stores following favorable late season conditions (Friend and Hafley, 1989).

Previous year climate conditions did play a significant role in the growth of these species (Friend and Hafley, 1989). An increase in soil moisture with a decrease in rainy days resulted in increased growth the next year. The authors suggested that the negative correlation between the number of rainy days and next season growth could be due to a decrease in light levels for late season photosynthesis.

Higher spring temperatures and high soil moisture levels were positively correlated with current season growth (Friend and Hafley, 1989). The positive correlation between growth and warm spring temperatures could be attributed to an early start to the growing season when the warmer temperatures would coincide with optimal moisture conditions. During late spring and summer, decreased moisture limits growth despite optimal temperatures. The most significant growth responses were found to occur during the very beginning and end of the growing season.

Friend and Hafley (1989) found this model to be an overall success for predicting significant climate variables for tree growth responses. They discovered that not all variables and responses followed a predictable pattern for determining growth for these species. Although growth responses to climate may vary in different areas of the southeastern U.S., this study illustrated that growth models could be constructed in this humid region despite the fact that specific climatic factors may elicit different responses depending on species and geography.

3.2.2 Jordan and Lockaby (1990)

Jordan and Lockaby (1990) investigated possible climatic influences on radial growth of loblolly pine (*Pinus taeda*). Their study site was located in Lee County, Alabama, which is between the Piedmont and the southern coastal plain. They used time series techniques for the purpose of modeling growth response with climate to examine a possible change in growth trends. All dominant and co-dominant trees at the study site were measured and sampled. Average height of the sampled trees was approximately 30 m. Average dbh was approximately 60 cm. The pith dates at breast height ranged from 1843 to1918 (Jordan and Lockaby, 1990).

The radial measurements from 91 dated samples were converted to area increment values, which were combined to create an annual basal area increment value for the study site. This value was the dependent variable for the growth-climate model. The time series model was created using basal area increment values for years 1906–1986. Precipitation and temperature data from the Auburn weather station were used in the analysis. Significant predictors of growth included: average June temperature, May, June, and August precipitation, and August PDSI (Jordan and Lockaby, 1990).

The model detected no significant change in growth trends for those years. There was, however, a consistent relationship between previous and current year growth. A significant relationship was also evident when the previous and current year predictor values were incorporated. Growth and precipitation variables produced significant positive autoregressive coefficients, while temperature variables produced weak, negative coefficients (Jordan and Lockaby, 1990). This study illustrated the possibility of using growth indices with incorporated temperature and precipitation data for modeling tree growth with climate as an alternative to using raw monthly data.

3.2.3 Devall *et al.* (1991)

Devall *et al.* (1991) conducted a dendroecological analysis of a longleaf pine (*Pinus palustris* Mill.) stand in southern Mississippi to determine the past and present ecological mechanisms that influence that area. The area was divided into eight sample areas of equal size. The four largest trees within each sample plot were cored on opposite sides. The resulting chronology was standardized and filtered using the Kalman filter, which Devall *et al.* (1991) described as similar to regression models that allow the parameters to vary over time, allowing the model to better predict growth with changing climate conditions. Monthly rainfall, temperature, and Palmer Drought Severity Index data were obtained for southern Mississippi. Pollution data were obtained from the

Environmental Protection Agency, and storm data were obtained from the NCDC (Devall *et al.*, 1991).

The mean age of the trees sampled was approximately 55 years. Devall *et al.* (1991) found that August rainfall, September temperature, and February drought had the strongest influence on tree growth. August rainfall remained a constant significant influence on growth over time unlike September temperature, which was not a consistent factor in determining growth. February drought was a significant influence on growth only between 1968–1983. Devall *et al.* (1991) noted increased growth after hurricane Camille struck in 1969. This growth increase was attributed to increased moisture and decreased competition via thinning of the stand from wind damage. No influences of pollution on growth could be determined in this area.

Devall *et al.* (1991) determined that this area has not been affected, directly or indirectly, by anthropogenic factors, and has remained in this natural, undisturbed state for at least the past 50 years. The conclusions of this study illustrate the importance of maintaining undisturbed forests in the coastal plain for their use in determining past and present climate mechanisms affecting growth, as well as for other future research.

3.2.4 West *et al.* (1993)

West *et al.* (1993) investigated changes in growth trends of longleaf pines (*Pinus palustris* Mill.) in the southeastern U.S. Their objective was to determine whether or not 20th century growth increases were climate-induced. Their study area was near Thomasville in southern Georgia. Seventy-five longleaf pines were randomly selected, cored, and crossdated. An average ring width from the same year from the 16 oldest trees was used to construct a 240-year curve of expected growth. All of the ring measurements used in constructing the growth curve predated 1890 to ensure there were no anthropogenic influences on tree growth. Climate data used in the analysis included monthly precipitation, monthly temperature, and PDSI for the years 1895–1987. The expected growth curve served as a standard for comparing growth for the period covered by the climate data. The rings from the older series comprising the expected growth curve were compared to rings of the same age from the younger cores.

West *et al.* (1993) found diminishing correlations after 1931 between growth and all three climate factors. They noted a significant upward departure from the expected negative exponential function of growth with time during this period. Average growing season temperatures have dropped slightly during this period reducing evaporation, but not enough to result in such a positive growth response in these older trees. Biomass gains in this area are up to 3Mg/ha more than what would occur with growth following the expected curve (West *et al.*, 1993). The low correlations with climate data suggest that other factors are causing this increase in growth during this period. The authors cited CO_2 enrichment along with increases in nitrogen and sulfur oxides as possible reasons for the change in growth.

3.2.5 Meldahl *et al.* (1999)

Meldahl *et al.* (1999) investigated climatic factors that influence tree growth in longleaf pines (*Pinus palustris* Mill.) growing in the Flomaton Natural Area in extreme southern Alabama. The entire area was divided into a 60 × 80 m grid containing 0.08 ha circular sample plots. Each tree with a dbh greater than 1.25 cm was surveyed and measured. One hundred trees with a dbh of 7.6 cm or greater were cored at breast height. To determine effects of climate on growth, Meldahl *et al.* (1999) developed chronologies for earlywood, latewood, and total ring widths. Correlation coefficients were calculated for seasonal and monthly precipitation, minimum and maximum temperature, and the Palmer Hydrological Drought Index (PHDI). Disturbance history was also noted in the raw ring measurements where serious declines in growth were present.

The resulting chronology contained 10 cores that dated back to 1817 (Meldahl *et al.*, 1999). The average age of the cored trees was 107 years. The earlywood chronology contained 10 cores dating back to 1920, and the latewood chronology, also containing 10 cores, dated back to 1900. All cores with poor COFECHA and ARSTAN correlations were rejected. Meldahl *et al.* (1999) concluded that the growth of the rejected trees was influenced by factors other than climate, such as overstory suppressions and stand dynamics.

The climate analyses demonstrated that climate plays a significant role in the growth of *Pinus palustris* in the Flomaton Natural Area. Meldahl *et al.* (1999) found that current year March–October precipitation had a significant positive relationship with latewood and total ring width. March and September precipitation were also found to be significant for total ring width (Meldahl *et al.*, 1999). March precipitation had the strongest influence on earlywood development, while latewood development was significantly influenced by August and September precipitation.

High February–April temperatures had a negative correlation with overall ring width. Higher summer and early fall temperatures negatively affected earlywood formation. However, high previous summer temperatures were positively correlated with ring width. This is possibly due to a shutdown in growth and an increase in root storage during the previous year that allow for increased growth the second year (Meldahl *et al.*, 1999).

Both Alabama and Florida PHDI correlated with growth in this longleaf pine stand, but at different times during the growing season with the only overlap between the two occurring during the month of September (Meldahl *et al.*, 1999). Alabama PHDI correlated more strongly, especially on latewood growth during the current year growing season, while Florida previous year September–December PHDI correlated more strongly with growth (Meldahl *et al.*, 1999).

Meldahl *et al.* (1999) determined that climate did play a significant role in growth and that longleaf pine is a good candidate for southeastern tree-ring analyses. They also noted that the latewood of this species shows a greater variation in growth than the earlywood.

Meldahl *et al.* (1999) also investigated influences of growth suppression due to factors other than climate. Fires have been suppressed in this area since the 1940s, and the numbers of old-growth trees suggest that no other large-scale disturbances have occurred on this tract. Other factors seem to influence growth in this area. Meldahl *et al.* (1999) suggested that resource competition might be playing a large role, despite the open, park-like appearance of the longleaf pine systems.

3.2.6 Parker *et al.* (2001)

Parker *et al.* (2001) investigated geographic disturbance regimes and the possible resulting population structures of two varieties of sand pine, *Pinus clausa* var.

immuginata Ward. (Choctawhatchee sand pine), which occurs along the Florida Panhandle, and *Pinus clausa* var. *clausa* Ward. (Ocala sand pine), in central peninsular Florida. They hypothesized that key differences in disturbance regimes would result in significant differences in ecology and structure of the sand pine systems. Nine sites containing sand pine as a dominant canopy species were selected in central and panhandle Florida. Study plots ranged between 40–60 m². Living and dead sand pines, sand pine seedlings, and all living trees other than sand pine were counted and mapped on each plot. Two cores were extracted from all healthy trees at all sites and cross-sections were collected from 25–30 small seedlings where sand pine regeneration was evident.

After the sand pine stems and cores were dated and measured, mean radial growth rates were calculated using two different methods. First, the unstandardized mean growth rate was determined by dividing radius at breast height by age (Parker *et al.* 2001). The second method calculated the standardized mean growth rate by calculating mean growth rates during the same 25 year period, then randomly selecting samples from only those that met the standardization criteria (Parker *et al.* 2001). Growth-release events were identified by comparing average growth rates of adjacent five-year segments in the series. The identified periods of release were then compared with climate records documenting hurricanes, tornadoes, and other gap-creating wind events.

The *Pinus clausa* var. *immuginata* stands in the Florida panhandle possessed high levels of stem recruitment and seedling establishment within the canopy gaps compared to slower recruitment and radial growth of *P.clausa* var. *clausa* (Parker *et al.*, 2001). *P. clausa* var. *immuginata* seemed to have sufficient recruitment and growth after small scale wind disturbances produced by hurricanes and tropical storms (Parker *et al.*, 2001).

P. clausa var. *clausa* occurred in even-aged stands established after catastophic, stand-clearing events. Parker *et al.* found that large-scale recruitment of *P. clausa* var. *clausa* only occurred in stands that have experienced crown fire since 1970. Growth-release events were uncommon for *P. clausa* var. *clausa* except for populations along the coast, which were exposed to a series of large hurricanes in the late 1940s (Parker *et al*., 2001). The findings of this study demonstrate the effect of geographic variation of disturbance regimes on growth and recruitment of a single species. Microsite differences in disturbance, climate, and geology must always be considered when conducting a scientific field study.

Chapter 4

Site Description

4.1 Introduction

Although the natural range of *T. taxifolia* lies completely within the Southeastern coastal plain, the habitat of this species is very different from the surrounding area. The habitat of *T. taxifolia* consists of steep, deeply shaded limestone slopes, bluffs, and wooded ravines and moist forest hammocks (Kurz, 1927). Soils are well drained with a pH range of 4.0–8.0. The climate is subtropical with wet summers and dry winters, and average annual rainfall is 1,420 mm. *Torreya taxifolia* is often associated with oak-pine and oak-tupelo-cypress forests along a 64 km stretch of the eastern bank of the Apalachicola River and tributaries (Statler, 1990). *T. taxifolia* is endemic to Liberty, Jackson, and Gadsden Counties in northern Florida, and extends into Decatur County in extreme southern Georgia (Kurz, 1927).

4.2 Geology

4.2.1 Landforms

The processes of erosion, alluvial deposition, and chemical weathering have resulted in a unique landscape for the northern Florida panhandle. Post Oligocene orogeny has produced two distinct areas of uplift within the panhandle known as the Ocala uplift and the Chattahoochee Arch (Brown *et al.*, 1990). Uplift events are also credited for heavy deposition of clastic sediments from southern Appalachian and coastal plain streams over the top of the limestone plateau that makes up the panhandle (Brown *et al.*, 1990). Much of northern Florida also has a karst landscape containing many sinkholes due to the presence of underlying limestone.

4.2.2 Geomorphology

The Apalachicola River system is the largest in Florida (Brown *et al.*, 1990) (Figure 4.1). The eastern bank consists of steep bluffs and ravines, some of which are the result of springs cutting channels in the limestone substrate. These springs were diverted away from the mouth of the stream, resulting in headward undercutting of the stream banks forming ravines known as steepheads (Sharp, 1938).

This river system originated in the Appalachian Mountains during the early Cenozoic (Hendry and Yon, 1958). Analyses of topography and drainage basins around the Apalachicola River revealed that the nearby Chattahoochee River valley was once farther west than its present location in Jackson County (Hendry and Yon, 1958). The Flint River flowed into the system from west of Chattahoochee. The ancient Apalachicola River was actually once a tributary of the Chattahoochee River (Hendry and Yon, 1958). The Apalachicola cut farther into the highlands, eventually capturing the Flint River. The Chattahoochee was then diverted eastward by the resulting enlarged river system (Hendry and Yon, 1958).

4.2.3 Soils

A feature known as the Cody Scarp divides the Apalachicola River valley. Above the scarp are rich, limestone-derived soils that originated in the Miocene. Plio-Pleistocene sandy soils persist below the scarp (Brown *et al.*, 1990). Areas closest to the river possess

Figure 4.1 The Apalachicola River as seen from the overlook at Garden of Eden Trail at the Apalachicola Bluffs and Ravines Preserve.

well-drained, sandy loams classified as Ultisols. Entisols (well-drained, thick sands) are located upslope from the river. Alfisols and Mollisols, which are associated with areas underlain with limestone bedrock, are also found in the area (Brown *et al.*, 1990).

4.3 Climate

4.3.1 Temperature

The climate of this area is classified as humid subtropical having a strong maritime influence with mild winters. Northern Florida has the highest seasonal temperature variations in the state due to the stronger influence of continental fronts. However, this area is considered to have a maritime temperate climate resulting in low temperature variations when compared with interior locations. The greatest seasonal temperature increase (11°C) occurs in the spring (Chen and Gerber, 1990). Daily temperature variations are greater than seasonal changes throughout the year (Chen and Gerber, 1990). The growing season in this area lasts approximately 210 days with the frost-free days occurring between April and November (Ware *et al.*, 1993).

Despite Florida's mild climate, temperatures do fall below freezing in the interior of the panhandle. Areas within the interior record below-freezing temperatures twice as often as areas along the coast (Henry *et al.*, 1994). Temperature data indicate that areas located short distances inland are twice as likely to record below freezing temperatures (Henry *et al.*, 1994). Summer temperatures are notably higher in some areas within the panhandle. The mean monthly temperature in May is 31°C (Chen and Gerber, 1990). Summer temperatures are often higher if the summer rainy period is delayed (Chen and Gerber, 1990).

4.3.2 Precipitation

The average annual rainfall is approximately 127 cm in the study area, falling mainly in midsummer. The lowest precipitation amounts occur during the fall. The coastal forest experiences hurricanes almost annually. This area has the highest frequency of downpours combined with the most rain-free days per year compared to the rest of the continental U.S. (Ware *et al.*, 1993). This area also has the highest rate of evapotranspiration in the eastern U.S. (Ware *et al.*, 1993). Annual precipitation amounts for the whole area range from 102–152 cm, and the average annual evapotranspiration amounts are between 107 and 121 cm (Ware *et al.*, 1993).

The Bermuda high pressure cell dominates in the fall and winter, reducing convection and thunderstorm occurrences. During spring and summer, however, afternoon thunderstorm events are frequent, giving the state of Florida the highest rate of lightning occurrences in the nation (Chen and Gerber, 1990).

4.3.3 Drought

The Florida Panhandle does experience periodic moderate droughts. Henry *et al.* (1994) defined drought as "a period of 21 days with no more than 30% of normal rainfall." The main cause of drought in this area is atmospheric subsidence (Henry *et al.*, 1994). Subsiding air inhibits convectional uplift, resulting in reduced rainfall amounts. Prolonged subsidence in this area is usually the result of stalled high-pressure systems originating to the west (Henry *et al.*, 1994).

Another contributor to subsidence over Florida is the formation of a ridge in upper atmosphere winds over the central U.S. (Henry *et al.* 1994). The resulting high-pressure system causes upper level winds to flow toward and sink over Florida (Henry *et al*., 1994). The displacement of the Azores-Bermuda high pressure cell to the west or north results in drought conditions as well. The displacement of this pressure system results in strong surface winds that inhibit convective processes (Henry *et al*., 1994).

The displacement of the mid-latitude jet stream is the cause of more severe drought episodes (Henry *et al*., 1994). Northerly shifts in the storm track will reduce frontal disturbances moving through the area. The negative index phase of the North Atlantic Oscillation (NAO) is associated with weakened subtropical high pressure and icelandic low resulting in the weakening of the west-east storm track of the jet stream (Visbeck, 2002).

Above average sea surface temperatures in the Atlantic Ocean may contribute to drought as well. Higher sea surface temperatures may increase subsidence in this area, causing air in the eastern U.S. to move south toward the equator. This northerly flow of air reduces the amount of moisture that is effectively transported across the Gulf of Mexico to Florida (Henry *et al*., 1994).

4.4 Vegetation

4.4.1 Mixed Hardwood Forests (Hammocks)

Growing along the Apalachicola River and its tributaries are mixed hardwood forests known in northern Florida as "hammocks" (Figure 4.2). These forests occur in narrow, mid-slope bands between mesic bottomland forests and upland pine ecosystems

Figure 4.2 Hammock forest in Torreya State Park.

(Platt and Schwartz, 1990). Hammock systems are very diverse, containing the largest number of temperate tree species in the eastern U.S. (Marks and Harcombe, 1975). The only hammocks containing species, such as *Torreya taxifolia*, are found along the bluffs above the Apalachicola River.

A large number of canopy-dominating tree species contribute to a substantial overstory within hammock systems. The understory consists of shrubs with very few herbs. Hammocks are often considered to be mature forests of the coastal plain following hardwood succession within pine forests (Monk, 1965). Pessin (1933) observed that mixed oak-hickory systems would succeed longleaf pine forests of Alabama, Georgia, and Florida before later being replaced by systems dominated by southern magnolia (*Magnolia grandiflora* (L.) Marsh) and American beech (*Fagus grandifolia* Ehrh.).

Hammock systems are not identical. Variations in structure and species composition exist due to differences in soil moisture and nutrient availability (Monk, 1965). Species diversity is highest on sites with mesic, calcareous soils with decreasing diversity on less fertile soils. Diversity was also lower on saturated soil. Species occurring most frequently at mesic hammock sites include *M. grandiflora*, sweetbay (*Magnolia virginiana* L.), American beech, loblolly pine (*Pinus taeda* L.), and blackgum (*Nyssa sylvatica* Marsh.) (Quarterman and Keever, 1962; Monk, 1965). Understory species include hop hornbeam (*Ostrya virginiana* Mill. K. Koch.), flowering dogwood (*Cornus florida* L.), wild olive (*Osmanthus americana* (L.) Benth & Hook), American holly (*Ilex opaca* Ait.), Florida anise tree (*Illicium floridanum* Ellis.), and large gallberry (*Ilex coriacea* (Pursh) Chapman) (Quarterman and Keever, 1962; Monk, 1965).

A much higher number of evergreen species occur on sites with decreased moisture and lower nutrient availability. Fifty to sixty percent more evergreen species occurred on drier sites when compared to moist sites (Monk, 1965). Frequently occurring overstory species at xeric sites include shortleaf pine (*Pinus echinata* Mill.), live oak (*Quercus virginiana* Mill.), post oak (*Q. stellata* Wangenh.), laurel oak (*Q. hemisphaerica* Bartr. ex Willd.), sand hickory (*Carya pallida* (Ashe) Engl. & Graebn.), and pignut hickory (*Carya glabra* (P. Mill) Sweet). Common understory species include sparkle berry (*Vaccinium arboreum* Marsh.), beauty berry (*Callicarpa americana* L.), smooth elephant's foot (*Elephantopus nudatus* Gray), Carolina laurel cherry (*Prunus caroliniana* (Mill.) Ait.), whip nut-rush (*Scleria triglomerata* Michx.), and sarsparilla (*Smilax pumila* Walt.) (Quarterman and Keever, 1962; Monk, 1965).

Mixed hardwood forest hammocks that occur along the Apalachicola River are often referred to as "relict forests" (Platt and Schwartz, 1990). Although these forests gained much of their diversity during the Pleistocene, they are believed to have originated during the Miocene when much of northern Florida initially emerged above sea level (Platt and Schwartz, 1990). Many disjunct Appalachian species are also found within these ravine forests (Platt and Schwartz, 1990). The presence of Appalachian species in these Floridian forests is possible due to a large influx of northern temperate species during Pleistocene migration events, in which boreal and temperate plant species moved south along major river channels (Delcourt and Delcourt, 1984). Many temperate Appalachian species moved south along the Apalachicola River, which has headwaters in the Appalachian Mountains. The moist, cool microclimate allowed mesic, hardwood forests to persist in the Apalachicola River corridor when the lands above were warming and drying (Delcourt and Delcourt, 1984). This idea is supported by paleoecological evidence found in Sheelar Lake in northern Florida that indicated the presence of mesic hardwood species in surrounding deep ravines and nearby sinkholes (Delcourt and Delcourt, 1984).

Although these forests have persisted in the Apalachicola River Bluffs for thousands of years, disturbance is constantly affecting the structure and species composition within them. Many species growing here (e.g. *T. taxifolia* and *Fagus grandifolia*) possess adaptations, such as basal sprouting, allowing them to grow and reproduce despite constant disturbance. Several different modes of disturbance occur in this system on a regular basis.

The erosional processes that shaped the Apalachicola River Bluffs are still in effect. However, current clear-cutting practices in adjacent pine forests may be increasing erosion levels in this area (Platt and Schwartz, 1990). Forest reconstructions based on land surveys conducted in the early 1800s indicated a greater occurrence of *Fagus grandifolia* and *Magnolia grandiflora* than are currently present (Delcourt and Delcourt, 1977). A later study by Clewell (1986) also noted fewer occurrences of these species. Clewell noted that these species seem to be more restricted to the lower slopes than in the past. This decrease and restriction of these two dominant hammock species may be due to an increased slumping of the soils on the slopes of the steepheads making up the ravine system (Platt and Schwartz, 1990). Approximately one out of every four steepheads along the tributaries of the Apalachicola River shows signs of significant slipping and slumping (Platt and Schwartz, 1990). Increased erosion may strongly affect the health and growth of many endemic species located in the bluffs along the Apalachicola River and tributaries.

Another disturbance mechanism in this area is gap-forming wind events. Such gaps are responsible for recruiting most understory species in the hammock system (Platt and Schwartz, 1990). The highest density of small trees and understory shrubs is found in recent gaps. The numbers of these species decrease as the canopy closes (Platt and Schwartz, 1990).

Fire does not play a significant role in the structure and species composition of hammock forests. Most fires occurring in this area are results of lightning in the adjacent upland pine forests (Platt and Schwartz, 1990). Once these cross into the moist hammocks, they are reduced to low intensity, slow burning fires that creep along the forest floor burning leaf litter (Platt and Schwartz, 1990).

4.4.2 Upland Pine Ecosystems

Open, park-like longleaf pine forests, also known as high pine ecosystems, occur on the well-drained, sandy soils of the Apalachicola River bluffs above the mesic hammock communities (Figure 4.3). High pine systems are generally very open consisting of *Pinus palustris* in the overstory with scattered xeric oaks in the understory and grasses in the herbaceous layer.

Longleaf pine communities covered approximately 12–24 million hectares in the southeastern U.S. prior to European land settlement (Eyre, 1980). Stands of longleaf pine now only occur in fragments covering less than 2 million hectares as a result of excessive logging, land clearing, and planting of slash pine (Eyre, 1980). Land abandonment has

Figure 4.3 Longleaf pine forest at the Apalachicola Bluffs and Ravines Preserve.

resulted in the encroachment of second growth hardwoods in many areas. Much of this area is now under control of the timber industry and contains both clear-cut sites and timber plantations. A large area of longleaf pine communities remains intact and under restoration on land owned by The Nature Conservancy of Florida just above the Apalachicola River.

Reaching heights of 30–36 meters with a lifespan of 400–500 years, longleaf pines are the largest of all southern pines (Boyer, 1990). Needles of longleaf pines are 20–46 cm long, and the cones are 15–20 cm long. The bark thickens with maturity and dissipates the heat of low intensity fires away from the cambium of the tree by flaking off as it burns (Means, 1985). Seedlings of longleaf pines are fire resistant. If the grass-stage seedling is top killed during a fire, sprouting may occur from a deep taproot. A dense tuft of fire resistant needles protects the apical meristem. As the tuft burns toward the bud from the needle tips, water contained within the needles is vaporized. The steam generated in this process reflects heat away from the terminal bud and extinguishes the fire (Means, 1985). Seedlings between 1–2 years of age, especially following a fire, quickly grow a long stem with no branches. This stem raises the terminal bud above the level of the next surface fire (Means, 1985).

Longleaf pine dominated ecosystems are often considered to be a fire sub-climax community that results from periodic surface fires. Established longleaf pine forests are self-perpetuating with needle litter from overstory trees supporting hot ground fires that limit invasions of hardwoods and brush while promoting favorable conditions for the establishment of longleaf seedlings, which are fire resistant in low intensity conditions (Eyre, 1980). This species primarily occurs in frequently burned areas on middle and upper-slope sites that are too dry or poor to support significant amounts of competing species (Eyre, 1980).

Associated woody species on mesic sites include southern red oak (*Quercus falcata* Michx.), blackjack oak (*Q. marilandica* Muenchh.), flowering dogwood, blackgum, common persimmon (*Diospyros virginiana* L.), and sassafras (*Sassafras albidum* (Nutt.) Nees.) (Boyer, 1990). Woody associates in xeric sites include turkey oak (*Q. laevis* Walt.), bluejack oak (*Q. incana* Bartr.), live oak, and post oak. Associated shrubs include inkberry (*Ilex glabra* (L.) Gray), yaupon (*I. vomitoria* Ait.), wax myrtle (*Myrica cerifera* (L.) Small), shining sumac (*Rhus copallina* L.), blueberry (*Vaccinium* spp.), huckleberry (*Gaylussacia* spp.), blackberry (*Rubus* spp.), and saw palmetto (*Serena repens* Hook. F. (Bartr.) Small) (Boyer,1990; Christensen, 1988). Groundcover in longleaf pine systems consists of bluestem grass (*Andropogon* spp.) and *Panicum* grass species in areas west of Alabama, and wiregrass (*Aristida strictata* Michx.) in the eastern range (Eyre, 1980).

Pine forests have a long history in the coastal plain. Shifts between hardwood and pine systems have occurred for the past 20,000 years (Myers, 1990). These shifts in forest structure and species composition were primarily determined by fire. Larger areas of high pine savannas were regularly maintained with higher fire frequencies. Without fire, encroaching hardwoods from neighboring mesic sites were able to encroach. According to evidence collected from sediments, a notable increase of high pine correlated with increased precipitation rates (Myers, 1990). The complete explanation for this is unattainable, although it is speculated that this increase with precipitation could be due to lightning-producing thunderstorm events (Myers, 1990).

Most trees and understory species found in the pine systems of the southeast coastal plain are adapted to frequent or occasional fires. The effects of fire or its exclusion can be detected in the vegetation composition and canopy structure of any coastal pine community. These effects are most notable in the longleaf pine systems, which are most dependent on stand-maintaining fires.

Fire, along with adult tree density, also affects the distribution and density of young longleaf pine seedlings. Grace and Platt (1995) found that high adult tree density increased fire intensity due to larger amounts of pyrogenic needle litter on the forest floor. Pre-grass-stage seedlings, which lack the second growth fire resistant needles, are smaller in high-density areas due to increased competition for light and water resources. This smaller stature coupled with the increased fuel and fire intensity levels results in a much higher mortality rate in young seedlings in high-density areas (Grace and Platt, 1995). Only 21% of the original, tagged seedling population was living one month after fire in areas of high adult density (Grace and Platt, 1995). This increased mortality rate leads to a more widely scattered seedling population in these areas, maintaining more open longleaf pine stands.

Common longleaf grass associates, such as *Andropogon* and *Panicum* species are classified as "fire followers" because they increase in density following winter prescribed burns (Hodgkins, 1958). Repeated growing season fires resulted in higher numbers of fall flowering species of *Asteraceae*, which are capable of reproducing via clonal growth (ramets) as well as sexually. These species have a tendency to quickly invade and fill freshly disturbed sites. Hodgkins (1958) concluded that "The reaction of any one species to fire depended on its morphological adaptations for invading litter-cleared ground after fire and avoiding debilitating damage from the fire itself." Fires that occurred during the growing season would seem to more closely match the natural regime of frequent, lightning-ignited fires that occurred between the months of April and August (Platt *et al.*, 1988).

Those who manage most pine systems are usually most interested in reducing and controlling encroaching hardwood species. Frequent, low intensity fires are capable of top killing and controlling many thin-barked hardwood species, although a few are known to sprout back. Late spring or early summer fires are most effective in controlling hardwood seedlings because of minimal carbohydrate stores (Hodgkins, 1958). When fires were repeated annually for 2, 3, and 4 years, progressively larger proportions of hardwood rootstocks were killed (Hodgkins, 1958). Annual winter burning had no effect on the sprouting abilities of hardwoods (Hodgkins, 1958). Summer fires are also believed to burn hotter than winter fires because of higher temperatures and resulting drier fuel load. These hotter summer fires are most successful at top killing larger hardwoods (Hodgkins, 1958).

Reductions of hardwoods following a single fire are temporary. In many cases, hardwood seedlings increase in the years following a fire. Hodgkins (1958) found that the influence of burning on the hardwood understory lasted no more than three years in mesic and xeric pine communities. Jacqmain *et al.* (1999) found a possible increase in oak seedling stems after 70 years of cool season burns that occurred over 2–4 year intervals. This increase would match the documented increases found by Waldrop *et al.* (1992), who observed an increase of hardwood seedlings from 16,000 to 47,000 stems per ha over a 30-year period of periodic burns in a longleaf pine forest in South Carolina.

Jacqmain *et al.* (1999) believed that the 2–4 year gaps between the low intensity fires are enough to allow many oak seedlings to mature and become fire resistant, thus increasing the numbers of survivors. Heterogeneous burning patterns may have allowed some oaks to mature and produce seeds. Once dropped on the charred soil, these seeds germinate very quickly. These seedlings may become established and resistant to the next fire leading to further fragmentation of the pure pine stand (Jacqmain *et al.*, 1999). The fact that these were cool season burns would have favored prompt sprouting of the rootstocks during the next growing season because the carbohydrate stores are at a maximum during the winter months (Hodgkins, 1958). The results from these studies illustrate the importance of timing and frequency of fires in longleaf pine ecosystems.

4.5 Land Use and Fire History

4.5.1 Human Influence

Many historians mentioned the burning of forests by Native and European settlers along with lightning-set fires when describing forests of the coastal plain during the 17th, 18th, and early 19th centuries (Quarterman and Keever, 1962). In addition to fire, abandonment of agricultural fields led to the establishment of extensive pine forests in the Southeast. Historical accounts by Bartram (1791) and Hawkins (1848) mentioned widespread agriculture among the Creek Indians who occupied large expanses of the coastal plain in Georgia, Florida, and Alabama (Quarterman and Keever, 1962). In 1791, Bartram described the land use mosaic of the Creeks as "extensive fields and old fields, abandoned when the Indians moved because of the necessity they were under of having fresh and new strong lands for their plantations or as a means of avoiding destructive wars with their neighbors" (Quarterman and Keever, 1962). In 1848, Hawkins described fenced, repeatedly cultivated fields used by the Creeks for the raising of hogs and crops such as peas and potatoes (Quarterman and Keever, 1962). Cotterill (1936) noted that the Creek and Choctaw natives often cleared land by girdling and burning trees. Cotterill also noted many examples of "tallahassees" or settlements abandoned when land fertility was diminished throughout Georgia, Alabama, and northern Florida.

European settlers started occupying northern Florida in 1565 (Ewel, 1990). Widespread settlement occurred after 1763 when this area was ceded to England. This settlement started a 200+ year tradition of widespread clearing of forests in the northern panhandle of Florida (Ewel, 1990). European settlers cleared and cultivated land throughout the 18th and early 19th centuries up until the Civil War when there was a decline in the labor force, and large tracts of land were abandoned (Cotterill, 1936). This widespread land clearing and abandonment along with frequent low intensity fires maintained even aged stands of longleaf and sand pines (Quarterman and Keever, 1962). Quarterman and Keever found several pine stands dating back to the mid 19th century during their 1962 study of coastal forest communities.

During World War I, the demand for forest products was very high creating a peak in the timbering/sawmill industry (Quarterman and Keever, 1962). Widespread use of available farmland was also in place because of the high demand for agricultural products in the new world market (Quarterman and Keever, 1962). During the depression era of the 1930s, pine forests were seen as potential crops (Quarterman and Keever, 1962). The desire to increase growth rates and minimize damage to the trunks resulted in a regimen of fire suppression that persisted for some time. Quarterman and Keever (1962) noted that "A concerted attempt was made by foresters, agriculture agents, and conservationists to educate land owners and the general public to the desirability of controlling the 'woods fires' that regularly swept the pine lands each year." This new philosophy of fire suppression coincided with the reforestation of abandoned or previously timbered land (Quarterman and Keever, 1962). Timber production remains as the most prevalent land use in the area. Widespread clear-cutting and fire suppression have resulted in the fragmentation of upland pine systems due to encroaching hardwoods.

Chapter 5

Methods

5.1 Field Methods

5.1.1 Site Selection

The first field trip to the Apalachicola River area was conducted during July of 2001 to find possible collection sites within the *T. taxifolia* population in northern Florida and southern Georgia. I selected Woodruff dam at Lake Seminole in Chattahoochee Georgia to represent the northern area of the range. I selected two sites within Torreya State Park, which is centrally located within the range. The Apalachicola Bluffs and Ravines Preserve (ABRP) was selected to represent the southern extent of the habitat (Fig. 5.1).

5.1.2 Collection of Increment Cores

Because the endangered status of *T. taxifolia* prevented the sampling of living trees, it was necessary to extract increment cores from nearby pines to build a master chronology and examine 20th century growth patterns within the area. Only healthy pines growing in well-drained soils and on slopes were selected for sampling. Pencil-sized cores were taken from selected trees with an increment borer, which extracts ring samples without seriously damaging the trees (Fig. 5.2) (Grissino-Mayer, 2003). Sample location, slope, aspect, diameter at breast height, tree height, and canopy coverage were noted on standard field sample cards.

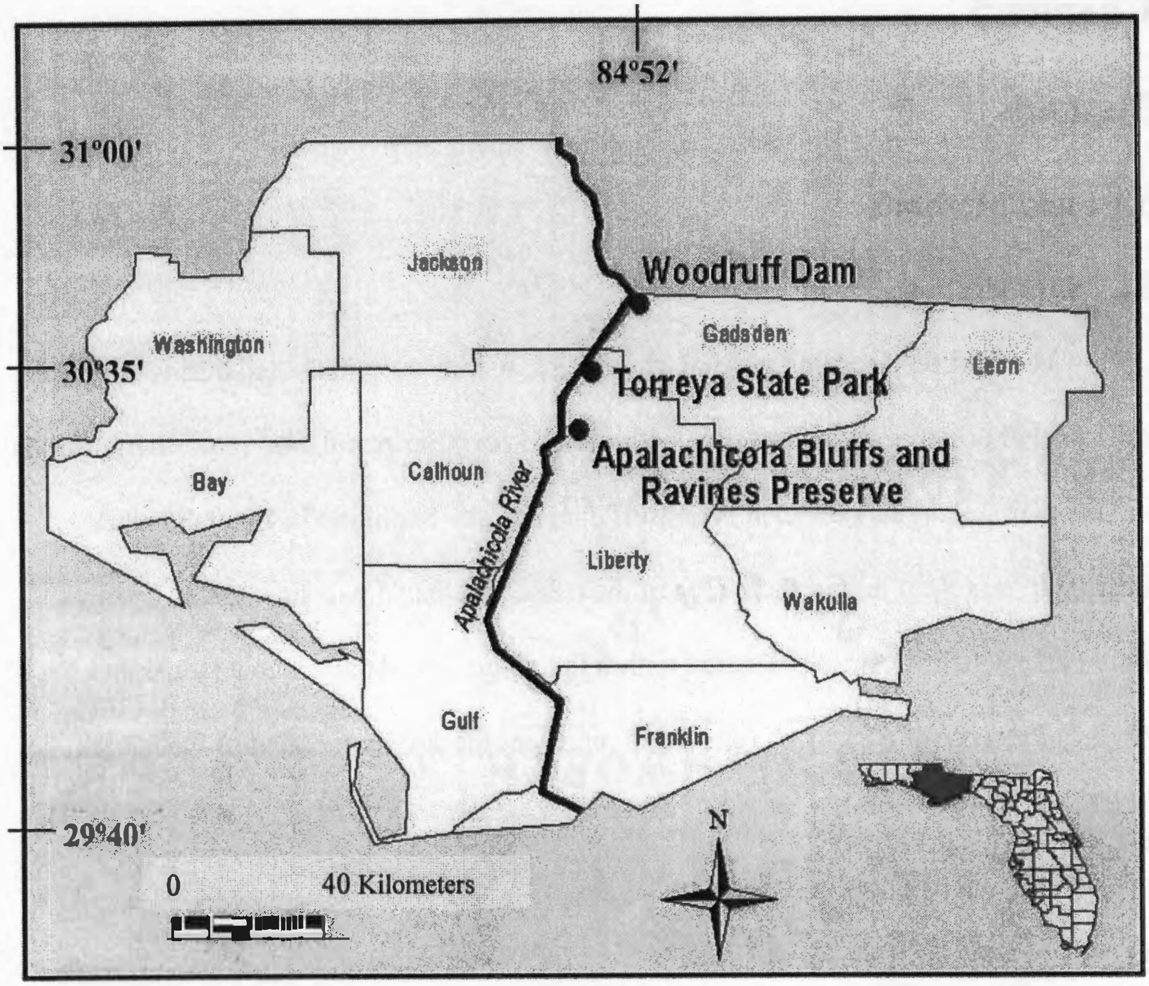


Figure 5.1 Map of collection sites along the Apalachicola River.

Figure 5.2 Coring a shortleaf pine at Torreya State Park

In February of 2002, 40 pines were cored in a wooded area near the Woodruff Dam in Chattahoochee, Georgia. The selected trees were located along a ridge approximately 100 meters mid-slope above Lake Seminole. In October of 2001, living pines were sampled along the Weeping Ridge trail in Torreya State Park. This site consisted of a small footpath that extended approximately 2.4 km through a moist, mixed pine/hardwood forest located upslope from a tributary of the Apalachicola River. Forty large shortleaf pines were selected along the path, which followed the slope above the tributary. In February of 2002, 20 pines were cored at the Gregory House site, also located within the park, approximately 3.2 km from the Weeping Ridge Trail. A footpath followed the top of a steep ridge adjacent to the Apalachicola River. The samples were taken along a transect that extended approximately 50 meters down-slope toward the river perpendicular to the footpath.

The Garden of Eden Trail (ABRP) was sampled in February of 2002. Because shortleaf pines were not as abundant at this site, longleaf pines located closest to the bluffs were also sampled. Increment cores from 15 shortleaf and 25 longleaf pines were obtained at this site.

5.1.3 Collection of Cross Sections

Cross sections were cut from downed *T. taxifolia* logs with a chainsaw. A description of the location, condition, measurements of d.b.h., and length of the downed *Torreya* from which sections were obtained were recorded on standard field sample cards.

The Gregory House trail in Torreya State Park possessed the largest number of downed *Torreya*. Twenty-five logs and snags were flagged for sampling. The locations of two *Torreya* logs at Woodruff Dam and four logs ABRP were also noted. These samples were collected in October of 2001 and February of 2002. In October of 2001, 24 cross sections were taken from the logs at the Gregory House site. The samples were clustered in a band along the middle of a 45–60° slope between a foot trail along the top of the ridge and the Apalachicola River at the bottom. In February of 2002, cross sections from four *Torreya* logs were obtained with the use of a handsaw at the ARBP site. These samples were located along a small stream at the bottom of a gully near the Apalachicola River.

5.2 Laboratory Methods

5.2.1 Sample Preparation

All increment cores were air dried for at least 24 hours. All cross-sections were placed in the University of Tennessee Herbarium freezer at –40°C for 48 hours to kill any fungi and/or insects. Cross-sections and cores were processed in the Laboratory of Tree-Ring Science at the University of Tennessee using standard dendrochronological techniques (Stokes and Smiley, 1996). The core samples were glued to wooden core mounts. All cores and cross-sections were sanded using progressively finer sand paper (ANSI 40-grit, 500–595µm to ANSI 400-grit, 20.6–23.6µm) to ensure maximum ring clarity under standard magnification (Orvis and Grissino-Mayer, 2002).

5.2.2 Visual Crossdating

Proper crossdating is the key to all studies involving dendrochronology (Douglass, 1946). This procedure involves the comparison of signature patterns of wide and narrow growth rings in different trees to establish the dates for the individual rings in a series. For my study, the core samples from living trees were visually crossdated by recognizing and noting the signature patterns of wide and narrow rings (Yamaguchi, 1991). Skeleton plotting involves comparing the locations of narrow ring patterns to align individual plots for the purpose of finding a period common for all specimens (Stokes and Smiley, 1996). Once 20 samples were visually dated, a master skeleton plot was created to confirm the dating and to detect possible missing rings (Swetnam *et al.*, 1985; Stokes and Smiley, 1996).

5.2.3 Measurement

The samples were measured using a movable stage micrometer, which measured ring widths with an accuracy of 0.01 mm (Stokes and Smiley, 1996). Ring-width measurements were recorded with Measure J2X software.

5.2.4 Quality Control with COFECHA

Ring patterns are generally less sensitive in mesic, temperate areas than in drier or colder climates because of fewer limiting factors on growth. For my study it was therefore important to maximize the amount of correct climate information by minimizing the "noise" that could be introduced by incorrect crossdating and inaccurate measurement (Holmes, 1983; Grissino-Mayer, 2001). Measurements and crossdating were checked using COFECHA, which reduces error by identifying data that need to be re-examined (Holmes, 1983). The program takes overlapping and successive segments of a particular measurement series, and compares these segments with a master chronology developed from the remainder of the series. 4 COFECHA flags segments that have low correlations with the master, marking them to be re-examined to determine the source of the low correlation. Unusually wide or very narrow rings, compared to the other rings measured in the series for the same year, are also flagged and cross-checked to ensure measurement error is minimized (Grissino-Mayer, 2001).

Once the chronology was established using the living pines, it was used to help date the *Torreya* cross-sections. The cross-sections were measured using the same procedures as the core samples. Because the outside dates for the *Torreya* samples were unknown, the series measurement started at year zero. The measured series were then entered into COFECHA as undated, and statistically correlated with the master pine chronology. If significant dating was achieved as noted by a statistically significant correlation coefficient ($p<0.01$), the series were visually checked and confirmed before assigning calendar dates. Once enough *Torreya* series were successfully dated, they were combined to create an independent chronology. The outer year of each cross-section was then plotted on a histogram to illustrate possible trends in mortality.

5.2.5 Standardization

Standardization of the measured ring series removes growth trends due to normal physiological aging processes not related to climate. This prevents the domination of the series by younger, faster-growing individuals with fluctuating ring widths. The measured ring widths are divided by expected growth values to create new indices of growth for the chronology. This process creates a mean growth value of one for all series, which increases the similarities between the series of the chronology by reducing the variance among the different series (Fritts, 1976). The software program CRONOL was used to standardize the raw measurements by fitting a trend line to the individual series being modeled using ordinary least squares techniques.

5.2.6 Analyzing the Climatic Response

Identifying the climate variable to which the trees are responding most strongly is a very important step in the tree growth-climate analysis. A climatic response model of tree growth was developed using divisional climate data for NOAA climate division 001 (northwest Florida) obtained from the National Climatic Data Center. The data cover historical and current periods and are updated every month. The climate variables examined included temperature, precipitation, and a drought index, the Palmer Hydrological Drought Index (PHDI). The statistical package SAS (Schotzhauer and Littell, 1987) was used to isolate those months in which a climatic variable had a statistically significant effect on tree growth. The climatic variable was then seasonalized based on those months with the most significant relationship for the purpose of gaining a better understanding of the timing during the tree's growing season in which the variable had the greatest effect (Grissino-Mayer and Butler 1993; Grissino-Mayer, 1995).

Once the climate data were seasonalized, correlation analyses were conducted just for those months in which the variables had significant effects on growth using the Pearson product moment. If a strong seasonal response was still present, the data for those months were copied to a spreadsheet in which yearly averages were calculated for temperature and PHDI data and yearly totals were calculated for precipitation. Correlation analyses were then conducted for the yearly averages and totals for each sample site, combined sample sites, and the *Torreya* cross sections.

5.2.7 Analyses of Temporal Growth Patterns

The quantitative assessment of growth rates was then compared with the climate data for the study area for the purpose of modeling this species' growth response to local climate. Early and late 20th century growth patterns were compared to determine if a possible unknown mechanism in the local environment weakened *Torreya taxifolia*, making them more susceptible to the stem and needle blight. Historical accounts of changes in the habitat and the surrounding area were also reviewed to determine if anthropogenic habitat changes, such as the construction of the dam near Chattahoochee or forest clearing, contributed to the increase in mortality of *Torreya taxifolia*.

Chapter 6

Results

6.1 Chronologies

6.1.1 Woodruff Dam

The Woodruff Dam shortleaf pine chronology consisted of 40 series representing 28 trees. This chronology dates from 1869–2001 with an interseries correlation of 0.56 (Table 6.1, Figure 6.1a). I found several narrow marker rings in most individual series for the years 1899, 1927, 1955, 1968, 1990, and 2000, which greatly aided the crossdating process. COFECHA flagged 17 of the 224 measured segments for possible error, but these segments did not date significantly better at the suggested alternate positions. The average mean sensitivity for these series was 0.30. The mean ring width for this series was 1.3 mm, while the average standard deviation was 1.02.

The trees at this site exhibited low growth rates during the early 20th century, followed by a gradual recovery that started in the early 1920s. Above average growth rates occurred during the late 1930s and lasted until a steady decline began in the early 1960s. Another recovery in growth occurred during the 1970s and early 1980s before a decline that occurred during the mid-to-late 1980s. A short recovery in growth occurred between 1991 and 1998 before growth dropped off again in 2000.

6.1.2 Torreya State Park

The Torreya State Park shortleaf pine chronology consisted of 59 series from a total of 40 trees dating from 1890–2001 (Figure 6.1b). The interseries correlation for this

Table 6.1 Site chronology table showing sample depth, dates, and interseries correlations.

Site	Samples	Date	Interseries Correlation
Woodruff Dam	40	1869–2001	0.56
Torreya State Park	59	1890–2001	0.57
ABRP	41	1887–2001	0.54

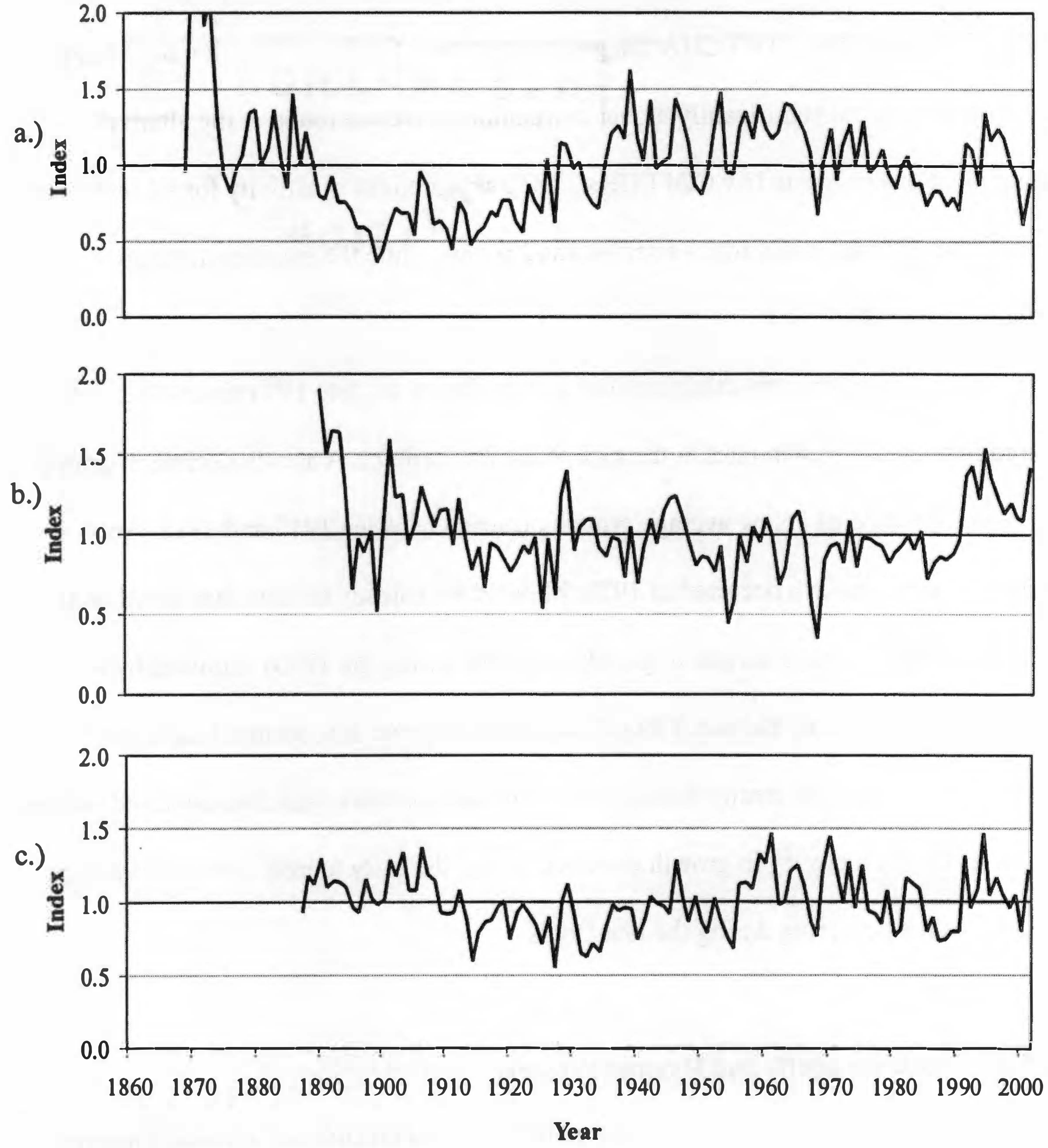


Figure 6.1 Graphs showing tree-growth within the individual site chronologies.
(a) Woodruff Dam chronology showing 19th and 20th century growth.
(b) Torreya State Park chronology showing 19th and 20th century growth.
(c) ABRP chronology showing 19th and 20th century growth.

series was 0.57 (Table 6.1). I found narrow marker rings for the years 1899, 1917, 1925, 1927, 1955, and 1968. COFECHA flagged six segments for re-examination out of 226 that were tested, but significantly higher correlations were not found at the alternate dating positions suggested by COFECHA. The average mean sensitivity for all series was 0.31. The mean ring width for this series was 2.6 mm, while the average standard deviation was 1.20.

The trees at this site exhibited low growth during the late 19th century followed by a rapid increase in growth rates at the turn of the 20th century. A steady decline in growth followed. A period of below average growth occurred between 1913 and 1928. Another rapid increase in growth occurred in 1928 followed by a steady decline that lasted until the early 1940s. Another decline in growth occurred during the 1950s followed by a recovery that lasted until the late 1960s. Following a decline that occurred during the late 1960s, growth remained steady through the 1970s until another reduction occurred during the late 1980s. A recovery in growth occurred during the early to mid 1990s followed by a slight decline occurring during the late 1990s.

6.1.3 Apalachicola Bluffs and Ravines Preserve

The shortleaf pine chronology for the Apalachicola Bluffs and Ravines Preserve was created using 41 series that represented 27 trees dating from 1887–2001(Figure 6.1c). I found narrow marker rings during the years 1887, 1895–96, 1914, 1927, 1954–55, 1968, and 2000, which aided crossdating. The interseries correlation for this chronology was 0.54 (Table 6.1). COFECHA flagged nine of the 191 segments tested for crossdating accuracy, but the alternate positions suggested by COFECHA did not have significantly higher correlations. The average mean sensitivity of the series for this site was 0.30. The mean ring width of this series was 1.7 mm, while the average standard deviation was 1.10.

Tree growth was steady during the late 19th and early 20th centuries before a decline that occurred between 1905 and 1915. A slight recovery lasted until another drop occurred during the mid 1920s. Another recovery occurred during the mid 1930s, and growth remained steady until declining during the mid-1950s. A sharp recovery in growth occurred during the late 1950s and early 1960s. After a dramatic drop in growth during the late 1960s, a rapid increase in growth occurred once again during the early to mid-1970s. Another steady decline in growth rates occurred during the late 1970s and 1980s until recovering once more during the early and mid-1990s. Growth was once again reduced during the late 1990s.

6.1.4 Master Pine Chronology

The shortleaf pine site chronologies were combined to create the master pine chronology, which represents tree growth for the range of *T. taxifolia* in its entirety. Fifteen measured series were removed once the site chronologies were combined because of low correlations that likely resulted from local disturbances not reflected in growth patterns from the wider area. The resulting chronology consisted of 125 series representing 86 trees that dated from 1869–2001 (Figure 6.2 a, b). I found narrow marker rings in the combined chronology during the years 1899, 1914, 1927, 1955, 1968, and 2000. The interseries correlation was 0.53 for these series (Table 6.2). Thirty-three measured series out of 562 that were tested by COFECHA were flagged for possible

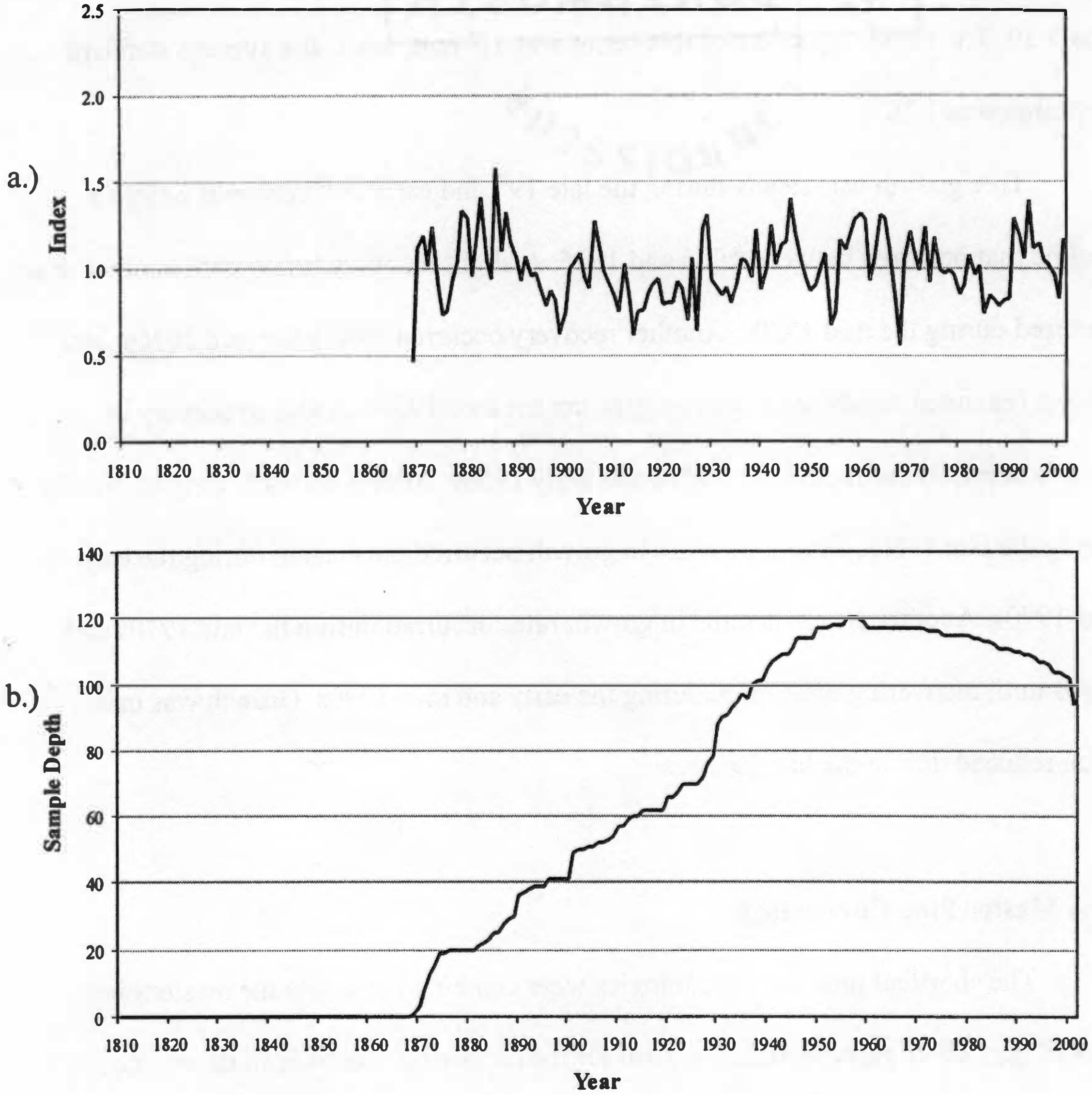


Figure 6.2 Graphs showing tree-growth and sample depth within the combined pine chronology.
(a) Combined pine chronology showing 19th and 20th century growth.
(b) Sample depth of each year within the combined pine chronology.

Table 6.2 Species chronology table showing sample depth, dates, and interseries correlations.

Species	Samples	Date	Interseries correlation
Pinus spp.	125	1869–2001	0.53
Torreya taxifolia	20	1814–1979	0.50

crossdating errors, but these series did not exhibit significantly higher correlations at the suggested alternate positions. The mean sensitivity for this combined chronology was 0.30. The mean ring width was 1.90 mm, while the average standard deviation was 1.40.

The master pine chronology contained eight distinct periods of growth during the late 19th and 20th centuries:

1. Tree growth was elevated during the 1870s and 1880s before declining during the 1890s.
2. A recovery in growth occurred in the beginning of the 20th century and lasted until 1906 when another steady decline occurred.
3. Growth rates remained below average until another sharp recovery occurred in 1928.
4. Another reduction in growth occurred during the early 1930s.
5. A long, steady recovery in growth occurred during the late 1930s and during the 1940s.
6. Growth rates were again reduced during the early-to-mid 1950s before recovering in the late 1950s.

7. A sharp drop in growth occurred in the late 1960s followed by a recovery that lasted until the mid-to-late 1980s.
8. Growth once again recovered during the 1990s before a dramatic drop in the year 2000.

6.1.5 Master *Torreya taxifolia* Chronology

The *T. taxifolia* chronology was constructed using 20 cross sections. This chronology dated from 1814–1979 (Figure 6.3a, 6.3b). The interseries correlation for these series was 0.50 (Table 6.2). COFECHA flagged two of the measured segments of the 37 that were tested by COFECHA, but these segments were correctly dated. The average mean sensitivity value for these series was 0.35. The mean ring width for this series was 1.20 mm, while the average standard deviation was 0.66.

Although sample depth was limited for the early and middle 19th century, a distinct pattern of growth was evident for *T. taxifolia*. This series exhibited multiple periods of growth suppression and release (Figure 6.3a). Initial growth rates were high preceding a decline that occurred during the 1820s and 1830s. Growth recovered during the 1840s before waning again during the 1850s. Tree growth levels remained low until recovering during the mid 1860s. After a slight peak in growth during the early 1870s, another reduction of growth occurred until a sharp recovery in the early 1880s. A steady decline in growth occurred between 1883 and 1899. A recovery in growth occurred at the turn of the 20th century and remained steady before dipping in 1914. A sharp recovery

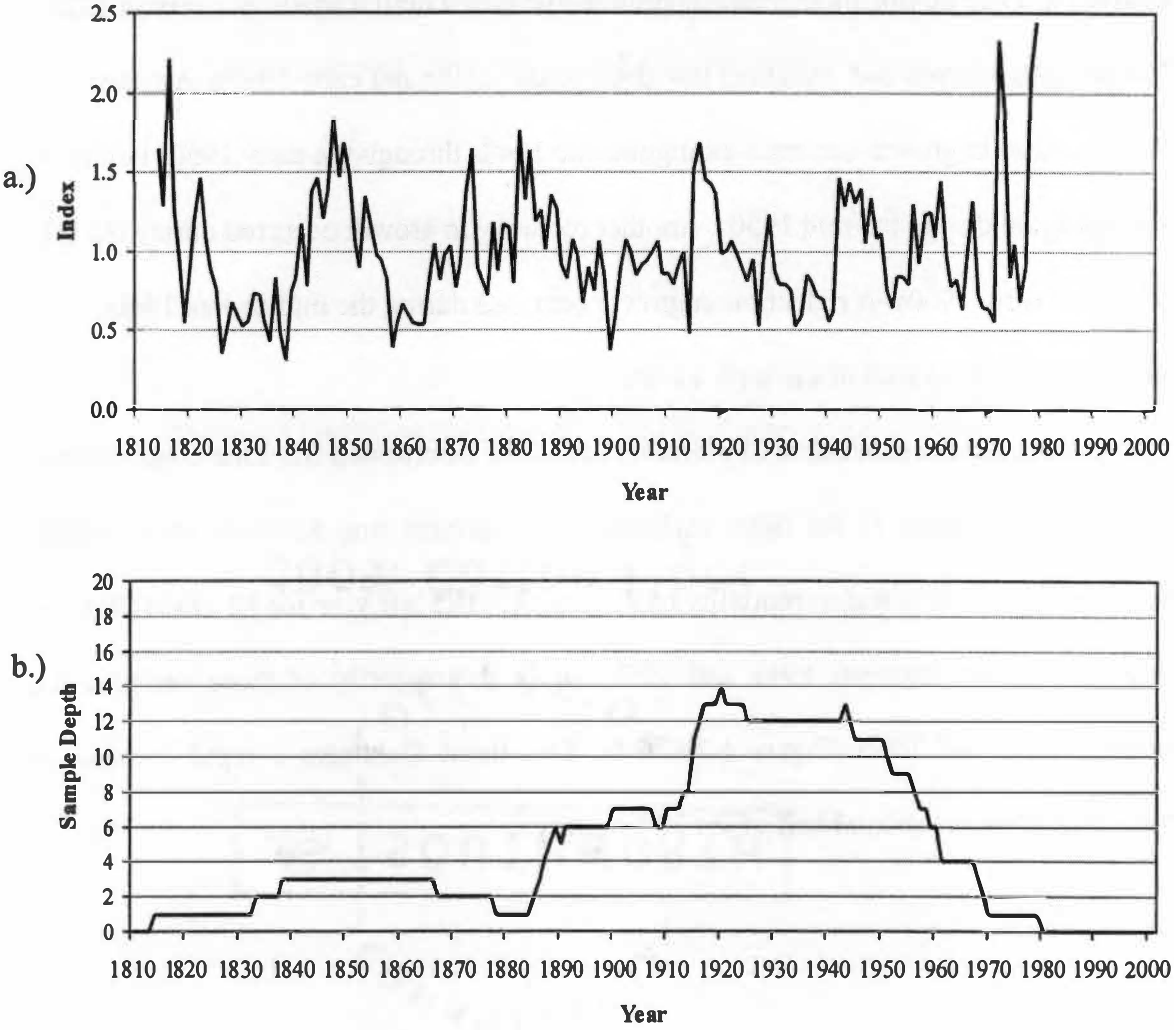


Figure 6.3 Graphs showing tree-growth and sample depth within the *T. taxifolia* chronology.

(a) *Torreya taxifolia* chronology showing 19th and 20th century growth.

(b) Sample depth for each year in the *T. taxifolia* chronology.

occurred in 1915 before another steady decline that lasted until a small recovery in 1928. Growth rates dropped and remained low through the 1930s and early 1940s. Another sharp increase in growth occurred during the late 1940s through the early 1950s before it dropped again during the mid 1950s. Another recovery in growth occurred during the late 1950s and early 1960s. A reduction in growth occurred during the mid-to-late 1960s before it again recovered in the early 1970s.

Although the exact time of mortality cannot be determined from the cross sections because of the decay of the outer surfaces, the outermost ring for each cross section illustrates a possible trend in mortality of *T. taxifolia.* The last year for 12 of the 20 cross sections occurred between 1941 and 1970, while the majority of those samples fell between 1951 and 1960 (Figure 6.3b, 6.4). This trend illustrates a rapid increase in mortality during the second half of the 20th century.

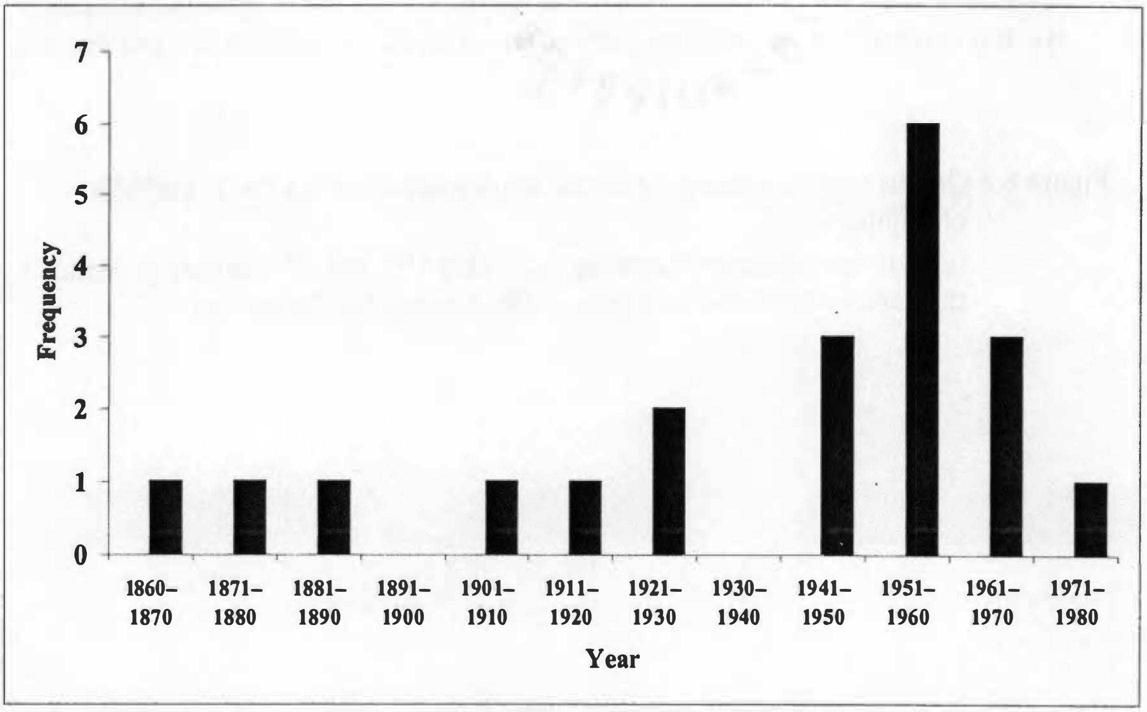


Figure 6.4 Histogram showing outside ring dates of the *T. taxifolia* cross sections.

6.2 Climate Analysis

6.2.1 Woodruff Dam

A significant positive correlation of growth ($r = 0.28$, $p = 0.004$) with current year March precipitation was found for this site (Figures 6.5a, 6.5b; Table 6.3). Increased growth did occur at this site with high precipitation levels during the late 1920s, early 1930s, late 1940s, late 1950s, early 1970s, and during the early-to-mid 1990s. No statistically significant response to temperature was found, although current year May–October temperature had a negative effect on growth. The relationship between growth and drought (PHDI) was statistically significant at this site (Figures 6.5a, 6.5c). The correlation coefficient was $r = 0.47$ ($p < 0.0001$) for current year April–September PHDI (Table 6.3). Reductions in growth coincided with major drought events that occurred during the years 1899, 1911, 1927, 1955, 1968, as well as during the mid-to-late 1980s.

6.2.2 Torreya State Park

A significant correlation ($r = 0.40$, $p < 0.0001$) between growth and current year March precipitation was found for this site (Figures 6.6a, 6.6b; Table 6.3). Increased growth occurred during years with high precipitation totals including 1901, 1906, 1928–29, the mid 1940s, 1973, and the early 1990s. No significant growth response to temperature was found, although negative responses with current year April–June temperature were observed. I found a significant relationship between growth and current year March–October PHDI ($r = 0.48$, $p < 0.0001$) (Figures 6.6a, 6.6c; Table 6.3). Decreased growth rates coincided with major drought events that occurred during the years 1913, 1927, 1955, 1963, 1968, 1981, and 1985.

Table 6.3 Correlation coefficients between tree growth and climate variables for the sample sites.

Site	Precipitation	Temperature	PHDI
Woodruff Dam	March r = 0.28 p= 0.004	Not Significant	April–September r = 0.47 p < 0.0001
Torreya State Park	March r = 0.40 p < 0.0001	Not Significant	March–October r = 0.48 p < 0.0001
ABRP	March r = 0.29 p = 0.002	June r = –0.25 p = 0.03	March–October r = 0.45 p < 0.0001

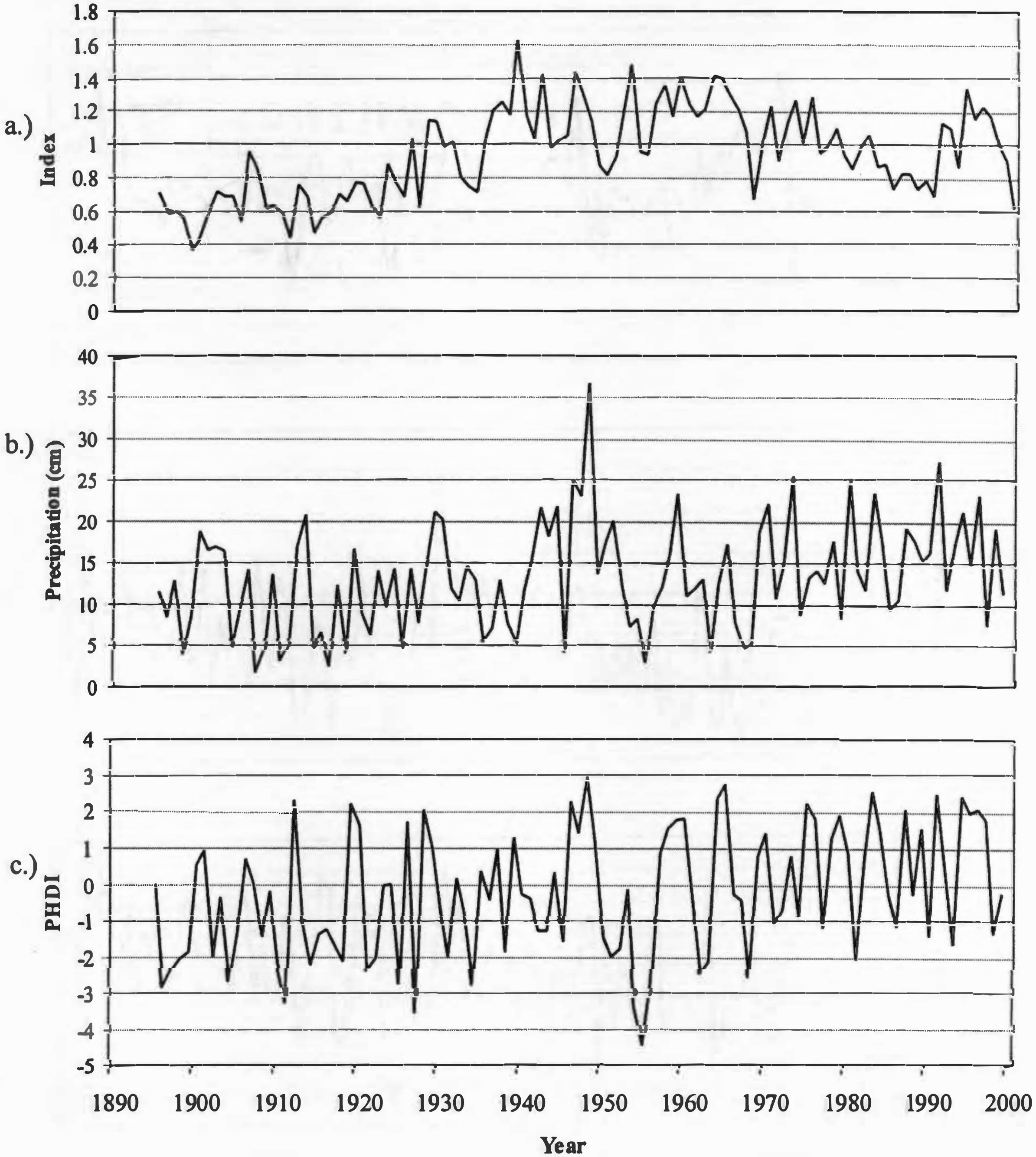


Figure 6.5 Graphs showing tree-growth and climate response at Woodruff Dam.
(a) Woodruff Dam chronology showing 20th century growth.
(b) 20th century March precipitation trends.
(c) 20th century April–September PHDI trends.

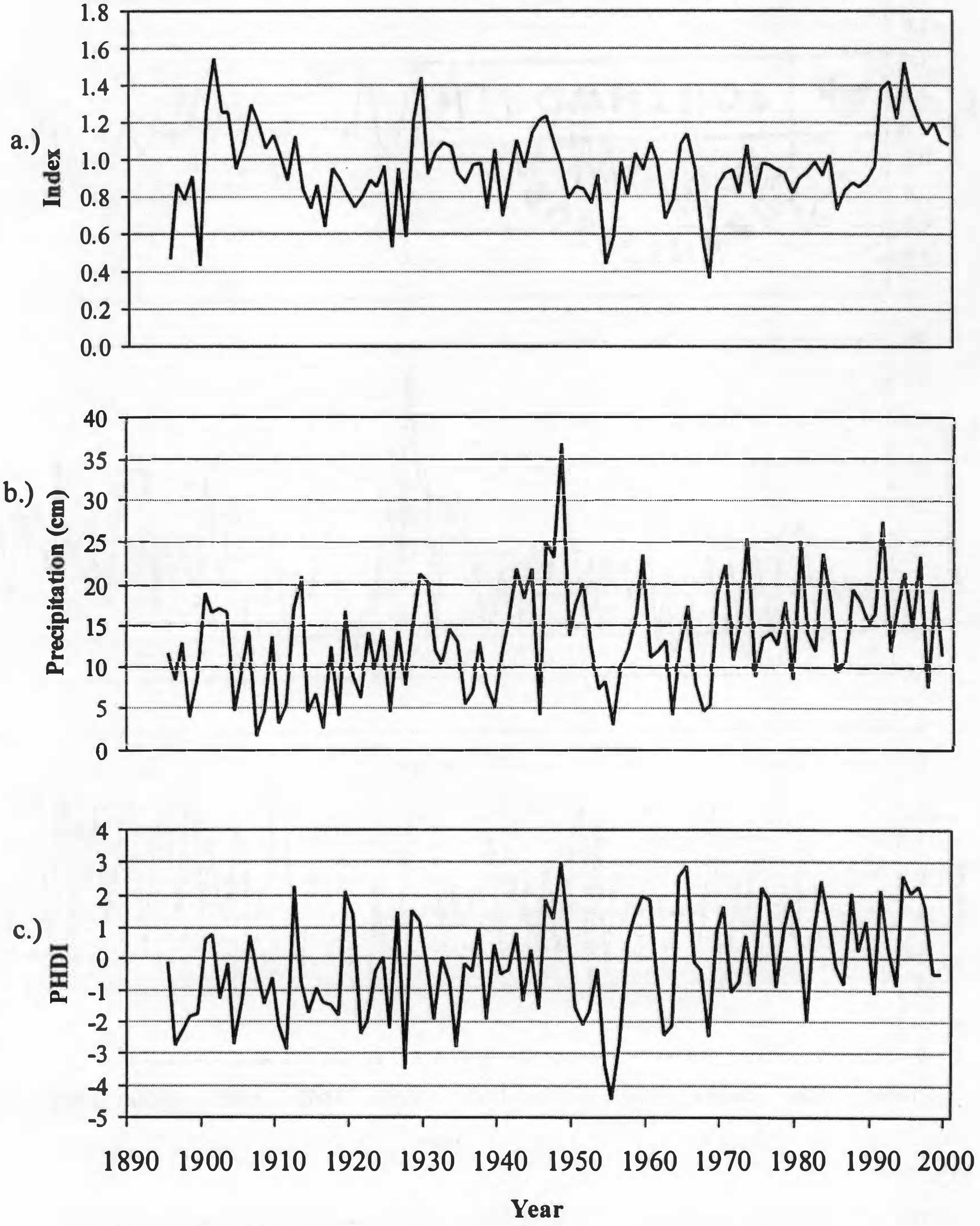


Figure 6.6 Graphs showing tree-growth and climate response at Torreya State Park.

(a) Torreya State Park chronology showing 20th century growth trends.
(b) 20th century March precipitation trends.
(c) 20th century March–October PHDI trends.

6.2.3 Apalachicola Bluffs and Ravines Preserve (ABRP)

A weak correlation ($r = 0.29$, $p = 0.002$) between growth and current year March precipitation was found at this site (Figures 6.7a, 6.7b; Table 6.3). An increase in growth rates occurred during periods with high precipitation totals including the early 1900s, late 1920s, late 1940s, late 1950s, early 1970s, early 1980s, and the early-to-mid 1990s. I also found a statistically significant yet weak negative correlation between growth and current year June temperature ($r = -0.25$, $p = 0.03$) (Figures 6.7a, 6.7c; Table 6.3). Growth rates were lower with high June temperatures that occurred during the years 1899, 1914, 1944, the mid 1950s, and late 1990s. A statistically significant growth response to current year March–October PHDI ($r = 0.45$, $p < 0.0001$) was also found at this site (Figures 6.7a, 6.7d; Table 6.3). Years in which drought events reduced growth rates at this site include 1899, 1911, 1927, 1955, 1963, 1968, 1981, and 1985.

6.2.4 Pines

The combined pine measurements from all three sites expressed an overall stronger response to the climate variables. A significant growth response to January–September precipitation ($r = 0.65$, $p < 0.0001$) was observed (Figures 6.8a, 6.8b; Table 6.4). Increased growth rates coincided with increased precipitation totals during the late 1920s, late 1940s, late 1950s, mid 1960s, early-to-mid 1970s, and the early-to-mid 1990s. I found a statistically significant negative correlation between growth and current year August ($r = -0.22$, $p = 0.03$) temperature (Figures 6.8a, 6.8c; Table 6.4). A reduction in tree growth occurred with above average August temperature in 1925, 1950, 1955, and 1990. A strong response to current year March–October PHDI ($r = 0.60$, $p < 0.0001$) was observed for this site (Figures 6.8a, 6.8d; Table 6.4). The years in which major drought

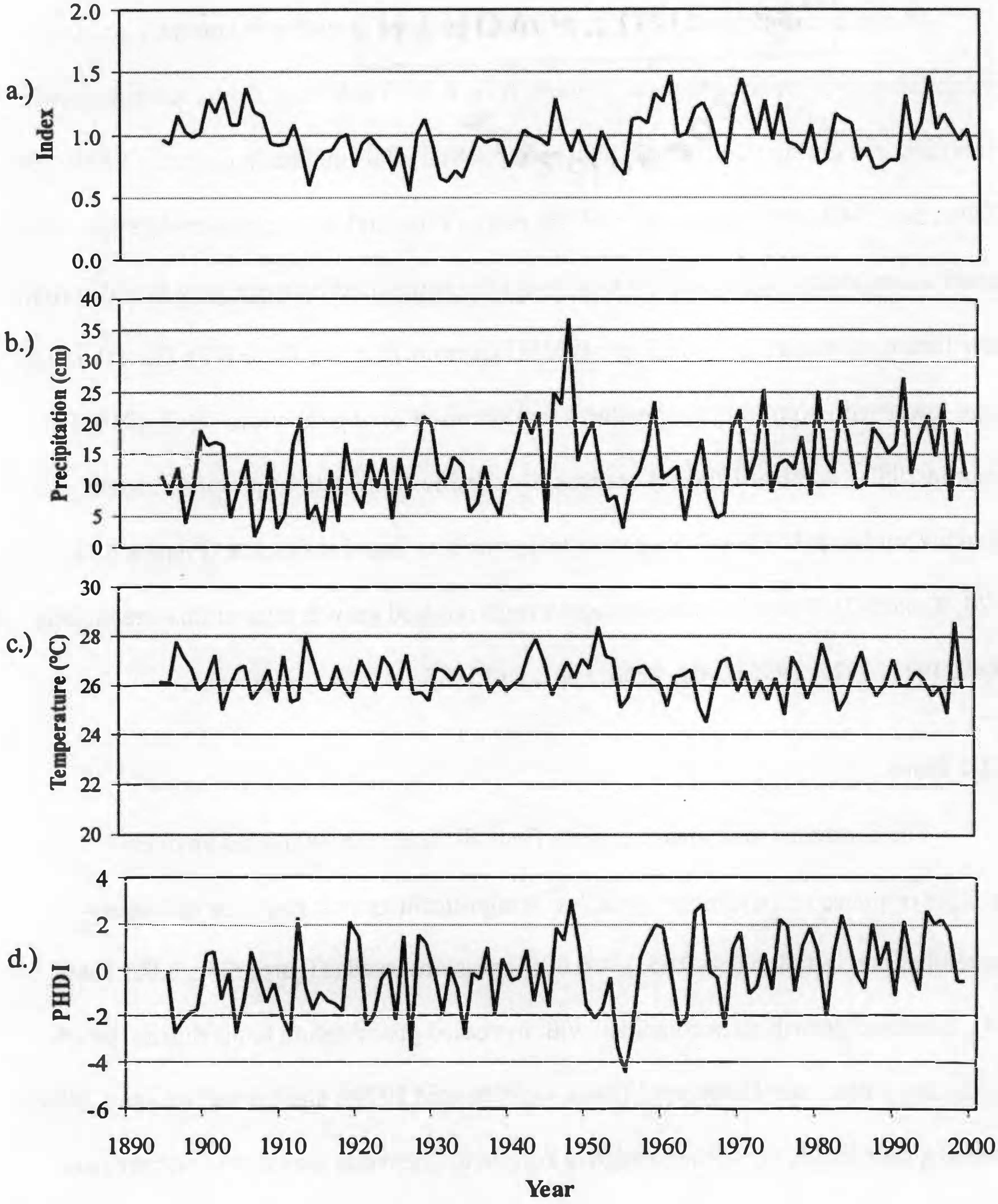


Figure 6.7 Graphs showing tree-growth and climate response at ABRP.
(a) ABRP chronology showing 20th century growth.
(b) 20th century March precipitation trends
(c) 20th century June temperature trends.
(d) 20th century March–October PHDI trends.

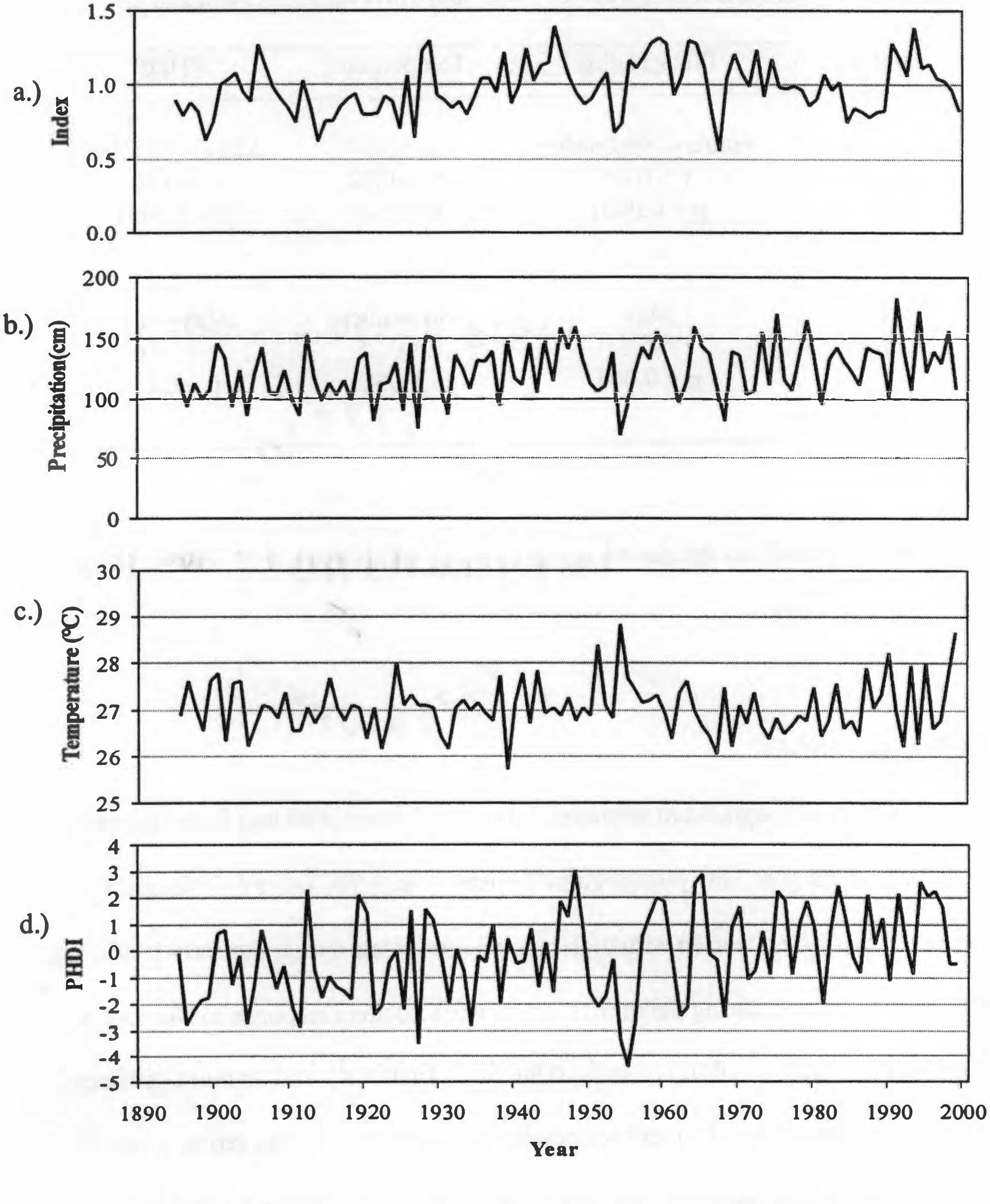


Figure 6.8 Graphs showing tree-growth and climate response for the combined pine series.

(a) Combined pine chronology showing 20th century growth

(b) 20th century January–September precipitation trends.

(c) 20th century August temperature trends.

(d) 20th century March–October PHDI trends.

Table 6.4 Correlation coefficients for *Pinus* and *Torreya* tree growth and climate.

Species	Precipitation	Temperature	PHDI
Pinus spp.	January–September r = 0.65 p < 0.0001	August r = –0.22 p = 0.03	March–October r = 0.60 p < 0.0001
Torreya taxifolia	May r = 0.31 p = 0.004	November r = 0.25 p = 0.02	May–July r = 0.26 p = 0.02

events reduced growth for the combined pine series include 1911, 1927, 1934, 1955, 1963, 1968, and 1981.

6.2.5 *Torreya taxifolia*

A statistically significant relationship (r = 0.31, p = 0.004) was found between growth and current year May precipitation (Figures 6.9a, 6.9b; Table 6.4). Increased growth in *T. taxifolia* occurred with high precipitation totals during the early 1920s, late 1940s, late 1950s, and during the mid 1970s. A weak positive response to November temperature (r = 0.25, p = 0.02) (Figures 6.9a, 6.9c; Table 6.4), and an non-significant, negative response to April–October temperature was observed in this series. *T. taxifolia* growth responded favorably to warm November temperatures during the late 1940s and 1970s. I also found a weak correlation coefficient with current year May–July PHDI (r = 0.26, p = 0.02) (Figures 6.9a, 6.9d; Table 6.4). The growth of *T. taxifolia* was negatively

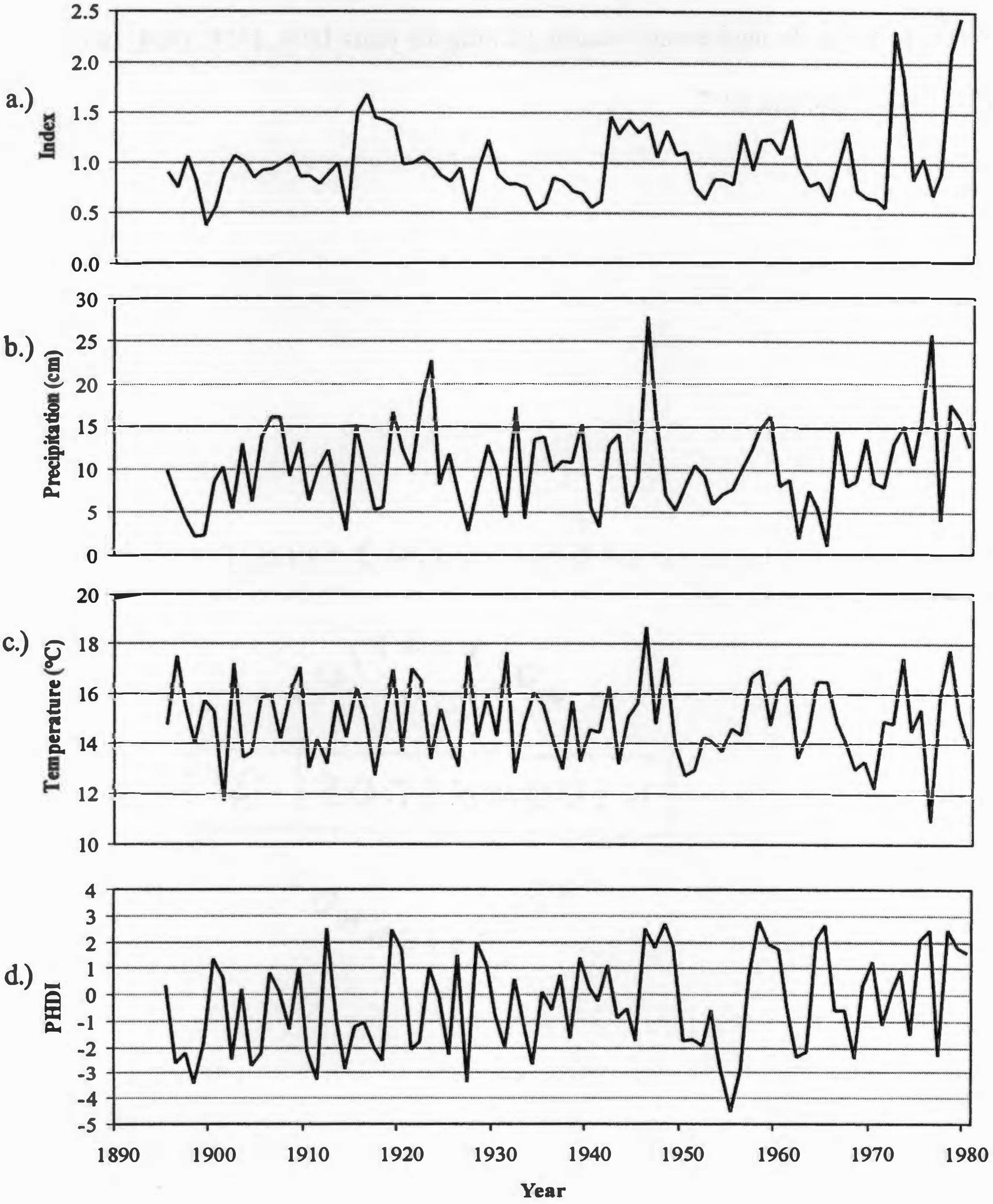


Figure 6.9 Graphs showing tree-growth and climate response for *T. taxifolia*.
(a) *Torreya taxifolia* chronology showing 20th century growth.
(b) 20th century May precipitation trends.
(c) 20th century November temperature trends.
(d) 20th century May–July PHDI trends.

affected by major drought events occurring during the years 1899, 1911, 1914, 1927, 1955, 1963, 1968, and 1977.

Chapter 7

Discussion

7.1 Chronologies

7.1.1 Pine Chronologies

7.1.1.1 Woodruff Dam

The Woodruff Dam shortleaf pine chronology, which represents the northern extent of the natural range of *T. taxifolia*, has the highest interseries correlation when compared with those from Torreya State Park and ABRP. This site also contains the oldest trees in the study area. Because there are fewer fluctuations in growth with increased age, the age of the trees at Woodruff Dam contribute to the clarity of the signature ring patterns and the reduction of "noise" from variables other than climate, such as disturbance and resource competition. The trees at this site also possess lower mean ring widths when compared with the other two sample sites. This is a result of a downward trend in growth with increasing age. Standard deviation is considerably lower for this series as well, indicating less variance in ring width among the trees at this site. Because this series contains the oldest trees, it was the cornerstone for the master pine chronology.

7.1.1.2 Torreya State Park

The Torreya State Park shortleaf pine chronology has the greatest sample depth of all the site chronologies. Torreya State Park contains a large concentration of remnant *T. taxifolia* making this an important chronology for use in dating the cross sections.

Because the trees in the Gregory House and Weeping Ridge sites are similar in age and share signature ring patterns, they crossdate very well to create one master chronology representing Torreya State Park. Most of the trees comprising this chronology initiated growth during the early 20th century indicating a presence of some widespread disturbance in and around the state park. Although this chronology contains tree-ring measurements from samples taken at two different sites, the interseries correlation for the Torreya State Park chronology is high. The trees comprising this chronology have the highest mean ring width because of their youth. Because younger trees have more fluctuation in ring widths with changes in climate and disturbance, the age of these trees also contribute to a higher standard deviation among the series of this chronology.

Seven trees at the Weeping Ridge sample site exhibit an abrupt, pronounced suppression in growth beginning in the early 1960s and never recovered despite a healthy outward appearance. No record of insect or pathogen outbreaks during this period was found. This suppression is isolated to trees near the Weeping Ridge campground and trail. This sharp reduction in growth corroborates the theory that major habitat changes have occurred in the latter 20th century, although the exact mechanism for this abrupt and sustained change in growth rates is unknown. The reduction in the growth of these trees may also be the result of trampling and soil compaction associated with campground and trail traffic. Because of suppressed growth, these samples could not be accurately dated or included in the analyses.

7.1.1.3 Apalachicola Bluffs and Ravines Preserve (ABRP)

The ABRP chronology has the lowest interseries correlation compared with the other two site chronologies, possibly because two different pine species were sampled and measured to construct this chronology. Approximately 50% of the samples were extracted from nearby longleaf pines while the remaining trees consisted of shortleaf pines. The longleaf pines are farther from the influence of the river than the others and grow in drier conditions above the river bluffs. Despite this, accurate crossdating between the two species was achieved. Most of the trees at this site established during the late 19th and early 20th centuries following widespread logging. Despite similar age structure, the mean ring width for the ABRP chronology was lower than that of the State Park. This is the result of the incorporation of longleaf pines, which possess more narrow rings, into the series. The addition of longleaf pines also contributes to the higher standard deviation for this series. The successful crossdating between the shortleaf and longleaf pines indicates that these two species have similar growth responses to both climate and disturbance processes.

7.1.1.4 Combined Pine Chronology

The combined pine chronology has a lower interseries correlation and higher standard deviation than any of the individual site chronologies indicating variability in tree growth among the sample sites. Despite the distance covered and differences in local environments, the same signature ring patterns are present and crossdating between the different site chronologies was successful. The 20th century trend in tree growth shown in the individual site chronologies is retained in the combined pine series. Mean sensitivity was consistent with those of the individual site chronologies indicating the presence of similar ring-width variability in the combined series. This chronology is important for determining regional tree growth and response to climate variables for the range of *T. taxifolia.*

7.1.2 *T. taxifolia* Chronology

The *T. taxifolia* cross sections were difficult to date because of missing rings and the presence of reaction wood. However, crossdating was accomplished using the master pine chronology created from the combined pine series. The younger sections with more 20th century growth were easier difficult to date due to greater sample depth of tree rings from that period in the pine chronology. The successful crossdating of the *Torreya* sections with the pine chronology indicates similar growth responses of these species to climate and other environmental factors. The standard deviation was higher for the *T. taxifolia* chronology indicating higher variance in ring width among the series. This is possibly because of the presence of reaction wood in many of the samples in which the overall ring width pattern would remain the same, but ring width would be greater. The formation of reaction wood is a mechanism that provides extra support and eventually straightens leaning trees by increasing the amount and density of the wood on the underside of the leaning individual. In *T. taxifolia*, the reaction wood forms on the downslope side of the tree. Mean sensitivity values were higher than that of the pines indicating greater ring-width variability within the series.

More instances of suppressed and released growth were observed in this series than in the pine series, which showed more steady growth. This growth pattern is likely due to the slow growth of *T. taxifolia* and the fact that this species spends much of its life in the understory under the thick canopy of the hammock forests. Although the outermost rings were missing due to decay, the last years on many of the samples coincide with the reported onset of widespread mortality that occurred during the mid-to-late 1950s and early 1960s.

7.2 Climate Analysis

7.2.1 Pine Series Climate-Growth Response

7.2.1.1 Precipitation

The tree growth response to precipitation was stronger than expected in an area of humid subtropical climate, possibly due to the steep slopes and the well-drained, sandy soils. The strongest seasonal growth response occurred for March precipitation at Woodruff Dam, Torreya State Park, and ABRP. January–September precipitation was most significant for the combined pine chronology. This consistent, positive growth response to spring and summer precipitation at all sites indicates low variability among the sites in moisture and evaporation rates.

The positive tree growth response to spring precipitation demonstrates the importance of available moisture during the early parts of the growing season. The slopes and sandy soils result in rapid moisture loss and an increased need for consistent precipitation in this area. The correlation between tree growth and precipitation at Woodruff Dam is slightly weaker than that at the other sites, possibly because of the moderating effects of Lake Seminole. In addition, growth in older trees is less affected by year-to-year variations in climate. The older age of the trees at this site would likely reduce the response to moisture as well.

The correlation between growth and precipitation was stronger at Torreya State Park because of competition for water resources between the many canopy-dominating and understory species that occur in the thick hammock forests of this site. The trees at this site are also younger than those at Woodruff Dam, contributing to stronger growth responses to changes in precipitation. This response, however, would be mediated by the shady, moist conditions within these systems, as well as the proximity of these trees to the Apalachicola River.

The relationship between tree growth and precipitation at ABRP was positive, but weaker than that found for trees at Torreya State Park. This weaker response is perhaps due to the incorporation of longleaf pine series into the chronology. Because longleaf pines possess deep taproots, they are adapted to drought and do not require consistent precipitation. The growth response to precipitation will not be as strong as those for less drought tolerant pine species.

The combined pine series yielded a very strong, positive growth response to January–September precipitation. The amplified growth response to precipitation illustrates the presence of a determining growth factor for the entire range of *T. taxifolia*. Although the growing season in this area does not begin until late March, an increase in precipitation just before and at the beginning of the growing season would increase available soil moisture for initial growth. An abundance of spring and summer precipitation maintains increased growth levels throughout the growing season.

This seasonal growth response to precipitation is similar to that found by Friend and Hafley (1989) who found the most significant growth responses of shortleaf pines in the coastal plain of North Carolina occurred in the very beginning of the growing season. Meldahl *et al*. (1999) also determined that March–October precipitation had the most significant effect on growth of longleaf pines in southern Alabama. Although precipitation may not be the primary limiting factor for growth in this humid subtropical climate, the strong, positive correlation between tree growth in the combined pine series and precipitation supports the use of this variable to model tree growth on a regional scale.

7.2.1.2 Temperature

The correlations between tree growth and temperature were not significant at Woodruff Dam or Torreya State Park. This weak growth response could be due to the mediating effect of the river on temperature within the ravines. The shady conditions of the hammock forests also reduce the effect of temperature on tree growth via reduced soil moisture evaporation rates. I found a significant negative response to summer temperature at the ABRP site, likely as a result of the greater distance of some samples from the river and the increased evapotranspiration rates in the open, upland longleaf pine forest. Meldahl *et al*. (1999) found that high summer and early fall temperatures negatively affected subsequent earlywood formation in longleaf pines of southern Alabama.

The statistically significant negative correlation between tree growth and summer temperature in the combined pine chronology suggests a regional response by pines to this variable. While some decreased growth does occur with higher temperatures, temperature alone does not serve as an accurate predictior for tree growth in this area as long as available moisture levels are sufficient.

7.2.1.3 Palmer Hydrological Drought Index (PHDI)

Summer PHDI is the climate variable with the strongest relationship with tree growth for all site chronologies. The study area receives most precipitation during the spring and summer seasons from frequent convective thunderstorms. Because the sandy soils of this area have low water-holding capacities, soil moisture levels remain low and quickly evaporates with increased temperatures. Tree growth is strongly inhibited during the hot summer months unless there is consistent precipitation.

The trees at Torreya State Park possess the strongest response to this variable because of the density of vegetation within the hammock forest. The dense understory at this site results in increasing competition for available moisture. Any reduction in available moisture would affect growth rates of the vegetation at this site. Furthermore, the trees sampled at this site were growing adjacent to the steep slopes above the river, in an area with gentle slopes and sandy soils, which are conducive to rapid drainage.

The trees at Woodruff Dam also demonstrate a significant relationship with PHDI despite higher humidity from the close proximity of Lake Seminole and a thin understory resulting in reduced moisture competition. This site did consist of steeper ridges and sandy soil, which increased the need for consistent moisture in the shortleaf pines.

The trees at ABRP exhibited the weakest response to summer drought. Half of the sampled pines were growing in mid-slope positions above the river, which possibly increased water vapor levels and reduced evapotranspiration rates. Approximately half of the sampled trees from this site were longleaf pines, which are drought tolerant and would further reduce the correlation between tree growth and drought at this site. Despite these factors, the relationship between tree growth and summer drought is statistically significant indicating the effect of drought on growth of multiple species that grow in the study area.

The growth response to summer drought is amplified in the combined pine chronology, which illustrates the underlying strength of summer drought on growth throughout the range of *T. taxifolia*. Despite the possibility of an increase in local humidity that results from the proximity of the sample area to the river, the trees in this area have a strong drought response. The terrain, soils, and upland land use are strong contributing factors to this response. Much of the suppressed growth in the pine series occurred during significant spring and summer drought events.

These results are similar to those of Friend and Hafley (1989) who found that decreased spring and summer moisture limited growth in shortleaf pines in North Carolina despite optimal temperatures. Meldahl *et al.* (1999) also determined that September PHDI played a significant role in tree growth of longleaf pines in southern Alabama. Based on the correlations between tree growth and PHDI, summer drought is the best variable for modeling tree growth response to climate in this area.

7.2.2 *Torreya taxifolia* Series Climate-Growth Response

Although the *T. taxifolia* cross sections were collected in Torreya State Park and ABRP, the growth response to climate was not as strong as that of the pines sampled at these sites, indicating that changes in climate may not be playing a large role in the demise of this species. The low correlations of growth with climate are possibly due to the occurrence of *T. taxifolia* in the understory of the moist, shaded hammock forests where responses to macroclimate signals may be muted. The proximity of these trees to the Apalachicola River and perennial streams may further decrease the influence of climate.

The positive correlation between growth and May precipitation illustrates a dependence on available moisture with increasing summer temperatures. Warmer temperatures increase moisture competition through increased evaporation and transpiration rates. Schwartz *et al.* (1995) found that *T. taxifolia* seedlings receiving abundant water gained much more biomass in a shorter period than those receiving minimal water treatments. Their conclusions concerning the dependence of the growth of *T. taxifolia* on abundant moisture are in agreement with my observations. May precipitation was low from 1955–1969 with the exception of a brief recovery in the late 1950s. The growth of *T. taxifolia* closely follows the trend in precipitation during this period.

The positive correlation with November temperature illustrates a favorable response to a longer growing season. Schwartz *et al.* (1995) determined that the optimal temperature for photosynthesis in *T. taxifolia* was 20ºC. A period of increased growth in the *T. taxifolia* series coincides with a series of warm Novembers during the late 1940s in which the temperature was near 20ºC. I found a non-significant, negative correlation between tree growth and summer temperatures. While the growth response of *T. taxifolia* to summer temperatures is not strong, it does indicate a reduction in photosynthesis with increased temperature. The growth response to summer temperature was likely weakened in the *Torreya* by the shaded conditions of their understory habitat.

The significant correlation between growth and summer drought illustrates the strain of summer drought on *T. taxifolia*. Several significant drought events occurred in the 20th century. The droughts that had the greatest effect on the growth of *T. taxifolia* occurred in 1899, 1914, 1927, 1954–55, and 1968. The strongest May–July drought of the 20th century occurred in the mid-1950s. This drought also occurred simultaneously with a prolonged warm period. Warmer temperatures and reduced moisture significantly affect the fragile ravine forest systems. River and backwaters would recede and perennial streams would evaporate while evapotranspiration rates and water competition increase. Schwartz *et al*. (1995) concluded that *T. taxifolia* is resistant to short-term water stress, but struggles to recover and grow during prolonged dry conditions. Based on the correlations with growth and timing of events, May–July drought is the most likely climate variable that could be contributing to the decline of *T. taxifolia*.

7.3 Anthropogenic Effects on the Vitality of *T. taxifolia*

7.3.1 Clear-cutting of Upland Forests

Large tracts of longleaf pine forests once covered the land above the bluffs of the Apalachicola River. Since the early 1900s, this land has been under the control of various timber operations. Large-scale clear-cutting practices were initiated during the 1950s. Since then, much of the longleaf pine forest has been cleared and replaced with slash pine plantations. Many tracts of this land are cleared on a regular basis leaving large areas of barren land (Figure 7.1). The timing of the decline of *T. taxifolia* closely followed the beginning of clear-cutting practices in the uplands of the bluffs.

While the timing of clear-cutting practices coincided with the widespread mortality of *T. taxifolia*, it is difficult to determine the degree to which this land-use practice affected the species. The growth of surviving *Torreya* and local pines was diminished during this period. However, periods of recovery also occurred during the late 1950s. Upland clear-cutting has negatively affected the habitat of *T. taxifolia*, but the overall effect of this land-use practice on the health of individual *T. taxifolia* is inconclusive, though speculation on possibilities may be helpful.

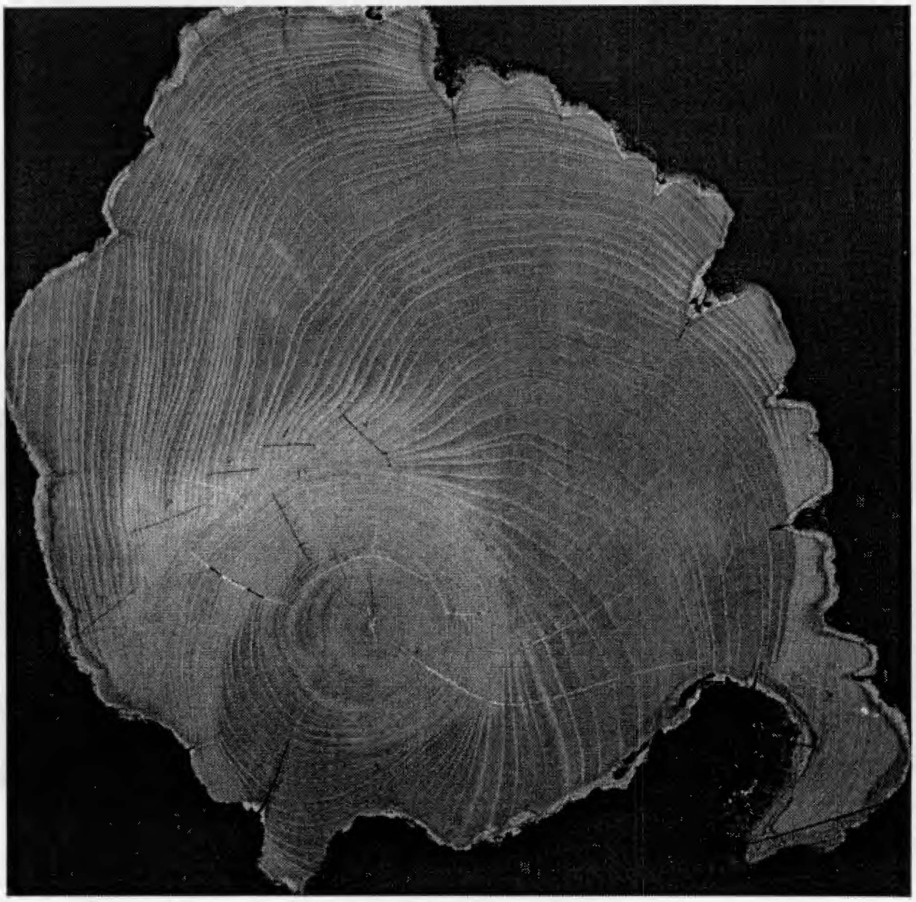
Upland clear-cutting has several possible effects on the hammock forests of the Apalachicola River bluffs below. Deforestation results in increased insolation that penetrates to the former understory and causes subsequent increases in ambient temperature of the surrounding areas. Any increases in temperature result in higher rates of transpiration and evaporation of soil moisture. Increased loss of soil moisture may weaken the slow-growing *T. taxifolia*, while increases in temperature above 20ºC simultaneously reduce photosynthesis rates in this species (Schwartz *et al*., 1995). This reduction in photosynthesis combined with decreased available moisture negatively affect the health and persistence of this species.

Increased runoff and erosion occur with the removal of upland vegetation as well. This overland runoff and erosion result in increased slumping of the soils in the ravines. Most of the *Torreya* cross sections possess reaction wood, illustrating the persistence of

Figure 7.1 Clear-cut area near Apalachicola River Bluffs and Ravines Preserve.

this species on the steep slopes of the ravines (Figure 7.2). *T. taxifolia* also, like many species evolved to grow on slopes, reproduce via basal sprouting (Platt and Schwartz, 1990). However, the slow growth habit of *T. taxifolia* does not allow this species to quickly recover when erosion increases.

Clear-cutting also opens large areas of land for the establishment of invasive plant species such as greenbrier and blackberry. Many invasive species establish on the edges of clearings and on forest margins. These species are often quite prolific and spread very rapidly. It is likely that the invasive plants could spread beyond the forest margin downslope into the ravines. Once established in the hammocks, these species may successfully compete with *Torreya* for light, moisture, and nutrients.



7.2 Reaction wood forming spiral pattern on a *T. taxifolia* cross section.

7.3.2 Fire Suppression

Low-intensity fires once swept through the upland longleaf pine forests every 2–5 years. The acquisition of much of the uplands by the timber industry has resulted in widespread fire suppression that is affecting the health and vitality of *T. taxifolia*. Smoke from longleaf pine ecosytems has been proven to reduce mycelial growth in the fungi that attack *T. taxifolia* (Schwartz *et al.*, 1995). It is possible that smoke from the frequent fires that once burned through the longleaf pine forests drifted into the ravines, keeping the fungi under control. The suppression of fire could upset this delicate balance, allowing the fungi to reach critical levels and terminally infect the *Torreya*. Because *T. taxifolia* is confined to a small area, widespread infection by the blight would be swift. This scenario, however, seems unlikely because many forest ecosystems worldwide have experienced prolonged fire suppression during the 20th century without catastrophic fungal outbreaks.

Fire is being reintroduced to the landscape in the Apalachicola Bluffs and Ravines Preserve. The Nature Conservancy acquired this land in the 1970s and started controlled burns to restore longleaf/wiregrass ecosystems during the mid-1980s. Although a reduction of smoke may not be the primary cause of the fungal outbreak, blight symptoms on the vegetation of *T. taxifolia* growing in the proximity of these burns should be monitored to determine the possible effects of smoke on the growth of the fungi in a pre-European settlement environment.

Fire suppression also allows the understory of upland pine systems to be invaded by woody understory vegetation such as turkey oak (*Quercus laevis* Walt) and blackberry (*Rubus* spp.). These species are known to increase moisture competition in the upland pine systems. Once established in the upland pine forests, these species may also become established in the hammock margins and down the slopes into the ravines where they would compete for light, moisture, and nutrients. Once established along the hammock margins, these species may populate gap areas deeper within the forest allowing them to spread in wider areas of the interior. Woody vines like blackberry and greenbrier spread very rapidly under canopy openings. The smaller slow-growing *T. taxifolia* would be easily dominated by these rapidly growing species.

7.3.3 Woodruff Dam

The Apalachicola River once flowed unobstructed through Georgia into the Florida panhandle south to the Gulf of Mexico. The Jim Woodruff Lock and Dam River and Harbor Acts were passed in 1946. The passing of this legislation started the Lake Seminole project and the construction of Jim Woodruff Dam in 1946, which was completed in 1957 (Figure 7.3).

Locals in northern Florida believe that the construction of this dam and Lake Seminole are to blame for the widespread mortality of *T. taxifolia* (Toops, 1980). They believe that the free-flowing river cooled the ravines and produced fog that the forest depended on to thrive. The impounding of Lake Seminole allowed heating of the water of the river before it flowed into the ravines of northern Florida. This heating could have resulted in increased ambient temperatures within the ravines. An increase in air and water temperatures would raise dew point temperatures, and therefore hinder the formation of radiation fog above the river. The absence of consistent fog would reduce available moisture for the *Torreya,* possibly resulting in water stress. Schwartz *et al.*

Figure 7.3 Woodruff Dam and Lake Seminole.

(1995) determined that long-term water stress reduces rates of photosynthesis in *T. taxifolia.* The timing of the construction of Woodruff Dam makes this scenario possible. If the flow of the Apalachicola River were constricted in the late 1940s, water temperature would steadily increase, possibly reducing fog in the ravines through the early to mid-1950s. The effects of this heating would appear downstream in the areas of Torreya State Park and the ABRP during the mid-1950s through the early 1960s. Biologists noticed high mortality among the *Torreya* populations in the state park beginning in the mid-1950s.

I found some instances of suppressed growth in the *Torreya* series during this period which might substantiate this hypothesis. However, several other factors, including a major drought, could be responsible for reduced growth during this period. The pines at the Woodruff Dam sample site maintained the same growth patterns as those at the other sample sites located further downstream. With the exception of dips in growth that occurred in 1945, 1950, and 1955, growth in the pines at this site remained above average during and just after the dam was constructed. A subtle increase in water temperature may reduce fog just above the surface of the river, however the effects of this reduction in fog would be minimal for the forests on the bluffs above. Warmer water temperatures may actually increase fog levels during periods of cooler air temperatures when the warm, moisture-laden air above the river cools to dew point temperature.

Based on my observations, the construction of Woodruff Dam was not a major factor contributing to the decline of *T. taxifolia* along the banks of the Apalachicola River. Several large-scale changes in the landscape coincided with unfavorable climate conditions during the mid-1950s decreasing photosynthesis rates and weakening *Torreya taxifolia*. The initiation of clear-cutting practices during the early 20th century increased erosion, while fire suppression allowed the establishment of understory hardwoods and invasive species in the upland pine systems. These species became established along the margins of the ravine forests that consisted of large, restricted populations of *T. taxifolia*. These species eventually invaded the hammock forests increasing competition for available moisture. The drought and warm period that occurred during the mid-1950s combined with the increased moisture competition from the invading species caused a reduction in rates of photosynthesis, strongly weakening the *Torreya*. Terminal infection by the stem and needle blight quickly followed. The effects of continuous clear-cutting and the slow growth habits of *T. taxifolia* are hindering the recovery of this species.

7.4 Conservation and Restoration

Conservationists have struggled to save and restore *T. taxifolia* in its natural range since the initial decline. Boy scouts planted *T. taxifolia* seedlings near the Gregory House in Torreya State Park during the 1970s. Botanical gardens throughout the eastern U.S. are propagating genetically diverse sets of seedlings and root cuttings for possible reintroduction into the natural range. Bailo *et al.* (1998) collected cuttings from *Torreya* growing in their native range. The genotype and time of collection were documented for each cutting. These cuttings were rooted at the Botanic Gardens of Smith College in Massachusetts. Several of these rooted cuttings were sent to the Atlanta Botanical Gardens where they were carefully grown for six years. The Atlanta Botanical Gardens and the Georgia Plant Conservation Alliance planted 19 of these trees on Department of Natural Resources land in north Georgia. Another 10 seedlings were planted along a nature trail at Callaway Gardens in Georgia. The goal of these plantings is to create healthy, sexually reproducing populations of *T. taxifolia* to further increase genetic variability. Several of the plantings have since produced fruit and seeds.

It is estimated that up to 99.9% of the native *T. taxifolia* population is gone (Bailo *et al.*, 1998). It would take approximately 500 sexually reproducing individuals to restore the population that was present before the decline. Bailo *et al.* (1998) determined that the most cost-effective and least environmentally-degrading mode of planting would be to use seeds that have been through an after-ripening process and are near germination.

Because of large-scale habitat alterations that have occurred since the mid-20th century, it is unlikely that a population of pre-decline stature could be re-established within the natural range of *T. taxifolia*. A successful large-scale reintroduction would require large-scale habitat restorations where possible. The ravines in the ABRP would be good candidates based on restoration efforts of the longleaf pine forests above the bluffs and the availability of constant protection and monitoring. Several areas located deep within Torreya State Park would be good candidates as well because a number of individuals exceeding three meters are currently growing there and constant protection and monitoring are possible. Planting sites should be as far from pine plantations as possible where conditions within the habitat are more consistent. Open areas under the canopy would reduce light competition and increase initial growth in the plantings. Planting the seeds or seedlings in large open areas within the hammocks would also decrease moisture competition and possibly reduce exposure to insects and/or pathogens in the area.

Climate conditions would need to be closely monitored before planting as well. Successful germination would be impossible during periods of drought. Periods of cool temperatures and abundant moisture would be the best scenario for initial growth of the planted seeds and/or seedlings. High January–March precipitation levels may indicate a favorable time for planting because available soil moisture would be abundant.

Chapter 8

Conclusions

Torreya taxifolia has persisted in the bluffs and ravines along a 60 km stretch of the east bank of the Apalachicola River in southern Georgia and northern Florida since the last ice age. Large populations of *Torreya* once flourished in the moist hammock forests until the mid-to-late 1950s. A stem and needle blight resulted in widespread mortality and a virtual halt in sexual reproduction throughout the natural range of *Torreya taxifolia.* Changes in the habitat and unfavorable climate conditions have weakened the *Torreya,* resulting in terminal infection by the blight.

While Schwartz and Hermann (1993, 1999, 2000) have conducted extensive research concerning the ecology of *T. taxifolia* and related species, my study focused on the effects of changes in the local climate and habitat on the growth of *T. taxifolia* and associated pines. The focus of this study was to construct tree-ring chronologies for pines and *Torreya* representing different areas within the natural range of *T. taxifolia*. The construction of a tree-ring chronology for this area makes possible the examination of temporal and spatial patterns of tree growth throughout the range of *T. taxifolia*. Climate analyses using these chronologies were an important step in determining which variable(s) have the strongest influence on tree growth in this area. The chronologies were also examined to determine if alterations within and around the habitat have affected the growth of *T. taxifolia* and associated pines. The results of this study may help determine optimal growth conditions for *T. taxifolia* for use in re-introduction and conservation programs.

8.1 Major Conclusions

1. Numerous remnants of fallen* T. taxifolia *persist on the floor of the hammock forests in the natural habitat.

The wood of *T. taxifolia* is very resistant to decay. Despite the warm, humid climate of this area, large remnants of *Torreya* remain on the forest floor. During this study, 25 remnant logs were sampled in Torreya State Park and ABRP. Many more remnant logs are scattered throughout southern Georgia and northern Florida. These remnants may not only extend the existing chronology back in time, but may also hold valuable information about past habitat conditions. More of these logs and snags must be sampled or salvaged before they are lost to fire or decay. A wide-scale effort to recover of remnant wood would benefit future research and conservation projects.

2. Tree-ring chronologies can be constructed in subtropical Florida using shortleaf and longleaf pines.

Pines are abundant in the southeast coastal plain making them useful for building chronologies and crossdating rare species for which large numbers of samples cannot be attained. Despite the subtropical climate of this area, signature patterns of wide and narrow rings were present in samples taken from all three sites. The site chronologies crossdated well, and produced a master pine chronology that represents tree growth for the entire range of *T. taxifolia*. In addition to the abundance of living pines, large numbers of pine remnants were available for sampling as well. The rings from these remnants would extend the chronology back in time allowing insights into climate and habitat conditions of the 18th and early 19th centuries.

3. The tree rings from cross sections of* T. taxifolia *can be crossdated successfully and anchored absolutely in time using the chronologies constructed from the shortleaf and longleaf pines.

The combined pine series worked very well as a reference chronology for cross dating the tree rings from the *T. taxifolia* cross sections. The same signature patterns of wide and narrow rings were present in samples from both genera. The fact that samples from these species crossdate well with each other indicates similar responses to climate and disturbance. Although a reference chronology was necessary for anchoring this series in time, the *Torreya* chronology was able to stand alone as an independent chronology after year dates were established. The *T. taxifolia* chronology was useful for analyzing the growth response of this species over time with changes in habitat and local climate.

4. Trees that grow in and around the habitat of* T. taxifolia *exhibit a strong response to variations in spring precipitation, spring temperature, and summer drought.

Despite the humid, subtropical climate of this area, I found significant correlations between tree growth and precipitation, PHDI, and temperature. The responses varied between sites and tree species. The growth rates of pines and *Torreya* respond very strongly to spring precipitation and summer drought despite the humid subtropical climate of northern Florida. The strong response to these variables is due, in part, to the well-drained, sandy soils and the steep slopes of this habitat. Consistent spring and summer precipitation is a strong determining factor for growth because of the necessity of available moisture for initiating growth during the early growing season and for maintaining growth during the hot summer season. A significant drought occurred during the mid-1950s that strongly affected the growth of *T. taxifolia* and the associate pines. This drought likely played a significant role in the demise of *T. taxifolia*, which have difficulty recovering from long-term water stress.

5. The growth of* T. taxifolia *is not affected by climate as strongly as that of the pines.

Although the *T. taxifolia* samples were collected in Torreya State Park and ABRP, the correlation coefficients between growth and the climate variables were not as high as those of the pine samples collected from the same sites. This could be explained by the protective understory habitat of *T. taxifolia.* The shady conditions keep temperatures and evaporation of available moisture low. The proximity of these trees to the Apalachicola River and perennial streams may also have a mediating effect on climate response. The slow growth of *T. taxifolia* also reduces the effect of climate on yearly growth when compared to the more rapidly growing pines.

***6. Climate factors alone did not cause the widespread infection and mortality of* T. taxifolia.**

The growth of *T. taxifolia* does respond to changes in local climate, however the response was not as strong as that of the associate pines. Whether the diminished response is the result of the sheltered understory of the hammock forests or the proximity of these trees to the Apalachicola River, it is indicative that unfavorable climate was not the determining factor in the mortality of *T. taxifolia.* While the severe drought in the mid-1950s did contribute to a reduction in growth, there were recoveries in growth after other major drought events that occurred during the early 20th century. It is possible that more *T. taxifolia* could have recovered after the 1955 drought if other habitat conditions were more favorable. Widespread habitat alterations such as clear-cutting of local forests compounded the effects of the 1955 drought making the trees susceptible to terminal infection by the stem and needle blight.

7. The construction of Jim Woodruff Dam and the impounding of Lake Seminole is not a strong factor in the demise of **T. taxifolia.**

While widespread habitat disturbance may be the strongest factor in the mortality of *T. taxifolia*, the construction of Woodruff Dam and Lake Seminole did not seem to play a large role. Locals living near the dam believed that the water flowing into the Apalachicola River from Lake Seminole would be warmer than before the impoundment, reducing fog within the ravines. Although slight increases in water temperature may reduce fog levels just above the surface of the water at times, it is unlikely to affect the forest growing on the bluffs above the river. In some instances warmer water may actually increase fog production if there is a cool air mass above the water surface. No reduction in growth occurred in the *Torreya* or associate pines during or immediately following the construction of the dam that could not be explained by other phenomena such as the major drought of 1955.

8. A combination of habitat degradation and unfavorable climate conditions has contributed to the demise of **T. taxifolia** *in its natural range.*

Large-scale clear-cutting operations, the construction of Woodruff Dam, and fire suppression occurred simultaneously with the severe drought during the 1950s. The timing of these events makes it difficult to determine which had the greatest effect on growth of *T. taxifolia* and associate pines in the natural range of *T. taxifolia.* All of these factors contributed to decreased growth and the degrading health of this species.

Widespread human modification of the landscape started with intensive clear-cutting of the upland pine forest during the early 20th century. The resulting increases in insolation and erosion negatively affected the vegetation growing on the steep slopes of the hammock forests below the pines. Fire suppression not only endangered the upland longleaf pine forests, but possibly allowed the encroachment of understory hardwoods and invasive species into the hammock forests below. This invasion increased resource competition for the hammock species. The warming of the Apalachicola waters by Woodruff Dam possibly raised ambient temperatures in the ravines above the river. The drought and simultaneous warm period that occurred in the mid-1950s stressed the *Torreya* allowing the fungi that lived in the bark of these trees to spread and terminally infect this species. While the local climate of this area has become more favorable since the mid-1950s, it is unknown whether the slow-growing *Torreya* could ever recover as long as the habitat continues to be altered.

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Appendix

A-1. Woodruff Dam COFECHA output.

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 PART 5:  CORRELATION OF SERIES BY SEGMENTS:                                                  10:53  Fri 26 SEP 2003
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-------------------------------------------------------------------------------------------------------------------
-----
 Correlations of  40-year dated segments, lagged  20 years
 Flags:  A = correlation under   .3665 but highest as dated;  B = correlation higher at other than dated position

 Seq Series  Time_span   1860 1880 1900 1920 1940 1960 1980
                         1899 1919 1939 1959 1979 1999 2019
   1 jwd001a  1870 2001   .36A .40  .51  .42  .36A .37  .43
   2 jwd002a  1874 2001   .51  .50  .30A .28B .34B .37  .47
   3 jwd003a  1870 2001   .50  .45  .45  .50  .37  .33A .38
   4 jwd003b  1872 2001   .44  .47  .58  .53  .52  .42  .43
   5 jwd004a  1870 2001   .42  .47  .63  .64  .47  .36A .44
   6 jwd005a  1927 2001                  .45  .65  .62  .62
   7 jwd006a  1887 2001        .51  .52  .40  .51  .70  .72
   8 jwd007a  1869 2001   .59  .61  .61  .57  .70  .77  .77
   9 jwd008a  1871 2001   .66  .71  .69  .59  .42  .39  .37
  10 jwd008b  1871 1935   .70  .66  .75
  11 jwd009a  1885 1959        .67  .70  .34A
  12 jwd010a  1906 2001             .54  .66  .69  .66  .69
  13 jwd010b  1920 2001                  .46  .78  .73  .76
  14 jwd011a  1924 2001                  .67  .42  .36A .37
  15 jwd011b  1925 2001                  .41  .65  .53  .51
  16 jwd012a  1940 2001                       .39  .46  .56
  17 JWD013A  1874 2001   .68  .68  .69  .63  .55  .38  .42
  18 jwd013b  1875 2001   .48  .45  .61  .74  .56  .34A .40
  19 JWD014A  1874 2001   .44  .34B .58  .68  .74  .76  .78
  20 jwd015a  1900 1999             .58  .65  .64  .55
  21 jwd016a  1876 2001   .56  .53  .27A .16B .54  .76  .79
  22 jwd017a  1904 2001             .45  .55  .65  .48  .59
  23 jwd018a  1872 2001   .65  .59  .75  .62  .54  .63  .67
  24 jwd018b  1872 1996   .52  .45  .61  .73  .70  .59
  25 jwd019a  1880 1948        .69  .54  .41
  26 jwd019b  1903 2001             .53  .43  .38B .36A .39
  27 jwd020a  1873 2001   .55  .50  .69  .79  .84  .85  .79
  28 jwd020b  1873 2001   .77  .70  .74  .76  .75  .75  .74
  29 jwd021a  1883 2001        .54  .55  .51  .38  .38  .41
  30 jwd023a  1874 1997   .65  .59  .68  .83  .73  .46
  31 jwd023b  1874 1999   .73  .77  .73  .76  .69  .42
  32 jwd024a  1871 2001   .72  .68  .57  .64  .69  .56  .62
  33 jwd024b  1871 1927   .67  .55  .47
  34 jwd025a  1871 2001   .77  .71  .65  .66  .65  .59  .67
```

```
35 jwd026a  1882 1980        .64  .60  .74  .36A .36A
36 jwd028a  1907 2001             .45  .53  .63  .62  .64
37 JWD029A  1872 2001   .61  .65  .75  .78  .72  .56  .60
38 JWD029B  1872 1987   .64  .74  .67  .66  .60  .44
39 jwd030a  1925 1993                  .42  .47  .43
40 jwd030b  1880 2001        .56  .43  .39  .39  .47  .55
```

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 PART 6:  POTENTIAL PROBLEMS:                                                      10:53  Fri 26 SEP 2003  Page
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-----

 For each series with potential problems the following diagnostics may appear:

 [A] Correlations with master dating series of flagged  40-year segments of series filtered with  32-year spline,
     at every point from ten years earlier (-10) to ten years later (+10) than dated

 [B] Effect of those data values which most lower or raise correlation with master series

 [C] Year-to-year changes very different from the mean change in other series

 [D] Absent rings (zero values)

 [E] Values which are statistical outliers from mean for the year

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 jwd001a   1870 to  2001     132 years
Series   1

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1  +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
   ---------   ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  --- ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
   1870 1909    0      -    -    -    -    -    -    -    -    -  .26 .36* .21  .21 -.10 -.16  .09 -.12 -.41  .02  .08 -.04
   - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
   1940 1979    0   -.03  .04  .11 -.21 -.04 -.23 -.15  .04 -.05  .02 .36*-.18  .10  .11  .06  .04  .04  .20 -.13 -.01  .16

 [B] Entire series, effect on correlation (  .433) is:
       Lower   1964  -.029   1996  -.022   1906  -.019   1954  -.013  Higher   2000   .018   1876   .018   1968   .016   1949
.014
     1870 to 1909 segment:
       Lower   1906  -.052   1884  -.041   1871  -.032   1897  -.028  Higher   1876   .089   1875   .028   1888  .028   1899
.023
     1940 to 1979 segment:
       Lower   1964  -.102   1969  -.040   1954  -.040   1950  -.038  Higher   1968   .070   1949   .051   1975   .026   1953
.026

 [D]    1 Absent rings:  Year   Master  N series Absent
                         1932   -.632     38        1
```

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 jwd002a   1874 to  2001     128 years
Series   2

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
   ---------   ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
   1900 1939     0    .11 -.10 -.23  .14 -.33  .09  .11  .11  .02  .22  .30*-.09 -.21  .03 -.24 -.12  .22 -.15  .06  .20 -.07
   1920 1959    -7    .11 -.17  .07  .29* .05  .02 -.04 -.02  .12  .01  .28|-.20 -.39  .04 -.25 -.34  .09 -.12 -.03  .15  .10
   1940 1979    -6    .09  .07 -.03  .00  .39* .07  .03  .03  .14  .01  .34|-.10 -.30 -.16 -.09 -.37 -.34  .17  .14 -.03  .08

 [B] Entire series, effect on correlation (  .423) is:
       Lower   1911  -.031   1991  -.019   1922  -.010   1935  -.010  Higher   1899   .036   2000   .021   1994   .017   1876
.015
     1900 to 1939 segment:
       Lower   1911  -.100   1922  -.033   1939  -.021   1935  -.020  Higher   1934   .058   1914   .043   1900   .027   1907
.025
     1920 to 1959 segment:
       Lower   1935  -.034   1939  -.029   1922  -.027   1956  -.025  Higher   1934   .046   1955   .029   1946   .026   1954
.024
     1940 to 1979 segment:
       Lower   1944  -.036   1956  -.031   1943  -.030   1960  -.025  Higher   1968   .046   1971   .035   1963   .034   1946
.030

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
       1911 +3.3 SD

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 jwd003a   1870 to  2001     132 years
Series   3

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
   ---------   ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
   1960 1999     0   -.18 -.04 -.12 -.22  .18 -.12 -.23  .20  .25 -.06  .33* .15  .13    -    -    -    -    -    -    -    -

 [B] Entire series, effect on correlation (  .456) is:
       Lower   1970  -.018   1982  -.011   1988  -.009   1902  -.009  Higher   1946   .011   1899   .011   1881   .011   1975
.010
     1960 to 1999 segment:
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```
       Lower   1970  -.067   1982  -.039   1988  -.033   1976  -.025  Higher   1968   .049   1975   .049   1994   .038   1985
.031

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 jwd003b   1872 to  2001     130 years
Series   4

 [B] Entire series, effect on correlation (  .466) is:
       Lower   1886  -.025   1949  -.023   1881  -.017   1982  -.014  Higher   1899   .038   1968   .026   1927   .013   1975
.010

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
       1949 +3.0 SD

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 jwd004a   1870 to  2001     132 years
Series   5

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
    ---------  ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
    1960 1999     0  -.02  .05 -.30  .19  .05 -.05  .28  .01  .03  .01  .36*-.08 -.20    -    -    -    -    -    -    -    -

 [B] Entire series, effect on correlation (  .484) is:
       Lower   1997  -.023   1975  -.017   1870  -.015   1926  -.015  Higher   1968   .018   2000   .017   1906   .016   1914
.012
     1960 to 1999 segment:
       Lower   1997  -.084   1975  -.066   1976  -.048   1995  -.035  Higher   1968   .113   1963   .035   1971   .032   1991
.029

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
       1881 -5.1 SD

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 jwd005a   1927 to  2001      75 years
Series   6
```

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 [B] Entire series, effect on correlation (  .554) is:
      Lower   1927  -.050   1983  -.015   1940  -.012   1956  -.011  Higher   1968   .048   1954   .028   1946   .017   1975
.016

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 jwd006a   1887 to  2001     115 years
Series   7

 [B] Entire series, effect on correlation (  .559) is:
      Lower   1947  -.023   1934  -.019   1955  -.017   1957  -.014  Higher   1968   .044   1906   .019   1954   .013   2000
.012

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 jwd007a   1869 to  2001     133 years
Series   8

 [*] Early part of series cannot be checked from 1869 to 1869 -- not matched by another series

 [B] Entire series, effect on correlation (  .637) is:
      Lower   1883  -.018   1949  -.015   1875  -.011   1880  -.011  Higher   1968   .031   1906   .014   1954   .012   1886
.009

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 jwd008a   1871 to  2001     131 years
Series   9

 [B] Entire series, effect on correlation (  .555) is:
      Lower   1968  -.017   1967  -.014   2001  -.012   1972  -.010  Higher   1927   .011   1906   .011   1911   .010   1928
.010

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 jwd008b   1871 to  1935      65 years
Series  10

 [B] Entire series, effect on correlation (  .713) is:
      Lower   1918  -.016   1907  -.016   1887  -.014   1880  -.013  Higher   1899   .032   1906   .028   1928   .012   1927
.011

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 jwd009a   1885 to  1959      75 years
Series  11

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
   ---------  ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
   1920 1959    0    .19 -.29 -.11 -.10 -.02  .18 -.02  .04 -.03  .00  .34* .32 -.04 -.06 -.24 -.09  .15  .14 -.10 -.23 -.23

 [B] Entire series, effect on correlation (  .521) is:
      Lower   1941  -.031   1953  -.030   1948  -.020   1928  -.017  Higher   1886   .025   1906   .024   1911   .021   1914
.020
    1920 to 1959 segment:
      Lower   1953  -.055   1941  -.050   1928  -.029   1948  -.029  Higher   1927   .050   1954   .049   1939   .035   1923
.030

 [E] Outliers      1   3.0 SD above or -4.5 SD below mean for year
      1941 +3.2 SD

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 jwd010a   1906 to  2001      96 years
Series  12

 [B] Entire series, effect on correlation (  .627) is:
      Lower   1912  -.026   1916  -.013   1928  -.011   1986  -.009  Higher   1968   .012   2000   .012   1939   .012   1949
.010

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```
 jwd010b   1920 to  2001      82 years
Series  13

 [B] Entire series, effect on correlation (  .612) is:
     Lower   1926  -.041   1982  -.020   1949  -.014   1928  -.014  Higher   1968   .058   2000   .027   1954   .022   1994
.013

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 jwd011a   1924 to  2001      78 years
Series  14

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
 ---------   ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
   1960 1999    0    .27  .27 -.08 -.21 -.07 -.05  .00  .32 -.11 -.05  .36*-.23 -.09    -    -    -    -    -    -    -    -

 [B] Entire series, effect on correlation (  .521) is:
     Lower   1964  -.090   1968  -.032   1955  -.023   1991  -.012  Higher   1994   .022   1928   .017   1949   .015   1953
.015
    1960 to 1999 segment:
     Lower   1964  -.154   1968  -.061   1991  -.019   1983  -.019  Higher   1994   .061   1971   .030   1975   .030   1990
.025

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 jwd011b   1925 to  2001      77 years
Series  15

 [B] Entire series, effect on correlation (  .456) is:
     Lower   1928  -.055   1927  -.022   1932  -.013   1925  -.013  Higher   1949   .018   1968   .017   1994   .015   1950
.013

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 jwd012a   1940 to  2001      62 years
Series  16
```

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 [B] Entire series, effect on correlation (  .451) is:
      Lower    1942  -.044    1998  -.037    1943  -.036    1948  -.016  Higher    2000    .056   1968    .030   1994    .025   1991
.017

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 JWD013A   1874 to  2001     128 years
Series  17

 [B] Entire series, effect on correlation (  .576) is:
      Lower    1938  -.029    1966  -.016    1993  -.015    1881  -.011  Higher    1906    .016   1876    .012   1911    .011   1949
.010

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 jwd013b   1875 to  2001     127 years
Series  18

 [A] Segment    High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
     ---------  ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
    1960 1999     0    .05 -.09  .03 -.32 -.13  .18 -.13  .26  .13 -.15  .34* .24 -.08    -    -    -    -    -    -    -    -

 [B] Entire series, effect on correlation (  .538) is:
      Lower    1968  -.037    1909  -.019    1911  -.014    1899  -.010  Higher    1906    .016   1876    .014   1886    .012   1914
.011
     1960 to 1999 segment:
      Lower    1968  -.122    1982  -.037    1993  -.034    1977  -.027  Higher    1971    .074   1975    .042   1976    .041   1970
.023

 [D]     1 Absent rings:  Year    Master   N series Absent
                          1949    -1.502      37        1

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 JWD014A   1874 to  2001     128 years
Series  19
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 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
   ---------   ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
   1880 1919    6     .20  .22  .01 -.23 -.08 -.03  .12 -.08 -.24 -.32  .34|-.10 -.26  .21  .06 -.06  .41* .08 -.20  .09 -.02

 [B] Entire series, effect on correlation (  .602) is:
     Lower    1899  -.036   1945  -.019   1886  -.017   1930  -.015  Higher   1968   .041   1906   .018   1954   .014   1939
.011
    1880 to 1919 segment:
     Lower    1899  -.094   1886  -.047   1897  -.031   1914  -.030  Higher   1906   .117   1912   .041   1884   .027   1885
.026

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
     1899 +3.1 SD

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 jwd015a   1900 to  1999     100 years
Series  20

 [B] Entire series, effect on correlation (  .556) is:
     Lower    1983  -.037   1907  -.012   1921  -.011   1919  -.010  Higher   1968   .044   1939   .017   1911   .015   1922
.012


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 jwd016a   1876 to  2001     126 years
Series  21

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
   ---------   ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
   1900 1939    0    -.20  .16  .06 -.28  .17  .16  .03  .11 -.15  .08  .27*-.36 -.10  .03 -.41  .07  .01 -.21  .07 -.06  .12
   1920 1959   -8    -.18 -.01  .19*-.17  .03 -.02 -.09  .01  .06  .15  .16|-.11 -.14  .02 -.20  .11 -.09 -.09  .06 -.11  .13

 [B] Entire series, effect on correlation (  .497) is:
     Lower    1939  -.024   1942  -.021   1935  -.021   1943  -.016  Higher   1968   .030   1899   .023   2000   .019   1906
.015
    1900 to 1939 segment:
```

```
      Lower    1939  -.064   1935  -.049   1936  -.038   1925  -.024  Higher   1906   .084   1922   .059   1928   .045   1907
.025
    1920 to 1959 segment:
      Lower    1939  -.063   1942  -.057   1935  -.050   1936  -.041  Higher   1922   .059   1928   .053   1954   .052   1953
.048

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 jwd017a   1904 to  2001      98 years
Series  22

 [B] Entire series, effect on correlation (  .549) is:
      Lower    1968  -.026   1990  -.023   1928  -.021   1989  -.014  Higher   2000   .042   1912   .013   1975   .012   1942
.012

 [D]    1 Absent rings:  Year   Master  N series Absent
                         1933   -1.166     38       1

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 jwd018a   1872 to  2001     130 years
Series  23

 [B] Entire series, effect on correlation (  .639) is:
      Lower    1896  -.022   1978  -.017   1955  -.017   1954  -.014  Higher   1906   .014   2000   .014   1876   .008   1928
.007

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 jwd018b   1872 to  1996     125 years
Series  24

 [B] Entire series, effect on correlation (  .590) is:
      Lower    1899  -.037   1891  -.015   1912  -.014   1978  -.010  Higher   1886   .019   1968   .016   1906   .014   1954
.013
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 jwd019a   1880 to  1948      69 years
Series  25

 [B] Entire series, effect on correlation (  .517) is:
     Lower   1939  -.032   1935  -.026   1945  -.017   1943  -.017  Higher   1899   .036   1906   .035   1914   .024   1922
.019

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 jwd019b   1903 to  2001      99 years
Series  26

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
   ---------   ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
   1940 1979    -3   -.07  .13 -.15 -.07  .19  .19  .02  .47* .05 -.13  .38|-.09 -.41  .10 -.17 -.11  .02 -.27 -.08 -.05 -.08
   1960 1999     0    .10 -.07 -.14 -.19 -.08  .24  .04  .34  .14 -.29  .36* .08 -.16    -    -    -    -    -    -    -    -

 [B] Entire series, effect on correlation (  .433) is:
     Lower   1985  -.018   1943  -.017   1957  -.017   1952  -.017  Higher   1954   .024   1927   .022   1914   .021   1971
.018
    1940 to 1979 segment:
     Lower   1957  -.044   1952  -.044   1973  -.040   1943  -.035  Higher   1954   .065   1971   .050   1942   .023   1949
.022
    1960 to 1999 segment:
     Lower   1985  -.044   1973  -.040   1979  -.034   1997  -.022  Higher   1971   .079   1994   .030   1996   .026   1991
.024

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 jwd020a   1873 to  2001     129 years
Series  27

 [B] Entire series, effect on correlation (  .705) is:
     Lower   1881  -.018   1923  -.017   1901  -.013   2001  -.011  Higher   1968   .029   1906   .009   1954   .009   1939
.007
```

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 jwd020b   1873 to  2001     129 years
Series  28

 [B] Entire series, effect on correlation (  .734) is:
       Lower    1987  -.012   1899  -.011   1913  -.010   1958  -.010  Higher   1968   .024   1886   .013   1906   .010   1994
.006

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 jwd021a   1883 to  2001     119 years
Series  29

 [B] Entire series, effect on correlation (  .484) is:
       Lower    1991  -.014   1930  -.013   1954  -.011   1983  -.011  Higher   1886   .023   1927   .014   1994   .013   1939
.013

 [D]    1 Absent rings:  Year   Master  N series Absent
                         1914   -1.238      34       1

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 jwd023a   1874 to  1997     124 years
Series  30

 [B] Entire series, effect on correlation (  .633) is:
       Lower    1993  -.019   1914  -.016   1884  -.012   1971  -.012  Higher   1968   .034   1899   .014   1954   .012   1927
.010

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 jwd023b   1874 to  1999     126 years
Series  31
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 [B] Entire series, effect on correlation (  .649) is:
      Lower   1993  -.019   1921  -.013   1874  -.013   1890  -.011  Higher   1899   .024   1968   .022   1886   .011   1939
.009

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 jwd024a   1871 to  2001     131 years
Series   32

 [B] Entire series, effect on correlation (  .644) is:
      Lower   1925  -.016   1965  -.012   1885  -.009   1966  -.009  Higher   1899   .015   2000   .014   1886   .013   1968
.010

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 jwd024b   1871 to  1927      57 years
Series   33

 [B] Entire series, effect on correlation (  .538) is:
      Lower   1927  -.063   1888  -.022   1917  -.021   1918  -.021  Higher   1899   .074   1886   .046   1906   .036   1871
.018

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 jwd025a   1871 to  2001     131 years
Series   34

 [B] Entire series, effect on correlation (  .672) is:
      Lower   1977  -.027   1928  -.011   1914  -.010   1882  -.010  Higher   1968   .032   2000   .019   1886   .009   1906
.008

 [D]    1 Absent rings:  Year   Master  N series Absent
                         1911   -1.552      34       1
```

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================================================================================================================================
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 jwd026a   1882 to  1980      99 years
Series  35

 [A] Segment    High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
    ---------   ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
    1940 1979     0    .02  .07 -.17  .10  .11 -.16  .09  .05 -.16  .15  .36* .02 -.06 -.05  .15 -.18  .17 -.08 -.21 -.18  .11
    1941 1980     0    .05  .04 -.15  .12  .11 -.13  .06  .04 -.15  .13  .36* .03 -.05 -.05  .15 -.20  .16 -.09 -.22 -.18  .09

 [B] Entire series, effect on correlation (  .515) is:
      Lower   1975  -.031   1968  -.028   1916  -.027   1977  -.025  Higher   1906   .020   1899   .018   1912   .013   1886
.012
     1940 to 1979 segment:
      Lower   1975  -.067   1968  -.058   1977  -.046   1970  -.046  Higher   1954   .030   1953   .028   1955   .027   1946
.026
     1941 to 1980 segment:
      Lower   1975  -.067   1968  -.057   1970  -.046   1977  -.045  Higher   1954   .031   1953   .028   1955   .028   1946
.026

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 jwd028a   1907 to  2001      95 years
Series  36

 [B] Entire series, effect on correlation (  .562) is:
      Lower   1992  -.029   1973  -.025   1945  -.020   1914  -.017  Higher   1968   .071   2000   .016   1953   .011   1994
.009

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JWD029A   1872 to  2001     130 years
Series  37

 [B] Entire series, effect on correlation (  .672) is:
      Lower   1954  -.015   1983  -.014   1903  -.011   1972  -.010  Higher   1968   .023   1906   .011   1939   .009   1927
.009
```

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==============================================================================================================================
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 JWD029B   1872 to  1987     116 years
Series  38

 [B] Entire series, effect on correlation (  .594) is:
      Lower   1961  -.020   1985  -.018   1911  -.018   1932  -.011  Higher   1968   .032   1899   .024   1886   .015   1906
.014

==============================================================================================================================
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 jwd030a   1925 to  1993      69 years
Series  39

 [B] Entire series, effect on correlation (  .432) is:
      Lower   1929  -.037   1932  -.031   1974  -.019   1962  -.015  Higher   1927   .034   1953   .023   1939   .022   1943
.022

==============================================================================================================================
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 jwd030b   1880 to  2001     122 years
Series  40

 [B] Entire series, effect on correlation (  .497) is:
      Lower   1950  -.024   1949  -.016   1906  -.013   1996  -.012  Higher   1899   .022   2000   .022   1886   .022   1939
.016

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PART 7:  DESCRIPTIVE STATISTICS:                                                                10:53  Fri 26 SEP 2003  Page
8
                                                        Corr   //-------- Unfiltered --------\\  //---- Filtered -----\\
                               No.     No.     No.     with   Mean    Max     Std    Auto   Mean    Max     Std   Auto   AR
Seq Series   Interval        Years   Segmt   Flags   Master   msmt    msmt    dev    corr   sens   value    dev   corr   ()
  1 jwd001a  1870 2001        132       7       2      .433   1.19    5.46    .883   .840   .318   1.97   .348   .018   1
  2 jwd002a  1874 2001        128       7       3      .423    .81    4.65    .825   .845   .312   2.10   .388   .022   1
  3 jwd003a  1870 2001        132       7       1      .456    .92    7.83   1.210   .937   .324   2.05   .320   .004   1
  4 jwd003b  1872 2001        130       7       0      .466   1.15    5.03    .906   .842   .326   2.06   .325  -.010   1
  5 jwd004a  1870 2001        132       7       1      .484   1.68   16.64   2.921   .960   .265   1.96   .306  -.044   1
  6 jwd005a  1927 2001         75       4       0      .554   1.09    2.27    .464   .617   .285   2.23   .455  -.011   1
  7 jwd006a  1887 2001        115       6       0      .559   1.12    2.88    .586   .699   .311   2.12   .413  -.029   1
  8 jwd007a  1869 2001        133       7       0      .637   2.27   19.50   2.952   .859   .309   2.02   .307   .000   1
  9 jwd008a  1871 2001        131       7       0      .555   1.25   15.15   1.601   .870   .268   2.24   .422  -.021   1
 10 jwd008b  1871 1935         65       3       0      .713   2.33   17.79   2.638   .884   .286   2.32   .422  -.066   1
 11 jwd009a  1885 1959         75       3       1      .521    .69    2.57    .431   .749   .276   2.20   .474   .057   1
 12 jwd010a  1906 2001         96       5       0      .627   2.11    4.90    .801   .695   .226   2.03   .429  -.023   1
 13 jwd010b  1920 2001         82       4       0      .612   2.28    4.40    .737   .667   .226   2.00   .398   .016   1
 14 jwd011a  1924 2001         78       4       1      .521   2.08    3.96    .751   .530   .267   2.02   .382   .053   1
 15 jwd011b  1925 2001         77       4       0      .456   2.04    4.76    .785   .657   .265   1.98   .379  -.029   1
 16 jwd012a  1940 2001         62       3       0      .451   1.13    2.30    .545   .774   .288   2.04   .508  -.056   1
 17 JWD013A  1874 2001        128       7       0      .576   1.06    6.02   1.082   .886   .341   2.35   .430   .051   1
 18 jwd013b  1875 2001        127       7       1      .538    .97    4.26    .712   .842   .307   2.02   .378   .014   1
 19 JWD014A  1874 2001        128       7       1      .602   2.09   11.38   2.228   .935   .265   2.10   .331   .002   1
 20 jwd015a  1900 1999        100       4       0      .556   1.36    2.48    .458   .624   .246   1.98   .317   .059   1
 21 jwd016a  1876 2001        126       7       2      .497   1.20    3.50    .668   .790   .299   1.97   .350   .064   1
 22 jwd017a  1904 2001         98       5       0      .549    .85    2.84    .521   .815   .334   2.22   .321  -.013   1
 23 jwd018a  1872 2001        130       7       0      .639   1.22    5.89    .820   .827   .295   2.14   .330   .017   1
 24 jwd018b  1872 1996        125       6       0      .590   1.28    5.86    .863   .821   .303   2.31   .412   .050   1
 25 jwd019a  1880 1948         69       3       0      .517    .86    2.93    .405   .556   .278   2.10   .409  -.020   1
 26 jwd019b  1903 2001         99       5       2      .433    .68    2.44    .461   .856   .337   2.02   .378   .055   1
 27 jwd020a  1873 2001        129       7       0      .705   1.03    4.11    .693   .802   .324   1.97   .347  -.017   2
 28 jwd020b  1873 2001        129       7       0      .734   1.35    3.38    .709   .718   .271   2.50   .396   .039   1
 29 jwd021a  1883 2001        119       6       0      .484    .69    3.01    .559   .821   .363   1.95   .269  -.071   1
 30 jwd023a  1874 1997        124       6       0      .633    .92    3.15    .657   .829   .319   1.96   .405   .009   1
 31 jwd023b  1874 1999        126       6       0      .649    .86    2.30    .503   .820   .293   2.01   .357   .026   1
 32 jwd024a  1871 2001        131       7       0      .644    .84    7.71   1.007   .895   .274   2.12   .391  -.001   1
 33 jwd024b  1871 1927         57       3       0      .538   1.18    5.99   1.144   .853   .287   2.14   .335   .015   2
 34 jwd025a  1871 2001        131       7       0      .672   1.10    6.92    .996   .907   .322   2.04   .350  -.017   1
 35 jwd026a  1882 1980         99       5       2      .515   1.38   10.16   1.476   .725   .352   2.01   .394   .031   1
 36 jwd028a  1907 2001         95       5       0      .562   1.41    3.56    .708   .665   .333   1.85   .306   .023   4
 37 JWD029A  1872 2001        130       7       0      .672   1.54    6.70   1.327   .916   .269   2.18   .476   .007   1
 38 JWD029B  1872 1987        116       6       0      .594   1.20    5.81    .838   .850   .312   2.16   .485   .073   1
```

```
 39 jwd030a  1925 1993    69     3     0   .432  1.31  3.60  .731  .806  .290  2.03  .373 -.043  1
 40 jwd030b  1880 2001   122     6     0   .497  1.25  3.43  .834  .858  .272  2.11  .355  .016  3
--- -------- ---------  ----- ----- -----  ------ ----- ----- ----- ----- ----- ----- ----- ----- --
Total or mean:          4350   224    17   .562  1.27 19.50 1.016  .809  .298  2.50  .375  .008
                                              - = [  COFECHA THEDACOF  ] = -
```

A-2. State Park COFECHA output.

```
 PART 5:  CORRELATION OF SERIES BY SEGMENTS:                                                  16:07  Sat 13 MAR 2004
Page   5
------------------------------------------------------------------------------------------------------------------------------
 Correlations of  40-year dated segments, lagged  20 years
 Flags:  A = correlation under   .3665 but highest as dated;  B = correlation higher at other than dated position

 Seq Series  Time_span   1880 1900 1920 1940 1960 1980
                         1919 1939 1959 1979 1999 2019
 --- -------- ---------  ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
   1 wrd001a  1933 1993            .63  .60  .61
   2 wrd001b  1933 1971            .53
   3 wrd002a  1930 2000            .59  .74  .65  .62
   4 wrd002b  1929 2000            .53  .60  .66  .66
   5 wrd005a  1932 2001            .56  .66  .75  .73
   6 wrd006a  1930 2000            .69  .60  .54  .51
   7 wrd006b  1946 2001                 .65  .77  .80
   8 wrd007a  1936 2000            .74  .78  .74  .70
   9 wrd007b  1928 2000            .75  .71  .45  .42
  10 wrd008a  1928 2001            .63  .65  .67  .68
  11 wrd009a  1930 1982            .68  .82  .76
  12 wrd009b  1927 2001            .57  .50  .55  .57
  13 wrd011a  1935 2001            .67  .69  .52  .51
  14 wrd011b  1929 2001            .51  .58  .38  .41
  15 wrd012a  1937 2001            .54  .50  .44  .50
  16 wrd015a  1937 2001            .60  .63  .71  .74
  17 wrd015b  1935 2001            .60  .69  .75  .76
  18 wrd016a  1938 1997            .56  .56  .43
  19 wrd016b  1941 2001                 .59  .51B .52
  20 wrd017b  1943 1993                 .52  .67
  21 wrd018a  1946 1995                 .69  .64
  22 wrd018b  1950 1996                 .75  .76
  23 wrd019a  1956 2001                 .40  .43  .47
  24 wrd020b  1937 2001            .71  .71  .63  .63
  25 wrd021a  1928 2001            .67  .56  .44  .43
  26 wrd021b  1930 2001            .61  .66  .48  .49
  27 wrd024a  1946 2001                 .67  .67  .67
  28 wrd024b  1946 2000                 .68  .51  .48
  29 wrd026a  1915 1990       .68  .69  .70  .74
  30 wrd027b  1913 2001       .30A .53  .62  .61  .59
  31 wrd028a  1927 2001            .66  .74  .63  .65
  32 wrd028b  1930 2001            .70  .71  .66  .67
  33 wrd029a  1928 2001            .69  .64  .60  .62
```

34	wrd029b	1930	2001			.59	.69	.57	.60
35	wrd030a	1929	2001			.65	.67	.69	.71
36	wrd030b	1930	2001			.54	.66	.72	.68
37	wrd033b	1934	2001			.65	.64	.60	.58
38	wrd034b	1923	2001			.63	.67	.62	.62
39	wrd037a	1950	2001				.82	.75	.73
40	wrd037b	1953	2001				.55	.41	.39
41	ght001a	1922	1984			.60	.48	.42	
42	ght002a	1910	2001		.58	.64	.65	.44	.45
43	ght003a	1912	2001		.50	.60	.53	.45	.42
44	ght004b	1906	2001		.49	.57	.49	.30B	.35A
45	ght005a	1900	2001		.53	.75	.79	.62	.65
46	ght006a	1912	2001		.54	.64	.59	.41	.37
47	ght006b	1921	2001			.31B	.51	.63	.61
48	ght007a	1900	2001		.51	.60	.64	.58	.58
49	ght008a	1890	2001	.52	.63	.73	.77	.63	.63
50	ght008b	1900	2001		.51	.71	.70	.48	.48
51	ght009b	1946	2000				.43	.43	.48
52	ght010a	1901	2001		.52	.64	.62	.56	.53
53	ght011a	1945	2001				.34B	.61	.56
54	ght015a	1950	2001				.67	.54	.57
55	ght016a	1901	2001		.70	.73	.57	.53	.52
56	ght016b	1896	2001	.51	.50	.53	.60	.53	.51
57	ght017a	1931	2001			.84	.83	.70	.66
58	ght020a	1923	2001			.74	.78	.71	.70
59	ght020b	1923	1992			.74	.72	.74	

```
 PART 6:  POTENTIAL PROBLEMS:                                                  16:07  Sat 13 MAR 2004  Page
8
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 For each series with potential problems the following diagnostics may appear:

 [A] Correlations with master dating series of flagged  40-year segments of series filtered with  32-year spline,
     at every point from ten years earlier (-10) to ten years later (+10) than dated

 [B] Effect of those data values which most lower or raise correlation with master series

 [C] Year-to-year changes very different from the mean change in other series

 [D] Absent rings (zero values)

 [E] Values which are statistical outliers from mean for the year

==============================================================================================================

 wrd001a   1933 to  1993      61 years
Series   1

 [B] Entire series, effect on correlation (  .569) is:
       Lower   1974  -.045   1947  -.018   1933  -.018   1971  -.015  Higher   1968   .045   1940   .036   1962   .013   1958
.013

==============================================================================================================

 wrd001b   1933 to  1971      39 years
Series   2

 [B] Entire series, effect on correlation (  .534) is:
       Lower   1968  -.080   1967  -.051   1953  -.026   1965  -.018  Higher   1954   .115   1964   .025   1962   .021   1938
.017

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
       1968 +3.3 SD

==============================================================================================================
  wrd002a   1930 to  2000      71 years
Series   3
```

```
 [B] Entire series, effect on correlation (  .537) is:
       Lower    1939  -.040   1934  -.029   1930  -.024   1994  -.021  Higher   1954   .054   1968   .031   1985   .030   1967
.021

================================================================================================================================

 wrd002b   1929 to  2000      72 years
Series   4

 [B] Entire series, effect on correlation (  .518) is:
       Lower    1995  -.022   1939  -.022   1954  -.021   1979  -.020  Higher   1968   .060   1967   .019   1985   .017   1973
.016

================================================================================================================================

 wrd005a   1932 to  2001      70 years
Series   5

 [B] Entire series, effect on correlation (  .604) is:
       Lower    1940  -.046   1957  -.029   1934  -.022   1972  -.014  Higher   1954   .068   1985   .024   1968   .020   1962
.011

================================================================================================================================

 wrd006a   1930 to  2000      71 years
Series   6

 [B] Entire series, effect on correlation (  .563) is:
       Lower    1985  -.035   1979  -.020   1995  -.020   1972  -.019  Higher   1967   .039   1940   .034   1968   .024   1930
.013

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 wrd006b   1946 to  2001      56 years
Series   7

 [B] Entire series, effect on correlation (  .688) is:
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       Lower    1948  -.036   1959  -.018   1960  -.018   1984  -.015  Higher   1985   .035   1968   .024   1991   .015   1967
.014

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 wrd007a   1936 to  2000      65 years
Series   8

 [B] Entire series, effect on correlation (  .663) is:
       Lower    1939  -.032   1940  -.020   2000  -.017   1990  -.015  Higher   1968   .061   1985   .021   1954   .019   1991
.015

================================================================================================================================

 wrd007b   1928 to  2000      73 years
Series   9

 [B] Entire series, effect on correlation (  .595) is:
       Lower    1997  -.026   1974  -.024   1933  -.021   2000  -.020  Higher   1954   .066   1940   .028   1968   .025   1962
.014

================================================================================================================================

 wrd008a   1928 to  2001      74 years
Series  10

 [B] Entire series, effect on correlation (  .619) is:
       Lower    1979  -.025   1939  -.022   1974  -.019   1929  -.011  Higher   1968   .048   1928   .015   1967   .013   1962
.013

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 wrd009a   1930 to  1982      53 years
Series  11

 [B] Entire series, effect on correlation (  .687) is:
       Lower    1930  -.057   1954  -.019   1938  -.013   1982  -.010  Higher   1940   .027   1968   .022   1974   .010   1967
.008
```

```
 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
       1930 -5.3 SD

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 wrd009b   1927 to  2001      75 years
Series  12

 [B] Entire series, effect on correlation (  .577) is:
       Lower   1944  -.024   1956  -.023   1967  -.016   1963  -.013  Higher   1940   .020   1927   .016   1929   .014   1930
.014

================================================================================================================================

 wrd011a   1935 to  2001      67 years
Series  13

 [B] Entire series, effect on correlation (  .525) is:
       Lower   1992  -.047   1999  -.022   1985  -.018   1983  -.009  Higher   1968   .082   1974   .015   1938   .014   1958
.010

================================================================================================================================

 wrd011b   1929 to  2001      73 years
Series  14

 [B] Entire series, effect on correlation (  .472) is:
       Lower   1932  -.031   1992  -.030   1988  -.018   1967  -.018  Higher   1940   .033   1930   .029   1962   .018   2001
.018

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 wrd012a   1937 to  2001      65 years
Series  15

 [B] Entire series, effect on correlation (  .483) is:
       Lower   1993  -.033   1964  -.020   1960  -.016   1946  -.013  Higher   1967   .032   1968   .025   2001   .019   1991
.018
```

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 wrd015a   1937 to  2001      65 years
Series  16

 [B] Entire series, effect on correlation (  .633) is:
       Lower    1940  -.035   1959  -.031   1966  -.023   1939  -.021  Higher    1954   .054   1968   .035   1985   .023   1991
.016

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  wrd015b   1935 to  2001      67 years
Series  17

 [B] Entire series, effect on correlation (  .625) is:
       Lower    1939  -.052   1940  -.024   1967  -.021   1944  -.009  Higher    1968   .081   1954   .024   1962   .010   1985
.009

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 wrd016a   1938 to  1997      60 years
Series  18

 [B] Entire series, effect on correlation (  .568) is:
       Lower    1958  -.089   1971  -.023   1997  -.021   1970  -.012  Higher    1954   .115   1985   .034   1964   .013   1938
.011

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 wrd016b   1941 to  2001      61 years
Series  19

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
   ---------   ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
   1960 1999    -1   -.15 -.26 -.12 -.06  .11 -.17 -.11 -.01  .05  .56* .51|-.07 -.20   -    -    -    -    -    -    -    -

 [B] Entire series, effect on correlation (  .518) is:
       Lower    1969  -.046   1985  -.045   1941  -.028   1958  -.023  Higher    1968   .126   1954   .061   2001   .019   1973
.017
     1960 to 1999 segment:
```

```
        Lower   1985  -.074   1969  -.071   1991  -.021   1967  -.017  Higher   1968   .228   1973   .027   1994   .013   1974
 .010

  [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
        1969 -5.1 SD
==================================================================================================================================
  wrd017b   1943 to  1993      51 years
 Series  20

  [B] Entire series, effect on correlation (  .523) is:
        Lower   1943  -.070   1946  -.031   1963  -.019   1949  -.013  Higher   1954   .048   1968   .045   1964   .017   1967
 .012
==================================================================================================================================
  wrd018a   1946 to  1995      50 years
 Series  21

  [B] Entire series, effect on correlation (  .639) is:
        Lower   1979  -.044   1991  -.020   1975  -.018   1967  -.017  Higher   1968   .056   1985   .044   1962   .016   1994
 .012

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  wrd018b   1950 to  1996      47 years
 Series  22

  [B] Entire series, effect on correlation (  .741) is:
        Lower   1967  -.017   1984  -.016   1988  -.012   1976  -.011  Higher   1968   .068   1985   .028   1962   .010   1994
 .009

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  wrd019a   1956 to  2001      46 years
 Series  23

  [B] Entire series, effect on correlation (  .419) is:
        Lower   1968  -.053   1982  -.033   1962  -.030   1958  -.024  Higher   1985   .118   1974   .037   2001   .034   1991
 .032
```

```
 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
      1968 +3.1 SD
=================================================================================================================================

 wrd020b   1937 to  2001      65 years
Series  24

 [B] Entire series, effect on correlation (  .674) is:
      Lower    1982  -.034   1993  -.016   1967  -.015   1969  -.009  Higher   1968   .045   1940   .026   1985   .021   1954
.017

=================================================================================================================================

 wrd021a   1928 to  2001      74 years
Series  25

 [B] Entire series, effect on correlation (  .537) is:
      Lower    1973  -.033   1945  -.029   1974  -.019   1969  -.015  Higher   1954   .085   1967   .030   1968   .018   1930
.014

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 wrd021b   1930 to  2001      72 years
Series  26

 [B] Entire series, effect on correlation (  .483) is:
      Lower    1993  -.056   1988  -.021   1930  -.017   1939  -.013  Higher   1968   .043   1954   .030   1962   .019   1985
.018

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
      1993 -5.2 SD
=================================================================================================================================

 wrd024a   1946 to  2001      56 years
Series  27

 [B] Entire series, effect on correlation (  .634) is:
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```
      Lower   1954  -.038   1964  -.019   1975  -.019   1996  -.017  Higher   1968   .045   1985   .041   1967   .020   1974
 .012

=================================================================================================================================

 wrd024b   1946 to  2000      55 years
Series  28

 [B] Entire series, effect on correlation (  .543) is:
      Lower   1991  -.024   1993  -.024   1955  -.021   2000  -.014  Higher   1967   .053   1954   .041   1968   .020   1985
 .018

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 wrd026a   1915 to  1990      76 years
Series  29

 [B] Entire series, effect on correlation (  .663) is:
      Lower   1943  -.024   1929  -.010   1933  -.009   1922  -.009  Higher   1954   .040   1927   .025   1925   .020   1940
 .019

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  wrd027b   1913 to  2001      89 years
Series  30

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
    ---------  ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
    1913 1952    0   -.10  .19 -.08  .15  .07  .11 -.09  .10 -.26 -.42  .30*-.14  .23 -.27  .03  .15  .25  .11  .04 -.13 -.20

 [B] Entire series, effect on correlation (  .499) is:
      Lower   1985  -.030   1940  -.026   1919  -.023   1947  -.021  Higher   1968   .047   1954   .043   1925   .024   1967
 .019
    1913 to 1952 segment:
      Lower   1940  -.050   1947  -.037   1927  -.035   1916  -.034  Higher   1925   .074   1930   .043   1929   .037   1926
 .029

=================================================================================================================================
```

```
 wrd028a   1927 to  2001      75 years
Series  31

 [B] Entire series, effect on correlation (  .627) is:
      Lower   1927  -.037   1990  -.020   1994  -.019   1967  -.014  Higher   1968   .058   1991   .013   1940   .012   1985
.012

==================================================================================================================================

 wrd028b   1930 to  2001      72 years
Series  32

 [B] Entire series, effect on correlation (  .662) is:
      Lower   1930  -.046   1946  -.017   1971  -.015   1962  -.014  Higher   1954   .064   1968   .041   1940   .024   1994
.009

==================================================================================================================================

 wrd029a   1928 to  2001      74 years
Series  33

 [B] Entire series, effect on correlation (  .658) is:
      Lower   1945  -.067   1974  -.021   1946  -.014   1983  -.014  Higher   1954   .060   1968   .026   1940   .024   1930
.015

==================================================================================================================================

 wrd029b   1930 to  2001      72 years
Series  34

 [B] Entire series, effect on correlation (  .569) is:
      Lower   1930  -.035   1947  -.027   1934  -.024   1996  -.015  Higher   1954   .033   1967   .025   1938   .015   2001
.012

==================================================================================================================================

 wrd030a   1929 to  2001      73 years
Series  35
```

```
 [B] Entire series, effect on correlation (  .630) is:
      Lower   1945  -.081   1985  -.017   1992  -.010   1935  -.010  Higher   1968   .055   1954   .029   1940   .015   1991
.012

====================================================================================================================

 wrd030b   1930 to  2001      72 years
Series  36

 [B] Entire series, effect on correlation (  .565) is:
      Lower   1954  -.048   1930  -.042   2000  -.017   1990  -.009  Higher   1962   .015   1967   .015   1973   .014   1985
.014

====================================================================================================================
  wrd033b   1934 to  2001      68 years
Series  37

 [B] Entire series, effect on correlation (  .582) is:
      Lower   1940  -.026   1999  -.018   1989  -.016   1974  -.014  Higher   1954   .036   1985   .033   1968   .029   1938
.015

====================================================================================================================

 wrd034b   1923 to  2001      79 years
Series  38

 [B] Entire series, effect on correlation (  .614) is:
      Lower   1974  -.042   1998  -.023   1924  -.020   1945  -.015  Higher   1954   .064   1968   .032   1985   .016   1991
.014

====================================================================================================================

 wrd037a   1950 to  2001      52 years
Series  39


 [B] Entire series, effect on correlation (  .757) is:
      Lower   2000  -.020   1998  -.018   1987  -.016   1977  -.016  Higher   1954   .044   1968   .030   1985   .027   1991
.013
```

```
==========================================================================================================

 wrd037b   1953 to  2001      49 years
Series  40

 [B] Entire series, effect on correlation (  .501) is:
      Lower   1976  -.035   1968  -.033   1995  -.030   1979  -.026  Higher   1954   .065   1985   .028   1991   .027   1974
.015

==========================================================================================================

 ght001a   1922 to  1984      63 years
Series  41

 [B] Entire series, effect on correlation (  .512) is:
      Lower   1975  -.029   1928  -.021   1934  -.021   1963  -.017  Higher   1927   .052   1940   .026   1954   .025   1925
.020

==========================================================================================================

 ght002a   1910 to  2001      92 years
Series  42

 [B] Entire series, effect on correlation (  .533) is:
      Lower   1975  -.023   1985  -.017   1991  -.015   1986  -.011  Higher   1968   .031   1925   .029   1967   .017   1954
.016

==========================================================================================================

 ght003a   1912 to  2001      90 years
Series  43

 [B] Entire series, effect on correlation (  .518) is:
      Lower   1968  -.034   1965  -.019   1913  -.015   1927  -.015  Higher   1954   .050   1967   .027   1925   .019   1928
.017

==========================================================================================================
```

```
 ght004b   1906 to  2001      96 years
Series  44

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
    ---------  ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
    1960 1999    1   -.01 -.04 -.13 -.19  .01  .29  .14 -.31 -.03  .27  .30| .39*-.25    -    -    -    -    -    -    -    -
    1962 2001    0    .03 -.06 -.18 -.05 -.03  .25  .15 -.34 -.05  .21  .35*   -    -    -    -    -    -    -    -    -    -

 [B] Entire series, effect on correlation (  .467) is:
      Lower   1931  -.025   1940  -.024   1993  -.024   1994  -.020  Higher   1954   .072   1967   .032   1925   .026   1930
.018
    1960 to 1999 segment:
      Lower   1993  -.056   1994  -.051   1973  -.039   1984  -.026  Higher   1967   .133   1968   .044   1991   .028   1964
.027
    1962 to 2001 segment:
      Lower   1993  -.058   1994  -.051   1973  -.039   1984  -.026  Higher   1967   .112   1968   .030   2000   .026   1991
.026

================================================================================================================================
 ght005a   1900 to  2001     102 years
Series  45

 [B] Entire series, effect on correlation (  .659) is:
      Lower   1910  -.018   1932  -.017   1938  -.017   1974  -.014  Higher   1954   .039   1968   .032   1967   .014   1927
.013

================================================================================================================================
  ght006a   1912 to  2001      90 years
Series  46

 [B] Entire series, effect on correlation (  .499) is:
      Lower   1978  -.053   1932  -.029   2000  -.020   1985  -.017  Higher   1954   .033   1927   .017   1940   .015   2001
.012

================================================================================================================================

 ght006b   1921 to  2001      81 years
Series  47
```

```
 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
 ---------   ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
   1921 1960   -2   -.32  .11 -.05 -.09 -.05 -.19 -.11  .02  .32*-.04  .31|-.14 -.19  .09 -.19  .09  .03  .02  .03 -.12 -.22

 [B] Entire series, effect on correlation (  .439) is:
     Lower   1956  -.059   1928  -.041   1938  -.018   1929  -.014  Higher   1954   .063   1967   .035   1927   .031   1985
.027
   1921 to 1960 segment:
     Lower   1956  -.099   1928  -.068   1938  -.029   1929  -.021  Higher   1954   .155   1927   .073   1958   .021   1925
.020

===============================================================================================================================

 ght007a   1900 to  2001     102 years
Series  48

 [B] Entire series, effect on correlation (  .556) is:
     Lower   1912  -.032   1977  -.019   1906  -.018   1925  -.017  Higher   1927   .026   1967   .023   1940   .017   1968
.015

===============================================================================================================================

 ght008a   1890 to  2001     112 years
Series  49

 [*] Early part of series cannot be checked from 1890 to 1895 -- not matched by another series

 [B] Entire series, effect on correlation (  .533) is:
     Lower   1899  -.090   1994  -.012   1932  -.009   1913  -.008  Higher   1927   .015   1968   .014   1967   .013   1925
.013

 [C] Year-to-year changes diverging by over 4.0 std deviations:
     1898 1899   4.7 SD    1899 1900  -4.4 SD

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
     1899 +4.7 SD

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```
 ght008b   1900 to  2001     102 years
Series  50

 [B] Entire series, effect on correlation (  .545) is:
      Lower   1991  -.029   1907  -.026   1985  -.021   1903  -.015  Higher   1954   .029   1925   .025   1967   .021   1927
.018

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 ght009b   1946 to  2000      55 years
Series  51

 [B] Entire series, effect on correlation (  .409) is:
      Lower   1952  -.027   1949  -.026   1960  -.024   1975  -.023  Higher   1985   .038   1973   .028   1967   .023   1946
.023

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 ght010a   1901 to  2001     101 years
Series  52

 [B] Entire series, effect on correlation (  .538) is:
      Lower   1978  -.026   1999  -.021   1916  -.017   1938  -.015  Higher   1927   .030   1968   .024   1925   .020   1930
.015

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  ght011a   1945 to  2001      57 years
Series  53

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
    ---------  ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
    1945 1984    1    .08 -.17  .04 -.33 -.18 -.01  .02 -.07 -.20  .16  .34| .36*-.14 -.11  .04 -.12  .29 -.01 -.25 -.09 -.06

 [B] Entire series, effect on correlation (  .365) is:
      Lower   1954  -.108   2001  -.041   1974  -.040   1953  -.022  Higher   1967   .067   1968   .063   1985   .046   1991
.024
     1945 to 1984 segment:
      Lower   1954  -.152   1974  -.055   1953  -.026   1962  -.022  Higher   1967   .095   1968   .088   1956   .022   1973
.022
```

```
 [C] Year-to-year changes diverging by over 4.0 std deviations:
       1953 1954   4.2 SD

=========================================================================================================================================
  ght015a   1950 to  2001      52 years
Series  54

 [B] Entire series, effect on correlation (  .659) is:
       Lower   1968  -.030   1995  -.021   1975  -.021   1973  -.018  Higher   1954   .106   1991   .014   1964   .013   1974
.010

=========================================================================================================================================
  ght016a   1901 to  2001     101 years
Series  55

 [B] Entire series, effect on correlation (  .618) is:
       Lower   1904  -.019   1974  -.015   1968  -.013   1977  -.011  Higher   1925   .017   1940   .016   1927   .011   1967
.009

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 ght016b   1896 to  2001     106 years
Series  56

 [B] Entire series, effect on correlation (  .510) is:
       Lower   1925  -.018   1988  -.013   2000  -.012   1929  -.011  Higher   1985   .019   1916   .014   1928   .013   1930
.010

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
       1899 -4.7 SD

=========================================================================================================================================
  ght017a   1931 to  2001      71 years
Series  57

 [B] Entire series, effect on correlation (  .724) is:
       Lower   1974  -.018   2001  -.018   1996  -.010   1995  -.010  Higher   1954   .054   1968   .021   1940   .017   1967
.014
=========================================================================================================================================
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```
  ght020a   1923 to  2001      79 years
Series  58

 [B] Entire series, effect on correlation (  .722) is:
      Lower   1976  -.014   1989  -.011   1930  -.010   1977  -.008  Higher   1968   .016   1954   .013   1940   .012   1928
.010

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 ght020b   1923 to  1992      70 years
Series  59

 [B] Entire series, effect on correlation (  .707) is:
      Lower   1974  -.037   1981  -.014   1989  -.011   1961  -.009  Higher   1954   .040   1927   .023   1985   .021   1940
.016

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```

```
PART 7:  DESCRIPTIVE STATISTICS:                                                  16:07  Sat 13 MAR 2004  Page
9
-----------------------------------------------------------------------------------------------------------------
                                                Corr  //-------- Unfiltered --------\\  //---- Filtered -----\\
                            No.    No.    No.   with   Mean   Max     Std   Auto   Mean   Max    Std   Auto  AR
Seq Series   Interval     Years  Segmt  Flags  Master  msmt   msmt    dev   corr   sens  value   dev   corr  ()
--- -------- ---------    -----  -----  -----  ------ -----  -----  -----  -----  -----  -----  -----  -----  --
  1 wrd001a  1933 1993       61      3      0    .569  3.07   9.87  2.776   .902   .332   1.91   .345  -.031   1
  2 wrd001b  1933 1971       39      1      0    .534  3.50  10.26  3.069   .898   .329   2.14   .498   .040   1
  3 wrd002a  1930 2000       71      4      0    .537  2.07   4.36  1.073   .748   .270   2.13   .502  -.002   1
  4 wrd002b  1929 2000       72      4      0    .518  2.24   4.68  1.136   .660   .380   2.18   .411   .034   1
  5 wrd005a  1932 2001       70      4      0    .604  3.20  13.92  3.194   .891   .368   2.03   .432  -.014   1
  6 wrd006a  1930 2000       71      4      0    .563  2.24   4.68  1.287   .920   .256   1.92   .393   .051   1
  7 wrd006b  1946 2001       56      3      0    .688  2.96   7.58  1.614   .766   .299   2.02   .455   .013   1
  8 wrd007a  1936 2000       65      4      0    .663  3.10   7.00  1.491   .714   .308   2.01   .401   .004   1
  9 wrd007b  1928 2000       73      4      0    .595  2.02  11.64  2.299   .925   .345   2.07   .427  -.077   1
 10 wrd008a  1928 2001       74      4      0    .619  1.84   6.90  1.228   .869   .256   1.98   .330   .009   1
 11 wrd009a  1930 1982       53      3      0    .687  4.27  13.17  4.148   .928   .303   1.89   .294  -.005   1
 12 wrd009b  1927 2001       75      4      0    .577  2.48  10.86  2.865   .952   .360   1.87   .315  -.011   1
 13 wrd011a  1935 2001       67      4      0    .525  3.38  11.15  2.843   .937   .276   1.92   .400   .000   1
 14 wrd011b  1929 2001       73      4      0    .472  3.46  13.69  3.518   .952   .280   2.05   .398  -.131   1
 15 wrd012a  1937 2001       65      4      0    .483  2.02   8.29  2.287   .938   .369   2.13   .414   .034   1
 16 wrd015a  1937 2001       65      4      0    .633  3.49  10.58  2.816   .927   .272   2.10   .489   .042   1
 17 wrd015b  1935 2001       67      4      0    .625  3.58   8.31  2.028   .879   .225   1.74   .298  -.052   1
 18 wrd016a  1938 1997       60      3      0    .568  2.51  10.35  2.669   .940   .261   1.89   .330  -.003   1
 19 wrd016b  1941 2001       61      3      1    .518  3.52  10.27  2.650   .925   .239   1.88   .317   .127   1
 20 wrd017b  1943 1993       51      2      0    .523  2.60   7.60  2.103   .880   .324   1.96   .348  -.049   1
 21 wrd018a  1946 1995       50      2      0    .639  2.93   7.47  1.812   .864   .242   1.94   .363  -.110   2
 22 wrd018b  1950 1996       47      2      0    .741  3.40   7.73  2.018   .869   .200   1.87   .340  -.032   1
 23 wrd019a  1956 2001       46      3      0    .419  5.01  21.29  5.722   .921   .331   2.03   .377  -.071   1
 24 wrd020b  1937 2001       65      4      0    .674  2.05   6.68  2.048   .951   .304   2.03   .463  -.041   1
 25 wrd021a  1928 2001       74      4      0    .537  2.64   9.55  1.657   .745   .314   2.07   .377  -.020   1
 26 wrd021b  1930 2001       72      4      0    .483  2.46   7.15  1.356   .753   .292   1.84   .337   .051   1
 27 wrd024a  1946 2001       56      3      0    .634  3.07  10.25  2.562   .863   .309   2.01   .350   .021   1
 28 wrd024b  1946 2000       55      3      0    .543  3.46   8.84  2.709   .876   .288   1.93   .395  -.027   2
 29 wrd026a  1915 1990       76      4      0    .663  2.65   9.89  2.309   .891   .288   2.15   .451  -.098   1
 30 wrd027b  1913 2001       89      5      1    .499  2.96   7.59  2.060   .859   .318   2.17   .455   .077   1
 31 wrd028a  1927 2001       75      4      0    .627  2.48  15.19  2.861   .949   .292   2.09   .367  -.066   1
 32 wrd028b  1930 2001       72      4      0    .662  2.32   8.61  1.609   .896   .285   2.04   .386  -.079   1
 33 wrd029a  1928 2001       74      4      0    .658  3.20  11.92  2.179   .937   .213   1.93   .395  -.053   2
 34 wrd029b  1930 2001       72      4      0    .569  2.78   7.81  1.396   .794   .225   1.99   .409  -.025   1
 35 wrd030a  1929 2001       73      4      0    .630  2.07   9.83  1.678   .932   .246   1.98   .430  -.006   1
 36 wrd030b  1930 2001       72      4      0    .565  1.74   8.87  1.496   .903   .323   1.87   .333   .023   1
```

37	wrd033b	1934	2001	68	4	0	.582	2.39	7.17	2.048	.945	.299	1.92	.382	-.035	1
38	wrd034b	1923	2001	79	4	0	.614	2.97	8.30	2.101	.902	.261	2.08	.356	.019	1
39	wrd037a	1950	2001	52	3	0	.757	3.87	7.53	1.443	.464	.301	2.10	.494	.008	1
40	wrd037b	1953	2001	49	3	0	.501	2.73	4.85	1.047	.491	.320	2.07	.452	-.012	2
41	ght001a	1922	1984	63	3	0	.512	1.07	3.57	.791	.667	.451	2.07	.425	.008	1
42	ght002a	1910	2001	92	5	0	.533	2.15	7.25	1.037	.731	.216	2.11	.331	.005	1
43	ght003a	1912	2001	90	5	0	.518	3.14	11.25	1.950	.785	.334	1.90	.293	-.072	2
44	ght004b	1906	2001	96	5	2	.467	2.42	13.55	2.403	.906	.342	2.20	.376	.051	1
45	ght005a	1900	2001	102	5	0	.659	2.35	7.63	1.422	.854	.277	1.97	.411	.039	1
46	ght006a	1912	2001	90	5	0	.499	1.44	3.42	.744	.576	.367	1.90	.370	-.017	1
47	ght006b	1921	2001	81	4	1	.439	1.01	2.14	.493	.645	.378	2.01	.491	-.075	1
48	ght007a	1900	2001	102	5	0	.556	2.35	11.79	1.942	.841	.346	1.96	.342	-.009	1

```
PART 7:  DESCRIPTIVE STATISTICS:                                          16:07  Sat 13 MAR 2004  Page
10
--------------------------------------------------------------------------------------------------------
                                                Corr  //-------- Unfiltered --------\\  //---- Filtered -----\\
                             No.    No.    No.  with   Mean    Max    Std   Auto   Mean   Max    Std   Auto  AR
Seq Series   Interval      Years  Segmt  Flags Master  msmt   msmt    dev   corr   sens  value    dev   corr  ()
--- -------- ---------     -----  -----  ----- ------ -----  -----  -----  -----  -----  -----  -----  -----  --
 49 ght008a  1890 2001      112      6      0   .533  2.22  10.40  1.816   .876   .317   2.03   .274   .013   1
 50 ght008b  1900 2001      102      5      0   .545  1.71   5.45  1.090   .756   .369   2.16   .508   .011   1
 51 ght009b  1946 2000       55      3      0   .409  1.16   3.49   .895   .845   .409   2.11   .402  -.059   1
 52 ght010a  1901 2001      101      5      0   .538  1.58   9.36  1.368   .860   .343   2.10   .400  -.007   1
 53 ght011a  1945 2001       57      3      1   .365  3.69   5.75  1.159   .562   .259   1.93   .481   .035   1
 54 ght015a  1950 2001       52      3      0   .659  3.83   7.21  1.261   .514   .263   1.86   .324  -.047   1
 55 ght016a  1901 2001      101      5      0   .618  2.41   7.24  1.671   .901   .267   2.12   .376  -.006   4
 56 ght016b  1896 2001      106      6      0   .510  1.92   6.43  1.656   .887   .318   1.77   .239  -.046   1
 57 ght017a  1931 2001       71      4      0   .724  3.26  11.29  2.701   .840   .380   1.99   .390   .000   1
 58 ght020a  1923 2001       79      4      0   .722  1.62   6.77  1.502   .920   .329   2.03   .353  -.039   1
 59 ght020b  1923 1992       70      3      0   .707  2.11   5.70  1.519   .905   .355   1.99   .414  -.004   1
--- -------- ---------     -----  -----  ----- ------ -----  -----  -----  -----  -----  -----  -----  -----  --
Total or mean:             4227    226      6   .574  2.56  21.29  1.914   .837   .307   2.20   .385  -.011

                                   - = [  COFECHA STATECOF  ] = -
```

A-3. ABRP COFECHA output.

```
 PART 5:  CORRELATION OF SERIES BY SEGMENTS:                                          12:59  Fri 10 OCT 2003
Page   5
-------------------------------------------------------------------------------------------------------------
 Correlations of  40-year dated segments, lagged  20 years
 Flags:  A = correlation under   .3665 but highest as dated;  B = correlation higher at other than dated position

 Seq Series   Time_span   1880 1900 1920 1940 1960 1980
                          1919 1939 1959 1979 1999 2019
 --- -------- ---------   ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
   1 arb001a  1909 1958        .52  .56
   2 arb001b  1920 2001             .44  .32B .43  .45
   3 arb004b  1890 1985    .51  .46  .57  .56  .53
   4 arb005a  1890 2001    .59  .60  .48  .55  .46  .44
   5 arb005b  1890 2001    .43  .43  .48  .34A .41  .49
   6 arb007a  1891 2001    .70  .63  .57  .55  .52  .44
   7 arb007b  1896 2001    .66  .58  .35A .27B .42  .42
   8 arb008a  1892 2001    .42  .41  .44  .33A .42  .44
   9 arb008b  1893 1980    .72  .69  .64  .44  .38
  10 arb009b  1889 1980    .55  .51  .49  .52  .53
  11 arb011b  1890 2001    .61  .52  .47  .41  .36A .37
  12 arb013a  1887 2001    .61  .66  .49  .45  .39  .42
  13 arb013b  1887 2001    .41  .52  .38  .29A .48  .51
  14 arb016a  1940 2001                  .41  .48  .46
  15 arb016b  1940 2001                  .60  .52  .53
  16 arb017a  1934 2001             .68  .66  .66  .65
  17 arb017b  1931 2001             .52  .66  .71  .68
  18 arb019a  1956 2001                  .66  .69  .68
  19 arb019b  1956 2001                  .60  .62  .63
  20 arb020b  1904 2001        .42  .50  .68  .62  .58
  21 arb021a  1945 2001                  .61  .66  .75
  22 arb021b  1945 2001                  .48  .59  .64
  23 arb022a  1910 2000        .45  .61  .68  .65  .56
  24 arb022b  1910 2001        .45  .64  .77  .62  .62
  25 arb023b  1910 2001        .75  .74  .66  .54  .51
  26 arb024a  1900 2001        .63  .64  .57  .62  .62
  27 arb024b  1900 2001        .65  .55  .58  .61  .65
  28 arb025a  1910 2001        .64  .77  .54  .37  .41
  29 arb026a  1915 2001        .44  .49  .59  .77  .76
  30 arb027a  1926 2001             .53  .62  .66  .64
  31 arb027b  1925 2001             .30A .63  .68  .67
  32 arb029a  1941 2001                  .41  .57  .56
  33 arb029b  1942 2001                  .58  .72  .74
  34 arb030a  1915 2001        .44  .48  .61  .62  .64
```

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 35 arb030b  1920 2001             .53  .73  .85  .79
 36 arb031b  1888 1989   .57  .68  .50  .56  .55
 37 arb032a  1920 2001             .56  .63  .62  .66
 38 arb032b  1890 2001   .42  .44  .53  .54  .70  .73
 39 arb033a  1890 2001   .48  .64  .41B .50  .66  .63
 40 arb034a  1890 2001   .55  .51  .51  .64  .69  .67
 41 arb034b  1890 2001   .50  .56  .68  .58  .66  .71
```

```
 PART 6:  POTENTIAL PROBLEMS:                                                            12:59  Fri 10 OCT 2003  Page
7
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 For each series with potential problems the following diagnostics may appear:

 [A] Correlations with master dating series of flagged  40-year segments of series filtered with  32-year spline,
     at every point from ten years earlier (-10) to ten years later (+10) than dated

 [B] Effect of those data values which most lower or raise correlation with master series

 [C] Year-to-year changes very different from the mean change in other series

 [D] Absent rings (zero values)

 [E] Values which are statistical outliers from mean for the year

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 arb001a   1909 to  1958      50 years
Series   1

 [B] Entire series, effect on correlation (  .533) is:
       Lower   1924  -.057   1914  -.034   1943  -.016   1911  -.016  Higher   1927   .063   1946   .032   1929   .020   1920
.014

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 arb001b   1920 to  2001      82 years
Series   2

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
    ---------  ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
    1940 1979   -1    .02  .02 -.21 -.22 -.09 -.12  .19 -.16  .01  .43* .32|-.14  .20  .25  .07 -.17 -.18 -.19 -.06 -.22 -.06

 [B] Entire series, effect on correlation (  .447) is:
       Lower   1984  -.022   1962  -.020   1968  -.019   1949  -.019  Higher   1927   .052   1955   .038   1991   .019   1970
.018
     1940 to 1979 segment:
```

```
        Lower   1962  -.038   1949  -.034   1968  -.034   1952  -.032  Higher   1955   .108   1970   .046   1951   .038   1946
 .025

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  arb004b   1890 to  1985      96 years
 Series   3

  [B] Entire series, effect on correlation (  .517) is:
        Lower   1900  -.025   1967  -.023   1914  -.022   1921  -.015  Higher   1955   .026   1968   .023   1890   .015   1903
 .012

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  arb005a   1890 to  2001     112 years
 Series   4

  [B] Entire series, effect on correlation (  .529) is:
        Lower   1976  -.019   1979  -.016   1987  -.015   1957  -.013  Higher   1914   .052   1968   .019   1946   .014   1896
 .011

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  arb005b   1890 to  2001     112 years
 Series   5

  [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
      ---------  ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
      1940 1979    0   -.14  .10  .25  .05  .25 -.05  .20 -.02 -.11 -.14  .34*-.01 -.39 -.21  .04  .13  .19 -.28 -.22 -.04  .06

  [B] Entire series, effect on correlation (  .438) is:
        Lower   1907  -.040   1918  -.022   1971  -.015   1948  -.014  Higher   1914   .028   1895   .017   1906   .014   1927
 .013
    1940 to 1979 segment:
        Lower   1971  -.055   1961  -.048   1948  -.045   1942  -.036  Higher   1968   .050   1954   .045   1955   .041   1946
 .032
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 arb007a   1891 to  2001     111 years
Series   6

 [B] Entire series, effect on correlation (  .562) is:
      Lower   1949  -.028   1937  -.016   1975  -.013   1929  -.013  Higher   1914   .041   1927   .027   1955   .021   1994
.012

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 arb007b   1896 to  2001     106 years
Series   7

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
     --------- ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
     1920 1959    0  -.01 -.34 -.13 -.02  .19  .06 -.28 -.07  .08 -.12  .35*-.11  .13  .04 -.03  .14 -.20  .01 -.17  .00  .12
     1940 1979    5  -.28 -.05  .07 -.16  .09  .01 -.16 -.07  .01 -.11  .27|-.05 -.01  .09  .04  .34*  .00 -.22 -.34  .19  .00

 [B] Entire series, effect on correlation (  .448) is:
      Lower   1946  -.030   1983  -.022   1971  -.021   1954  -.015  Higher   1927   .033   1980   .018   1914   .017   1906
.015
     1920 to 1959 segment:
      Lower   1946  -.081   1954  -.039   1945  -.034   1934  -.027  Higher   1927   .114   1928   .039   1929   .032   1940
.018
     1940 to 1979 segment:
      Lower   1946  -.071   1971  -.045   1954  -.039   1975  -.032  Higher   1968   .051   1961   .037   1970   .033   1940
.021

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 arb008a   1892 to  2001     110 years
Series   8

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
     --------- ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
     1940 1979    0  -.16 -.03  .00 -.09  .09  .00 -.31 -.02  .18  .31  .33*-.19  .09  .02  .18  .11 -.05 -.14 -.25 -.20 -.26
```

```
 [B] Entire series, effect on correlation (  .427) is:
     Lower   1930  -.023   1956  -.019   1976  -.015   1932  -.014  Higher   1991   .016   1994   .016   1927   .015   1946
.015
    1940 to 1979 segment:
     Lower   1956  -.062   1976  -.044   1969  -.033   1962  -.024  Higher   1946   .055   1973   .033   1951   .028   1959
.025

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 arb008b   1893 to  1980      88 years
Series   9

 [B] Entire series, effect on correlation (  .559) is:
     Lower   1973  -.033   1980  -.026   1975  -.015   1898  -.014  Higher   1914   .071   1927   .024   1955   .023   1895
.016

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 arb009b   1889 to  1980      92 years
Series  10

 [B] Entire series, effect on correlation (  .511) is:
     Lower   1899  -.026   1959  -.019   1931  -.017   1937  -.016  Higher   1927   .050   1955   .025   1906   .018   1914
.018

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 arb011b   1890 to  2001     112 years
Series  11

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
   ---------   ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
   1960 1999     0   -.02 -.13  .00  .11  .07 -.18  .10 -.07 -.03  .14  .36*-.01 -.08    -    -    -    -    -    -    -    -

 [B] Entire series, effect on correlation (  .450) is:
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```
     Lower   1976  -.024   1984  -.020   1959  -.015   1939  -.015  Higher   1927   .037   1914   .026   1955   .017   1968
.016
    1960 to 1999 segment:
     Lower   1976  -.071   1984  -.067   1995  -.040   1967  -.034  Higher   1968   .071   1991   .053   1987   .020   1962
.020

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 arb013a   1887 to  2001     115 years
Series  12

 [B] Entire series, effect on correlation (  .507) is:
     Lower   1896  -.030   1987  -.026   1948  -.021   1978  -.010  Higher   1914   .039   1968   .016   1895   .014   1955
.014

 [E] Outliers     2   3.0 SD above or -4.5 SD below mean for year
     1948 +3.0 SD;    1987 +3.1 SD

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 arb013b   1887 to  2001     115 years
Series  13

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
 ---------  ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
   1940 1979    0   -.15 -.04 -.08  .08 -.02 -.06 -.04 -.02 -.02 -.18  .29* .27  .14 -.04 -.07  .04  .10 -.24 -.21 -.40  .15

 [B] Entire series, effect on correlation (  .429) is:
     Lower   1896  -.026   1952  -.024   1975  -.017   1943  -.015  Higher   1914   .018   1895   .016   1890   .014   1994
.013
    1940 to 1979 segment:
     Lower   1952  -.075   1975  -.056   1943  -.044   1951  -.038  Higher   1968   .048   1946   .037   1962   .035   1970
.030

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 arb016a   1940 to  2001      62 years
Series  14
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 [B] Entire series, effect on correlation (  .401) is:
     Lower   1986  -.029   1955  -.026   1997  -.018   1949  -.017  Higher   1968   .037   1991   .020   1954   .018   1940
.018

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 arb016b   1940 to  2001      62 years
Series  15

 [B] Entire series, effect on correlation (  .515) is:
     Lower   1954  -.038   1987  -.026   1993  -.024   2000  -.014  Higher   1968   .042   1980   .019   1982   .018   1967
.018

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 arb017a   1934 to  2001      68 years
Series  16

 [B] Entire series, effect on correlation (  .657) is:
     Lower   1955  -.024   1972  -.024   1987  -.021   1988  -.012  Higher   1994   .022   1980   .018   1991   .015   1967
.011

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 arb017b   1931 to  2001      71 years
Series  17

 [B] Entire series, effect on correlation (  .550) is:
     Lower   1937  -.022   1988  -.022   1939  -.021   1934  -.019  Higher   1968   .023   1994   .022   2000   .018   1967
.014

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 arb019a   1956 to  2001      46 years
Series  18

 [B] Entire series, effect on correlation (  .658) is:
      Lower   1956  -.021   1958  -.021   1995  -.019   1976  -.014  Higher   1991   .025   1968   .023   1961   .015   1980
.013

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 arb019b   1956 to  2001      46 years
Series  19

 [B] Entire series, effect on correlation (  .616) is:
      Lower   1976  -.061   1958  -.025   1990  -.024   1963  -.019  Higher   1994   .035   1991   .023   1967   .015   2000
.015

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 arb020b   1904 to  2001      98 years
Series  20

 [B] Entire series, effect on correlation (  .562) is:
      Lower   1928  -.019   1929  -.016   1934  -.014   1985  -.014  Higher   1955   .022   1961   .015   1994   .014   1991
.013

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 arb021a   1945 to  2001      57 years
Series  21

 [B] Entire series, effect on correlation (  .613) is:
      Lower   1955  -.061   1961  -.035   1985  -.023   1986  -.018  Higher   1968   .026   2000   .016   1991   .015   1980
.014

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```
 arb021b   1945 to  2001      57 years
Series  22

 [B] Entire series, effect on correlation (  .520) is:
       Lower   1955  -.071   1985  -.043   1947  -.028   1961  -.028  Higher   1968   .043   1994   .034   1946   .018   1976
.016

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
       1955 +3.1 SD

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 arb022a   1910 to  2000      91 years
Series  23

 [B] Entire series, effect on correlation (  .533) is:
       Lower   2000  -.035   1914  -.028   1927  -.023   1962  -.016  Higher   1955   .026   1946   .015   1928   .012   1961
.012

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 arb022b   1910 to  2001      92 years
Series  24

 [B] Entire series, effect on correlation (  .589) is:
       Lower   1913  -.023   1999  -.021   1926  -.015   1927  -.015  Higher   1955   .019   1961   .014   1946   .012   2000
.011

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 arb023b   1910 to  2001      92 years
Series  25

 [B] Entire series, effect on correlation (  .662) is:
       Lower   1985  -.017   1996  -.015   1976  -.014   1974  -.012  Higher   1914   .034   1927   .013   1961   .011   1994
.010
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 arb024a   1900 to  2001      102 years
Series  26

 [B] Entire series, effect on correlation (  .623) is:
      Lower   1909  -.025   1962  -.013   1968  -.008   1976  -.008  Higher   1914   .030   1970   .009   1980   .008   1928
.008

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 arb024b   1900 to  2001      102 years
Series  27

 [B] Entire series, effect on correlation (  .625) is:
      Lower   1906  -.023   1920  -.017   1999  -.011   1911  -.010  Higher   1914   .053   1980   .011   1929   .009   2000
.008

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 arb025a   1910 to  2001       92 years
Series  28

 [B] Entire series, effect on correlation (  .563) is:
      Lower   1912  -.040   1985  -.017   1999  -.015   1996  -.013  Higher   1927   .042   1914   .014   1991   .011   1946
.010

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 arb026a   1915 to  2001       87 years
Series  29

 [B] Entire series, effect on correlation (  .604) is:
      Lower   1920  -.031   1923  -.018   1968  -.016   1958  -.013  Higher   1955   .018   1970   .012   1927   .011   1991
.011
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 arb027a   1926 to  2001      76 years
Series  30

 [B] Entire series, effect on correlation (  .590) is:
       Lower   1929  -.017   1933  -.015   1937  -.014   1927  -.013  Higher   1991   .021  1968   .020  1980   .015  1931
.009

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 arb027b   1925 to  2001      77 years
Series  31

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
    ---------  ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
    1925 1964     0  -.03  .02  .07  .25 -.15 -.21 -.21 -.05  .03 -.10  .30*-.07  .07  .20  .11 -.08 -.10 -.04  .02 -.10 -.01

 [B] Entire series, effect on correlation (  .483) is:
       Lower   1927  -.071   1929  -.044   1928  -.039   1931  -.017  Higher   1991   .026  1980   .025  1976   .013  1940
.013
     1925 to 1964 segment:
       Lower   1927  -.125   1929  -.076   1928  -.067   1931  -.029  Higher   1940   .045  1934   .036  1962   .032  1946
.032

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 arb029a   1941 to  2001      61 years
Series  32

 [B] Entire series, effect on correlation (  .523) is:
       Lower   1968  -.035   1955  -.032   1942  -.029   1972  -.023  Higher   1991   .033  1946   .029  1976   .017  1961
.012
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 arb029b   1942 to  2001      60 years
Series  33

 [B] Entire series, effect on correlation (  .636) is:
      Lower   1946  -.048   1955  -.043   1987  -.018   1968  -.010  Higher   1991   .023   1976   .013   2000   .012   2001
.010

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 arb030a   1915 to  2001      87 years
Series  34

 [B] Entire series, effect on correlation (  .545) is:
      Lower   1939  -.036   1936  -.018   1928  -.015   1940  -.015  Higher   1927   .053   1955   .018   1946   .014   2000
.013

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 arb030b   1920 to  2001      82 years
Series  35

 [B] Entire series, effect on correlation (  .665) is:
      Lower   2000  -.023   1925  -.021   1932  -.020   1941  -.015  Higher   1946   .013   1961   .011   1994   .011   1928
.010

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 arb031b   1888 to  1989     102 years
Series  36

 [B] Entire series, effect on correlation (  .541) is:
      Lower   1895  -.023   1940  -.020   1987  -.014   1980  -.012  Higher   1914   .041   1955   .020   1968   .017   1946
.017
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 arb032a   1920 to  2001      82 years
Series  37

 [B] Entire series, effect on correlation (  .599) is:
       Lower   1920  -.029   1922  -.022   1971  -.019   1993  -.015  Higher   1927   .032   1994   .017   1980   .015   1929
.013

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 arb032b   1890 to  2001     112 years
Series  38

 [B] Entire series, effect on correlation (  .522) is:
       Lower   1901  -.062   1935  -.022   1894  -.018   1958  -.015  Higher   1914   .026   1927   .023   1895   .013   1991
.011

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 arb033a   1890 to  2001     112 years
Series  39

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
    ---------  ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
    1920 1959     7   .07 -.25 -.15  .00  .24  .12 -.07 -.03 -.07  .19  .41| .04 -.33 -.08 -.16 -.14 -.06  .47* .09 -.09 -.04

 [B] Entire series, effect on correlation (  .509) is:
       Lower   1892  -.065   1944  -.022   1926  -.021   1967  -.016  Higher   1955   .021   1994   .017   1968   .013   1906
.013
     1920 to 1959 segment:
       Lower   1944  -.061   1926  -.058   1959  -.033   1931  -.027  Higher   1955   .084   1929   .039   1920   .024   1932
.019
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 arb034a   1890 to  2001     112 years
Series  40

 [B] Entire series, effect on correlation (  .580) is:
      Lower    1895  -.024   1968  -.016   1901  -.012   1935  -.011  Higher   1914   .040   1994   .015   1927   .013   1980
.012

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 arb034b   1890 to  2001     112 years
Series  41

 [B] Entire series, effect on correlation (  .591) is:
      Lower    1909  -.024   1960  -.023   1895  -.017   1997  -.011  Higher   1980   .012   1927   .010   1890   .010   1946
.008

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 PART 7:  DESCRIPTIVE STATISTICS:                                                12:59  Fri 10 OCT 2003  Page
8                                                   Corr  //-------- Unfiltered --------\\  //---- Filtered -----\\
                                No.   No.    No.    with   Mean    Max     Std   Auto   Mean   Max     Std   Auto  AR
 Seq Series   Interval        Years Segmt  Flags  Master   msmt   msmt    dev   corr   sens  value    dev   corr  ()
 --- -------- ---------        ----- -----  -----  ------ -----  -----  -----  -----  -----  -----  -----  -----  --
   1 arb001a  1909 1958          50     2      0    .533   4.12  10.22  2.059   .549   .355   2.17   .538  -.107   2
   2 arb001b  1920 2001          82     4      1    .447   3.26  12.41  2.274   .754   .313   2.15   .424  -.016   1
   3 arb004b  1890 1985          96     5      0    .517   1.67   7.93  1.294   .878   .325   2.18   .414   .005   1
   4 arb005a  1890 2001         112     6      0    .529   1.66   4.77  1.095   .898   .271   2.03   .372   .005   2
   5 arb005b  1890 2001         112     6      1    .438   1.58   5.75  1.171   .864   .265   1.90   .312  -.033   1
   6 arb007a  1891 2001         111     6      0    .562   1.95   8.84  1.960   .939   .272   1.93   .401  -.031   1
   7 arb007b  1896 2001         106     6      2    .448   1.31   5.39  1.312   .945   .282   2.25   .512  -.015   1
   8 arb008a  1892 2001         110     6      1    .427   2.02   7.86  1.531   .891   .314   2.09   .405   .011   1
   9 arb008b  1893 1980          88     5      0    .559   2.12   6.87  1.562   .909   .280   1.93   .327   .020   1
  10 arb009b  1889 1980          92     5      0    .511   1.84   8.10  1.862   .910   .301   1.99   .320  -.019   1
  11 arb011b  1890 2001         112     6      1    .450   1.64   6.31  1.367   .919   .335   2.03   .391  -.021   1
  12 arb013a  1887 2001         115     6      0    .507   2.27   7.57  2.065   .947   .275   2.07   .416  -.056   1
  13 arb013b  1887 2001         115     6      1    .429   2.31   8.95  2.027   .927   .236   2.02   .395  -.011   1
  14 arb016a  1940 2001          62     3      0    .401   2.21   5.52  1.441   .780   .324   1.94   .313  -.007   2
  15 arb016b  1940 2001          62     3      0    .515   2.17   6.76  1.521   .829   .288   2.07   .385   .101   1
  16 arb017a  1934 2001          68     4      0    .657   2.38   6.42  1.309   .792   .280   2.19   .464  -.006   1
  17 arb017b  1931 2001          71     4      0    .550   2.23   5.62  1.244   .661   .320   1.89   .336   .028   1
  18 arb019a  1956 2001          46     3      0    .658   2.15   3.91   .735   .355   .279   2.07   .485   .080   1
  19 arb019b  1956 2001          46     3      0    .616   2.24   3.47   .661   .084   .301   2.20   .498  -.035   1
  20 arb020b  1904 2001          98     5      0    .562    .98   3.21   .637   .819   .315   2.14   .350  -.051   1
  21 arb021a  1945 2001          57     3      0    .613   2.78   6.90  1.493   .640   .336   1.91   .449   .072   1
  22 arb021b  1945 2001          57     3      0    .520   2.28   6.09  1.228   .745   .316   2.09   .428  -.040   1
  23 arb022a  1910 2000          91     5      0    .533    .81   2.10   .447   .717   .329   1.99   .326   .024   2
  24 arb022b  1910 2001          92     5      0    .589   1.42   3.79   .723   .674   .304   2.16   .378   .050   1
  25 arb023b  1910 2001          92     5      0    .662   1.71   3.39   .713   .716   .251   2.15   .486   .006   1
  26 arb024a  1900 2001         102     5      0    .623   1.84   3.79   .814   .815   .211   2.07   .348  -.033   1
  27 arb024b  1900 2001         102     5      0    .625   1.64   3.77   .745   .856   .196   1.90   .307   .011   1
  28 arb025a  1910 2001          92     5      0    .563   1.61   3.65   .774   .834   .231   1.93   .367  -.020   1
  29 arb026a  1915 2001          87     5      0    .604   1.56   3.90   .651   .678   .265   1.94   .311  -.025   2
  30 arb027a  1926 2001          76     4      0    .590   1.01   3.16   .548   .606   .333   2.05   .353  -.039   1
  31 arb027b  1925 2001          77     4      1    .483   1.27   3.44   .595   .541   .332   2.21   .468  -.065   2
  32 arb029a  1941 2001          61     3      0    .523   1.61   5.20   .900   .530   .344   2.19   .444   .066   1
  33 arb029b  1942 2001          60     3      0    .636   2.19   6.21  1.200   .570   .356   2.22   .535  -.002   1
  34 arb030a  1915 2001          87     5      0    .545   1.98   5.02   .861   .543   .343   2.12   .352  -.032   3
  35 arb030b  1920 2001          82     4      0    .665   1.92   4.17   .867   .739   .244   2.07   .427   .026   1
  36 arb031b  1888 1989         102     5      0    .541    .97   2.70   .600   .855   .259   2.06   .352   .036   1
  37 arb032a  1920 2001          82     4      0    .599    .94   1.83   .358   .427   .307   2.15   .501   .090   1
  38 arb032b  1890 2001         112     6      0    .522   1.05   2.16   .380   .535   .293   2.08   .509   .049   1
```

```
39 arb033a  1890 2001    112      6      1    .509   1.04   3.36   .741   .853   .300   1.95   .330   .018   1
40 arb034a  1890 2001    112      6      0    .580   1.24   3.35   .691   .772   .307   2.14   .429   .027   2
41 arb034b  1890 2001    112      6      0    .591   1.29   3.25   .571   .723   .271   1.91   .337  -.015   2

Total or mean:           3601    191      9    .542   1.73  12.41  1.096   .761   .290   2.25   .396   .000

                                        - = [  COFECHA BLUFFCOF  ] = -
```

A-4. Combined pine COFECHA output.

```
 PART 5:  CORRELATION OF SERIES BY SEGMENTS:                                                 13:02  Fri 10 OCT 2003
Page   5
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 Correlations of  40-year dated segments, lagged  20 years
 Flags:  A = correlation under   .3665 but highest as dated;  B = correlation higher at other than dated position

 Seq Series  Time_span   1860 1880 1900 1920 1940 1960 1980
                         1899 1919 1939 1959 1979 1999 2019
 --- -------- ---------  ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
   1 jwd003a  1870 2001   .53  .51  .52  .59  .48  .41  .44
   2 jwd003b  1872 2001   .43  .47  .64  .59  .50  .37  .39
   3 jwd004a  1870 2001   .46  .49  .62  .60  .34A .33A .41
   4 jwd005a  1927 2001                  .46  .65  .61  .61
   5 jwd006a  1887 2001        .67  .53  .44  .56  .61  .63
   6 jwd007a  1869 2001   .63  .63  .69  .69  .70  .71  .76
   7 jwd008a  1871 2000   .66  .69  .72  .55  .37  .33A .35A
   8 jwd008b  1871 1935   .70  .60  .64
   9 jwd009a  1885 1959        .58  .60  .41
  10 jwd010a  1906 2001             .47  .55  .66  .58  .56
  11 jwd010b  1920 2001                  .43  .81  .70  .71
  12 jwd011b  1930 2001                  .40  .46  .38  .39
  13 jwd012a  1940 2001                       .42  .42  .55
  14 JWD013A  1874 2001   .57  .59  .67  .48  .34A .38  .45
  15 JWD014A  1874 2001   .46  .34B .49  .57  .61  .60  .60
  16 jwd015a  1900 1999             .47  .50  .57  .52
  17 jwd016a  1876 2001   .48  .44B .26A .24B .50  .70  .71
  18 jwd017a  1904 2001             .28A .30A .45  .40  .50
  19 jwd018a  1872 2001   .58  .53  .63  .46  .36A .48  .50
  20 jwd018b  1872 1996   .47  .44  .61  .56  .49  .39
  21 jwd019a  1880 1948        .62  .52  .41
  22 jwd020a  1873 2001   .55  .50  .62  .66  .66  .71  .65
  23 jwd020b  1873 2001   .79  .74  .64  .58  .58  .60  .60
  24 jwd021a  1883 2001        .58  .57  .41  .34A .40  .41
  25 jwd023a  1874 1997   .57  .46  .48  .71  .66  .51
  26 jwd023b  1874 1999   .68  .72  .67  .69  .59  .41
  27 jwd024a  1871 2001   .74  .68  .49  .47  .47  .50  .55
  28 jwd024b  1871 1927   .63  .52  .43
  29 jwd025a  1871 2001   .72  .61  .52  .47  .48  .49  .56
  30 jwd026a  1882 1974        .65  .62  .67  .40
  31 jwd028a  1946 2001                       .53  .63  .65
  32 JWD029A  1872 2001   .56  .60  .57  .52  .49  .44  .47
  33 JWD029B  1872 1987   .58  .67  .65  .56  .43  .30A
  34 jwd030b  1930 2001                  .51  .48  .41  .47
```

```
35 arb001a  1909 1958          .52  .50
36 arb004b  1890 1985     .45  .46  .49  .51  .51
37 arb005a  1890 2001     .50  .48  .55  .71  .67  .65
38 arb005b  1908 2001          .39  .51  .45  .54  .59
39 arb007a  1891 2001     .70  .63  .51  .50  .56  .50
40 arb007b  1896 2001     .68  .62  .28A .22A .46  .46
41 arb008a  1892 2001     .43  .44  .44  .30B .48  .49
42 arb008b  1893 1980     .68  .69  .54  .34A .32A
43 arb009b  1889 1980     .51  .60  .49  .42  .42
44 arb011b  1890 2001     .54  .49  .48  .56  .42  .44
45 arb013a  1887 2001     .53  .60  .48  .55  .57  .60
46 arb013b  1887 2001     .44  .46  .40  .40  .59  .61
47 arb016a  1940 2001                    .69  .57  .56
48 arb016b  1940 2001                    .59  .63  .61
49 arb017a  1934 2001               .58  .58  .56  .56
50 arb017b  1931 2001               .61  .72  .65  .66
51 arb019a  1956 2001                    .54  .61  .62
52 arb019b  1956 2001                    .58  .63  .65
53 arb020b  1930 2001               .44  .54  .40  .38
54 arb021a  1945 2001                    .65  .59  .65
55 arb021b  1945 2001                    .47  .48  .51
56 arb022a  1910 2000          .39  .41B .51  .50  .41
57 arb022b  1910 2001          .36A .49  .58  .49  .53
58 arb023b  1910 2001          .57  .58  .53  .42  .42B
59 arb024a  1900 2001          .46  .46  .41  .40  .42
60 arb024b  1900 2001          .44  .44  .50  .42  .46
61 arb026a  1915 2001          .46  .41  .41  .58  .58
62 arb029a  1941 2001                    .32B .44  .45
63 arb029b  1942 2001                    .41  .54  .57
64 arb030a  1940 2001                    .39  .44  .49
65 arb030b  1920 2001               .52  .54  .57  .54
66 arb031b  1888 1989     .54  .64  .40  .44  .55
67 arb032a  1920 2001               .53  .52  .52  .53
68 arb032b  1902 2001          .51  .39  .37  .56  .63
69 arb033a  1890 2001     .38  .49  .17B .37  .63  .62
70 arb034a  1890 2001     .41  .39  .37A .40  .48  .49
71 arb034b  1890 2001     .40  .40  .50  .46  .46  .53
72 wrd001a  1933 1993               .60  .53  .58
73 wrd001b  1933 1971               .53
74 wrd002a  1930 2000               .47  .70  .64  .60
75 wrd002b  1929 2000               .44  .58  .60  .60
76 wrd005a  1932 2001               .50  .63  .70  .67
77 wrd006a  1930 2000               .59  .53  .54  .49
```

78	wrd006b	1946	2001				.60	.74	.80
79	wrd007a	1936	2000			.72	.76	.65	.59
80	wrd007b	1928	2000			.64	.63	.45	.40
81	wrd008a	1928	2001			.60	.70	.71	.70
82	wrd009a	1930	1982			.57	.79	.78	
83	wrd009b	1927	2001			.52	.47	.52	.55
84	wrd011a	1935	2001			.65	.69	.52	.51
85	wrd011b	1929	2001			.45	.54	.37	.40
86	wrd012a	1937	2001			.45	.45	.38	.42
87	wrd015a	1937	2001			.56	.61	.70	.73
88	wrd015b	1935	2001			.57	.67	.73	.73
89	wrd016a	1938	1997			.51	.52	.45	
90	wrd016b	1941	2001				.57	.52B	.49
91	wrd017b	1943	1993				.48	.62	
92	wrd018a	1946	1995				.69	.63	
93	wrd018b	1950	1996				.74	.79	
94	wrd020b	1937	2001			.65	.65	.57	.56
95	wrd021a	1928	2001			.57	.48	.38	.36A
96	wrd021b	1930	2001			.55	.66	.42	.43
97	wrd024a	1946	2001				.59	.61	.64
98	wrd024b	1946	2000				.58	.45	.40
99	wrd026a	1915	1990		.68	.67	.65	.63	
100	wrd027b	1920	2001			.39	.58	.61	.59
101	wrd028a	1927	2001			.65	.75	.58	.62
102	wrd028b	1930	2001			.64	.65	.66	.66
103	wrd029a	1928	2001			.60	.58	.61	.67
104	wrd029b	1930	2001			.60	.67	.54	.58
105	wrd030a	1929	2001			.65	.70	.72	.75
106	wrd030b	1930	2001			.57	.66	.67	.68
107	wrd033b	1934	2001			.60	.64	.57	.61
108	wrd034b	1923	2001			.58	.65	.64	.63
109	wrd037a	1950	2001				.76	.72	.67
110	wrd037b	1953	2001				.54	.43	.40
111	ght001a	1922	1984			.56	.36A	.30A	
112	ght002a	1900	2001		.28A	.58	.68	.44	.49
113	ght003a	1912	2001		.56	.65	.48	.40B	.34A
114	ght005a	1900	2001		.52	.77	.76	.65	.68
115	ght006a	1912	2001		.74	.71	.54	.40	.34A
116	ght007a	1913	2001		.45	.61	.59	.53	.53
117	ght008a	1884	2001	.42	.62	.75	.69	.52	.51
118	ght008b	1900	2001		.46	.72	.66	.49	.48
119	ght010a	1901	2001		.48	.73	.66	.55	.50
120	ght015a	1950	2001				.59	.50	.55

```
121 ght016a  1901 2001            .62  .53  .52  .60  .57
122 ght016b  1896 2001       .51  .47  .50  .55  .51  .47
123 ght017a  1931 2001                 .81  .77  .71  .67
124 ght020a  1923 2001                 .55  .76  .68  .66
125 ght020b  1923 1992                 .75  .67  .69
```

```
 PART 6:  POTENTIAL PROBLEMS:                                                            13:02  Fri 10 OCT 2003  Page
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 For each series with potential problems the following diagnostics may appear:

 [A] Correlations with master dating series of flagged  40-year segments of series filtered with  32-year spline,
     at every point from ten years earlier (-10) to ten years later (+10) than dated

 [B] Effect of those data values which most lower or raise correlation with master series

 [C] Year-to-year changes very different from the mean change in other series

 [D] Absent rings (zero values)

 [E] Values which are statistical outliers from mean for the year

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 jwd003a   1870 to  2001     132 years
Series   1

 [B] Entire series, effect on correlation (  .526) is:
      Lower   1970  -.018   1982  -.012   1988  -.010   1895  -.009  Higher   1985   .014   1881   .013   1946   .011   1928
.010

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 jwd003b   1872 to  2001     130 years
Series   2

 [B] Entire series, effect on correlation (  .480) is:
      Lower   1886  -.028   1881  -.023   1982  -.015   1988  -.011  Higher   1899   .032   1968   .025   1927   .018   1954
.012

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```
 jwd004a   1870 to  2001     132 years
Series   3

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
   ---------   ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
   1940 1979     0   -.19 -.10 -.33  .11  .23  .14  .04  .28 -.16  .14  .34* .05 -.09 -.08 -.13 -.20  .11 -.01 -.06 -.40 -.06
   1960 1999     0   -.06  .01 -.19  .12  .04  .13  .08  .04  .04 -.03  .33*-.07 -.06    -    -    -    -    -    -    -    -

 [B] Entire series, effect on correlation (  .476) is:
     Lower    1896  -.020   1926  -.015   1883  -.014   1870  -.013  Higher   1968   .019  1914   .018  1906   .016  1928
.015
    1940 to 1979 segment:
     Lower    1975  -.054   1973  -.049   1962  -.042   1967  -.027  Higher   1968   .130  1946   .047  1954   .037  1942
.034
    1960 to 1999 segment:
     Lower    1975  -.048   1973  -.045   1962  -.039   1967  -.028  Higher   1968   .114  1991   .037  1982   .026  1994
.025

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
     1881 -4.9 SD

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 jwd005a   1927 to  2001      75 years
Series   4

 [B] Entire series, effect on correlation (  .538) is:
     Lower    1927  -.071   1938  -.018   2001  -.016   1956  -.015  Higher   1954   .049  1968   .049  1940   .020  1946
.019

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 jwd006a   1887 to  2001     115 years
Series   5

 [B] Entire series, effect on correlation (  .589) is:
     Lower    1947  -.024   1955  -.019   1934  -.017   1924  -.015  Higher   1968   .041  1906   .017  1954   .015  1991
.011
```

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 jwd007a   1869 to  2001     133 years
Series   6

 [*] Early part of series cannot be checked from 1869 to 1869 -- not matched by another series

 [B] Entire series, effect on correlation (  .673) is:
      Lower   1883  -.019   1875  -.014   1956  -.013   1880  -.010  Higher   1968   .027   1954   .017   1927   .014   1906
.013

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 jwd008a   1871 to  2000     130 years
Series   7

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
   ---------   ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
   1960 1999     0    .09 -.01 -.01 -.11 -.06  .14  .11  .12 -.11  .06  .33* .17 -.25    -    -    -    -    -    -    -    -
   1961 2000     0    .11 -.04 -.02 -.12 -.06  .17  .08  .12 -.12  .05  .35* .12    -    -    -    -    -    -    -    -    -

 [B] Entire series, effect on correlation (  .538) is:
      Lower   1968  -.014   1961  -.012   1971  -.012   1956  -.011  Higher   1927   .016   1914   .015   1928   .013   1906
.011
    1960 to 1999 segment:
      Lower   1968  -.038   1980  -.033   1961  -.031   1985  -.024  Higher   1967   .084   1994   .049   1991   .026   1982
.022
    1961 to 2000 segment:
      Lower   1968  -.039   1961  -.032   1980  -.031   1971  -.025  Higher   1967   .072   1994   .050   1991   .027   1982
.023

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 jwd008b   1871 to  1935      65 years
Series   8

 [B] Entire series, effect on correlation (  .649) is:
```

```
      Lower   1918  -.027   1914  -.020   1887  -.015   1933  -.012  Higher   1899   .033   1906   .031   1928   .020   1927
.015

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 jwd009a   1885 to  1959      75 years
Series   9

 [B] Entire series, effect on correlation (  .506) is:
      Lower   1890  -.030   1928  -.024   1938  -.019   1940  -.018  Higher   1914   .032   1886   .027   1927   .025   1906
.025

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 jwd010a   1906 to  2001      96 years
Series  10

 [B] Entire series, effect on correlation (  .536) is:
      Lower   1912  -.020   1916  -.017   1985  -.015   1928  -.013  Higher   1968   .019   1967   .013   2000   .013   1994
.012

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 jwd010b   1920 to  2001      82 years
Series  11

 [B] Entire series, effect on correlation (  .575) is:
      Lower   1926  -.040   1982  -.021   1920  -.019   1928  -.018  Higher   1968   .064   1954   .042   2000   .020   1994
.015

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 jwd011b   1930 to  2001      72 years
Series  12
```

```
 [B] Entire series, effect on correlation (  .397) is:
      Lower   1933  -.031   1983  -.019   1965  -.016   1964  -.016  Higher   1968   .021   1994   .019   1946   .018   1956
.016

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 jwd012a   1940 to  2001      62 years
Series  13

 [B] Entire series, effect on correlation (  .464) is:
      Lower   1942  -.031   1940  -.031   1998  -.029   1960  -.029  Higher   2000   .035   1968   .028   1994   .024   1991
.021

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 JWD013A   1874 to  2001     128 years
Series  14

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
   ---------   ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
   1940 1979     0   -.03 -.02 -.13  .02 -.05 -.17  .10 -.16 -.24  .00  .34*-.07 -.01  .03 -.05  .11  .29  .07 -.09 -.21 -.02

 [B] Entire series, effect on correlation (  .497) is:
      Lower   1944  -.014   1881  -.014   1964  -.012   1966  -.011  Higher   1906   .019   1928   .015   1876   .009   1973
.009
    1940 to 1979 segment:
      Lower   1944  -.037   1964  -.031   1940  -.031   1961  -.027  Higher   1973   .039   1955   .036   1975   .030   1946
.027

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 JWD014A   1874 to  2001     128 years
Series  15

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
   ---------   ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
   1880 1919     6    .14  .27 -.08 -.18 -.03 -.04  .08 -.06 -.27 -.30  .34|-.11 -.22  .10  .09  .03  .40* .02 -.17  .09 -.06
```

```
 [B] Entire series, effect on correlation (  .506) is:
      Lower   1945  -.028   1899  -.028   1914  -.020   1886  -.016  Higher   1968   .052   1954   .029   1906   .022   1928
.012
    1880 to 1919 segment:
      Lower   1899  -.078   1886  -.051   1914  -.048   1888  -.025  Higher   1906   .112   1912   .034   1884   .033   1881
.027

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 jwd015a   1900 to  1999     100 years
Series  16

 [B] Entire series, effect on correlation (  .481) is:
      Lower   1983  -.048   1944  -.014   1969  -.012   1914  -.011  Higher   1968   .051   1928   .015   1985   .011   1994
.011

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 jwd016a   1876 to  2001     126 years
Series  17

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
   ---------   ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
   1880 1919    -9    .16  .51* .07 -.07  .20 -.12  .07  .32 -.26 -.02  .44|-.29 -.27  .02 -.38 -.12  .23 -.31  .04  .08 -.12
   1900 1939     0   -.16  .20  .11 -.23  .20  .19  .04  .02 -.13  .07  .26*-.28 -.07  .06 -.28  .20 -.06 -.33 -.02 -.05 -.14
   1920 1959     5   -.15 -.04  .22 -.27 -.02 -.10 -.08 -.09  .08  .10  .24|-.04  .00  .25 -.06  .27*-.25 -.28 -.03 -.24 -.10

 [B] Entire series, effect on correlation (  .474) is:
      Lower   1942  -.015   1939  -.013   1935  -.013   1925  -.012  Higher   1968   .031   1899   .023   1906   .015   1994
.014
    1880 to 1919 segment:
      Lower   1881  -.034   1895  -.020   1919  -.019   1905  -.016  Higher   1899   .073   1906   .047   1888   .020   1886
.017
    1900 to 1939 segment:
      Lower   1925  -.041   1939  -.035   1936  -.030   1935  -.025  Higher   1906   .086   1928   .060   1929   .035   1926
.024
    1920 to 1959 segment:
```

```
      Lower   1942  -.046   1939  -.040   1936  -.036   1925  -.034  Higher   1954   .065   1928   .061   1929   .036   1956
.032

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 jwd017a   1904 to  2001      98 years
Series  18

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
   ---------   ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
   1904 1943     0    .02 -.25  .01 -.05  .05 -.05 -.15 -.01 -.13  .09  .28* .03 -.16  .10 -.16  .19  .09  .08 -.12 -.07  .15
   1920 1959     0    .00 -.28  .03 -.09  .08 -.17 -.27 -.10 -.24  .21  .30* .03  .03  .14 -.09  .26  .15 -.01  .18 -.22 -.16

 [B] Entire series, effect on correlation (  .408) is:
      Lower   1940  -.025   1928  -.024   1968  -.016   1984  -.013  Higher   2000   .032   1991   .021   1912   .015   1975
.014
    1904 to 1943 segment:
      Lower   1928  -.058   1940  -.054   1926  -.020   1929  -.020  Higher   1942   .049   1912   .046   1925   .028   1923
.017
    1920 to 1959 segment:
      Lower   1940  -.060   1928  -.060   1946  -.025   1926  -.020  Higher   1942   .051   1954   .048   1925   .027   1959
.021

 [D]    1 Absent rings:  Year   Master  N series Absent
                         1933   -.335      94       1  >> WARNING:  Ring is not usually narrow

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 jwd018a   1872 to  2001     130 years
Series  19

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
   ---------   ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
   1940 1979     0    .07 -.07 -.09 -.02  .01 -.06  .11  .02  .07  .29  .36*-.20 -.16 -.20 -.12 -.05 -.10  .09  .00  .04  .04

 [B] Entire series, effect on correlation (  .517) is:
      Lower   1896  -.027   1954  -.021   1967  -.019   2001  -.009  Higher   1906   .019   1991   .013   2000   .013   1928
.012
    1940 to 1979 segment:
```

```
       Lower   1954  -.059   1967  -.056   1974  -.017   1948  -.016  Higher   1955   .043   1973   .035   1968   .031   1946
.029

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 jwd018b   1872 to  1996     125 years
Series  20

 [B] Entire series, effect on correlation (  .479) is:
       Lower   1899  -.028   1890  -.023   1891  -.017   1985  -.013  Higher   1886   .025   1954   .024   1968   .022   1906
.017

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 jwd019a   1880 to  1948      69 years
Series  21

 [B] Entire series, effect on correlation (  .476) is:
       Lower   1940  -.031   1890  -.023   1922  -.019   1939  -.015  Higher   1914   .039   1906   .037   1899   .036   1928
.022

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 jwd020a   1873 to  2001     129 years
Series  22

 [B] Entire series, effect on correlation (  .608) is:
       Lower   2001  -.023   1881  -.022   1901  -.020   1962  -.019  Higher   1968   .039   1954   .016   1906   .012   1927
.012

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 jwd020b   1873 to  2001     129 years
Series  23
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 [B] Entire series, effect on correlation (  .631) is:
     Lower   1958  -.021   1987  -.011   1971  -.010   1944  -.010  Higher   1968   .032   1886   .020   1906   .014   1927
.011

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 jwd021a   1883 to  2001     119 years
Series  24

 [A] Segment  High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
   --------- ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
   1940 1979    0    .02 -.13 -.26 -.03 -.01 -.07 -.13 -.24 -.12  .11  .34* .00  .11  .21 -.16  .05 -.02  .02 -.06 -.06  .10

 [B] Entire series, effect on correlation (  .480) is:
     Lower   1930  -.021   1954  -.020   1991  -.018   1890  -.017  Higher   1914   .034   1886   .024   1927   .018   1994
.013
    1940 to 1979 segment:
     Lower   1954  -.062   1973  -.038   1962  -.020   1952  -.016  Higher   1940   .048   1970   .030   1968   .028   1960
.024

 [D]    1 Absent rings:  Year   Master  N series Absent
                         1914   -2.028     60       1

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 jwd023a   1874 to  1997     124 years
Series  25

 [B] Entire series, effect on correlation (  .563) is:
     Lower   1914  -.025   1901  -.017   1967  -.015   1884  -.014  Higher   1968   .039   1954   .021   1899   .016   1927
.015

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 jwd023b   1874 to  1999     126 years
Series  26
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 [B] Entire series, effect on correlation (  .606) is:
      Lower   1874  -.014   1969  -.012   1984  -.012   1954  -.010  Higher   1968   .025   1899   .023   1886   .013   1928
.012

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 jwd024a   1871 to  2001     131 years
Series  27

 [B] Entire series, effect on correlation (  .563) is:
      Lower   1965  -.018   1929  -.017   1960  -.013   1921  -.012  Higher   1899   .017   1886   .016   1968   .015   1985
.012

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 jwd024b   1871 to  1927      57 years
Series  28

 [B] Entire series, effect on correlation (  .519) is:
      Lower   1927  -.084   1888  -.022   1916  -.016   1917  -.016  Higher   1899   .062   1886   .049   1906   .036   1871
.023

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 jwd025a   1871 to  2001     131 years
Series  29

 [B] Entire series, effect on correlation (  .546) is:
      Lower   1977  -.023   1914  -.016   1940  -.015   1928  -.013  Higher   1968   .044   2000   .014   1927   .013   1886
.013

 [D]    1 Absent rings:  Year   Master  N series Absent
                         1911   -1.063      57       1

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 jwd026a   1882 to  1974      93 years
Series  30

 [B] Entire series, effect on correlation (  .545) is:
      Lower    1970  -.040   1968  -.022   1916  -.021   1967  -.013  Higher   1906   .020   1899   .016   1928   .015   1886
.012

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 jwd028a   1946 to  2001      56 years
Series  31

 [B] Entire series, effect on correlation (  .551) is:
      Lower    1946  -.053   1992  -.035   1954  -.029   1973  -.021  Higher   1968   .133   2000   .025   1994   .023   1991
.012

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 JWD029A   1872 to  2001     130 years
Series  32

 [B] Entire series, effect on correlation (  .527) is:
      Lower    1954  -.021   1903  -.016   1985  -.013   1921  -.012  Higher   1968   .033   1927   .017   1906   .016   1881
.013

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 JWD029B   1872 to  1987     116 years
Series  33

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
   ---------   ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
   1948 1987     0    .01 -.09 -.20  .09  .25  .03 -.28 -.14 -.15  .18  .30* .16 -.23 -.34 -.07 -.19  .14  .30  .25  .08 -.06

 [B] Entire series, effect on correlation (  .501) is:
```

```
     Lower   1961  -.031   1985  -.030   1962  -.014   1960  -.011  Higher   1968   .038   1899   .027   1914   .024   1927
.022
   1948 to 1987 segment:
     Lower   1961  -.088   1985  -.078   1962  -.035   1960  -.031  Higher   1968   .184   1954   .044   1964   .028   1965
.025

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 jwd030b   1930 to  2001     72 years
Series  34

 [B] Entire series, effect on correlation (  .467) is:
     Lower   1950  -.019   1996  -.018   1965  -.014   1947  -.013  Higher   2000   .031   1940   .019   1939   .017   1968
.017

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 arb001a   1909 to  1958     50 years
Series  35

 [B] Entire series, effect on correlation (  .514) is:
     Lower   1924  -.042   1949  -.021   1938  -.017   1930  -.017  Higher   1927   .063   1946   .030   1912   .024   1929
.022

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 arb004b   1890 to  1985     96 years
Series  36

 [B] Entire series, effect on correlation (  .466) is:
     Lower   1967  -.027   1899  -.020   1979  -.014   1900  -.013  Higher   1968   .050   1955   .013   1927   .013   1954
.012

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 arb005a   1890 to  2001     112 years
Series  37

 [B] Entire series, effect on correlation (  .575) is:
       Lower   1925  -.022   1907  -.012   1939  -.011   1900  -.010  Higher   1968   .034   1914   .028   1954   .024   1928
.014

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 arb005b   1908 to  2001      94 years
Series  38

 [B] Entire series, effect on correlation (  .498) is:
       Lower   1918  -.027   1967  -.018   1942  -.015   1939  -.014  Higher   1914   .031   2000   .020   1928   .020   1927
.018

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 arb007a   1891 to  2001     111 years
Series  39

 [B] Entire series, effect on correlation (  .552) is:
       Lower   1954  -.020   1975  -.015   1937  -.014   1929  -.013  Higher   1914   .028   1927   .026   1968   .015   1994
.012

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 arb007b   1896 to  2001     106 years
Series  40

 [A] Segment    High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
     ---------  ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
     1920 1959    0    .06 -.41 -.03 -.01  .10  .06 -.27 -.04  .14 -.08  .28*-.10 -.01  .20  .02  .09 -.15 -.06 -.11  .03 -.05
     1940 1979    0   -.23 -.15  .08 -.03  .08 -.03 -.09  .08  .03  .08  .22*-.04 -.09  .13  .07  .21 -.08 -.39 -.26  .19 -.15

 [B] Entire series, effect on correlation (  .443) is:
```

```
      Lower    1954  -.036   1953  -.025   1946  -.025   1945  -.020  Higher   1927   .031   1906   .021   1968   .018   1928
.016
    1920 to 1959 segment:
      Lower    1954  -.084   1946  -.061   1953  -.056   1945  -.044  Higher   1927   .114   1928   .059   1929   .037   1940
.025
    1940 to 1979 segment:
      Lower    1954  -.077   1946  -.052   1953  -.048   1945  -.037  Higher   1968   .084   1974   .031   1964   .027   1940
.026

 [C] Year-to-year changes diverging by over 4.0 std deviations:
      1953 1954   4.1 SD

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 arb008a   1892 to  2001     110 years
Series  41

 [A] Segment    High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
     ---------  ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
     1940 1979    -1  -.11 -.06 -.11  .05  .08 -.15 -.22 -.06  .29  .38* .30|-.16 -.07 -.03  .23  .16 -.13 -.14 -.38 -.20 -.31

 [B] Entire series, effect on correlation (  .443) is:
      Lower    1956  -.022   1913  -.019   1954  -.018   1905  -.010  Higher   1985   .019   1991   .014   1927   .014   2000
.014
    1940 to 1979 segment:
      Lower    1956  -.068   1954  -.030   1969  -.028   1963  -.026  Higher   1946   .047   1973   .036   1974   .031   1940
.018

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 arb008b   1893 to  1980      88 years
Series  42

 [A] Segment    High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
     ---------  ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
     1940 1979     0  -.21 -.26  .16  .24  .13  .16 -.16  .04  .13 -.01  .34*-.02 -.43 -.03  .27 -.04 -.11 -.09 -.34 -.07 -.02
     1941 1980     0  -.20 -.25  .15  .26  .09  .18 -.16  .04  .13  .00  .32*-.02 -.39 -.04  .29 -.07 -.09 -.10 -.36 -.08 -.04

 [B] Entire series, effect on correlation (  .517) is:
```

```
    Lower   1968  -.033   1973  -.033   1949  -.020   1975  -.016  Higher   1914   .042   1927   .025   1955   .012   1899
.011
   1940 to 1979 segment:
    Lower   1973  -.073   1968  -.050   1949  -.044   1975  -.034  Higher   1955   .046   1974   .031   1946   .021   1967
.021
   1941 to 1980 segment:
    Lower   1973  -.073   1968  -.047   1949  -.043   1975  -.035  Higher   1955   .053   1974   .036   1967   .024   1954
.022

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 arb009b   1889 to  1980      92 years
Series  43

 [B] Entire series, effect on correlation (  .462) is:
    Lower   1899  -.064   1949  -.020   1912  -.018   1967  -.015  Higher   1927   .056   1906   .030   1968   .022   1914
.020

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
    1899 +3.4 SD

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 arb011b   1890 to  2001     112 years
Series  44

 [B] Entire series, effect on correlation (  .448) is:
    Lower   1939  -.028   1985  -.018   1967  -.016   1920  -.015  Higher   1927   .036   1968   .024   1914   .021   1991
.013

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 arb013a   1887 to  2001     115 years
Series  45

 [B] Entire series, effect on correlation (  .526) is:
    Lower   1909  -.023   1896  -.020   1939  -.017   1987  -.017  Higher   1914   .026   1968   .025   1906   .018   1985
.017
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 arb013b   1887 to  2001     115 years
Series  46

 [B] Entire series, effect on correlation (  .476) is:
      Lower    1909  -.024   1975  -.021   1896  -.019   1952  -.015  Higher   1985   .020   1906   .016   1914   .014   1928
.012

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 arb016a   1940 to  2001      62 years
Series  47

 [B] Entire series, effect on correlation (  .608) is:
      Lower    1986  -.034   1973  -.016   1997  -.015   1955  -.015  Higher   1954   .070   1968   .032   1940   .016   1975
.013

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 arb016b   1940 to  2001      62 years
Series  48

 [B] Entire series, effect on correlation (  .519) is:
      Lower    1954  -.086   1977  -.024   2000  -.019   1943  -.016  Higher   1968   .106   1967   .024   1940   .022   1975
.016

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 arb017a   1934 to  2001      68 years
Series  49

 [B] Entire series, effect on correlation (  .563) is:
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```
       Lower   1972  -.032   1998  -.014   1938  -.014   1988  -.012  Higher   1994   .025   1991   .019   1967   .017   1975
.013

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 arb017b   1931 to  2001      71 years
Series  50

 [B] Entire series, effect on correlation (  .591) is:
       Lower   1939  -.043   1988  -.024   1937  -.021   1989  -.018  Higher   1954   .067   1968   .026   2000   .022   1994
.018

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 arb019a   1956 to  2001      46 years
Series  51

 [B] Entire series, effect on correlation (  .551) is:
       Lower   1992  -.048   1958  -.042   1956  -.025   1985  -.020  Higher   1967   .041   1968   .034   1991   .030   1975
.017

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 arb019b   1956 to  2001      46 years
Series  52

 [B] Entire series, effect on correlation (  .592) is:
       Lower   1958  -.053   1976  -.025   1968  -.022   1990  -.021  Higher   1985   .042   1994   .033   1991   .023   1967
.018

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 arb020b   1930 to  2001      72 years
Series  53
```

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 [B] Entire series, effect on correlation (  .432) is:
     Lower   1992  -.033   1968  -.032   1985  -.031   1939  -.022  Higher   1954   .027   1994   .024   1991   .023   1967
.022

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 arb021a   1945 to  2001      57 years
Series  54

 [B] Entire series, effect on correlation (  .617) is:
     Lower   1985  -.039   1955  -.032   1953  -.025   1988  -.018  Higher   1954   .060   1968   .037   1967   .022   2000
.020

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 arb021b   1945 to  2001      57 years
Series  55

 [B] Entire series, effect on correlation (  .451) is:
     Lower   1985  -.060   1955  -.038   1947  -.031   1967  -.022  Higher   1968   .116   1994   .036   1946   .019   1973
.017

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 arb022a   1910 to  2000      91 years
Series  56

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
   ---------   ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
   1920 1959     7    .16  .01 -.28  .10  .15 -.10  .12 -.22 -.12  .19  .41|-.03  .07 -.12  .07 -.02 -.12  .43*-.36 -.21 -.13

 [B] Entire series, effect on correlation (  .393) is:
     Lower   2000  -.038   1920  -.031   1954  -.021   1927  -.015  Higher   1928   .022   1973   .020   1946   .018   1955
.017
    1920 to 1959 segment:
     Lower   1920  -.063   1954  -.063   1927  -.046   1922  -.021  Higher   1928   .051   1946   .040   1955   .039   1939
.033
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 arb022b   1910 to  2001      92 years
Series  57

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
    ---------  ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
    1910 1949    0    .31  .09 -.28  .18  .18 -.02  .11 -.09 -.25  .03  .36*-.10 -.12 -.18  .03  .09  .05  .35 -.25 -.17  .13

 [B] Entire series, effect on correlation (  .471) is:
       Lower   1926  -.026   1920  -.024   1999  -.020   1992  -.016  Higher   2000   .019   1946   .014   1929   .013   1955
.013
     1910 to 1949 segment:
       Lower   1926  -.065   1920  -.051   1916  -.030   1913  -.021  Higher   1946   .042   1939   .041   1929   .039   1928
.033

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 arb023b   1910 to  2001      92 years
Series  58

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
    ---------  ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
    1962 2001  -10    .46* .06 -.21 -.02 -.17  .12  .09 -.03 -.19  .01  .42|   -    -    -    -    -    -    -    -    -    -

 [B] Entire series, effect on correlation (  .509) is:
       Lower   1985  -.025   1911  -.016   1974  -.015   1917  -.014  Higher   1914   .034   1927   .020   1940   .017   1994
.015
     1962 to 2001 segment:
       Lower   1985  -.058   1974  -.036   1996  -.030   1972  -.025  Higher   1994   .047   1991   .042   1975   .032   2001
.030

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 arb024a   1900 to  2001     102 years
Series  59
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 [B] Entire series, effect on correlation (  .454) is:
      Lower   1911  -.022   1968  -.020   1976  -.019   1992  -.018  Higher   1914   .032   1928   .016   1991   .011   1927
.011

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 arb024b   1900 to  2001     102 years
Series  60

 [B] Entire series, effect on correlation (  .447) is:
      Lower   1906  -.030   1911  -.028   1958  -.016   1926  -.014  Higher   1914   .048   1929   .015   2000   .015   1940
.014

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 arb026a   1915 to  2001      87 years
Series  61

 [B] Entire series, effect on correlation (  .488) is:
      Lower   1968  -.036   1958  -.026   1923  -.019   1954  -.019  Higher   1940   .022   1927   .017   1991   .014   1925
.014

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 arb029a   1941 to  2001      61 years
Series  62

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
   ---------   ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
   1941 1980    -8    .03  .20  .37* .02 -.19 -.06 -.21 -.29 -.13 -.19  .32| .13 -.15  .02  .30  .17  .20  .05 -.18 -.02 -.06

 [B] Entire series, effect on correlation (  .405) is:
      Lower   1968  -.070   1954  -.031   1942  -.030   1947  -.019  Higher   1991   .038   1946   .032   1962   .020   1967
.017
    1941 to 1980 segment:
      Lower   1968  -.097   1954  -.041   1942  -.039   1947  -.023  Higher   1946   .055   1962   .042   1956   .028   1967
.027
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 arb029b   1942 to  2001      60 years
Series  63

 [B] Entire series, effect on correlation (  .490) is:
       Lower    1946  -.035   1968  -.029   1943  -.020   1955  -.018  Higher   1991   .029   2000   .019   1975   .018   1962
.015

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 arb030a   1940 to  2001      62 years
Series  64

 [B] Entire series, effect on correlation (  .477) is:
       Lower    1947  -.067   1968  -.059   1976  -.033   1949  -.017  Higher   2000   .025   1973   .021   1967   .018   1946
.017

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 arb030b   1920 to  2001      82 years
Series  65

 [B] Entire series, effect on correlation (  .527) is:
       Lower    2000  -.024   1943  -.019   1930  -.019   1939  -.014  Higher   1928   .022   1994   .016   1946   .016   1954
.015

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 arb031b   1888 to  1989     102 years
Series  66

 [B] Entire series, effect on correlation (  .525) is:
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```
       Lower    1940  -.025   1954  -.021   1892  -.017   1960  -.017  Higher   1914   .029   1968   .028   1928   .019   1985
.018

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 arb032a   1920 to  2001      82 years
Series  67

 [B] Entire series, effect on correlation (  .536) is:
       Lower    1954  -.024   1928  -.021   1985  -.019   1968  -.017  Higher   1927   .034   1994   .018   1929   .016   1967
.012

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 arb032b   1902 to  2001     100 years
Series  68

 [B] Entire series, effect on correlation (  .498) is:
       Lower    1958  -.029   1968  -.028   1960  -.022   1935  -.020  Higher   1914   .030   1927   .027   1985   .015   1967
.015

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 arb033a   1890 to  2001     112 years
Series  69

 [A] Segment    High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
     ---------  ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
     1920 1959    7    .16 -.24 -.11  .05  .18  .14 -.09 -.02 -.03  .25  .17|-.01 -.29 -.15 -.02 -.15 -.01  .35*-.01 -.12  .12

 [B] Entire series, effect on correlation (  .405) is:
       Lower    1892  -.077   1926  -.032   1944  -.019   1967  -.018  Higher   1968   .023   1899   .023   1906   .022   1994
.019
     1920 to 1959 segment:
       Lower    1926  -.078   1944  -.043   1949  -.037   1956  -.026  Higher   1955   .065   1929   .056   1927   .035   1946
.025
```

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 [C] Year-to-year changes diverging by over 4.0 std deviations:
       1891 1892  -4.2 SD

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 arb034a    1890 to  2001     112 years
Series  70

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
    ---------  ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
    1920 1959    0    .23 -.10  .00 -.08  .03 -.08  .04  .17 -.04  .03  .37* .04 -.17 -.16  .08 -.12 -.14  .27 -.13 -.16 -.02

 [B] Entire series, effect on correlation (  .421) is:
       Lower    1968  -.032   1911  -.015   1958  -.014   1913  -.013  Higher   1914   .037   1994   .020   1927   .020   1967
.015
     1920 to 1959 segment:
       Lower    1958  -.043   1926  -.032   1949  -.032   1922  -.030  Higher   1927   .069   1928   .055   1942   .029   1946
.027

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 arb034b    1890 to  2001     112 years
Series  71

 [B] Entire series, effect on correlation (  .443) is:
       Lower    1960  -.028   1911  -.018   1974  -.013   1922  -.011  Higher   1927   .016   1991   .011   1946   .011   1928
.010

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 wrd001a    1933 to  1993      61 years
Series  72

 [B] Entire series, effect on correlation (  .540) is:
       Lower    1974  -.039   1976  -.018   1961  -.017   1949  -.013  Higher   1968   .051   1940   .019   1939   .014   1973
.013
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 wrd001b   1933 to  1971      39 years
Series  73

 [B] Entire series, effect on correlation (  .527) is:
      Lower    1968  -.103   1967  -.036   1959  -.026   1953  -.023  Higher   1954   .099   1964   .024   1939   .021   1934
.018

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 wrd002a   1930 to  2000      71 years
Series  74

 [B] Entire series, effect on correlation (  .469) is:
      Lower    1939  -.052   1934  -.041   1994  -.034   1950  -.015  Higher   1954   .053   1968   .038   1985   .027   1973
.020

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
      1934 +3.1 SD

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 wrd002b   1929 to  2000      72 years
Series  75

 [B] Entire series, effect on correlation (  .438) is:
      Lower    1979  -.031   1939  -.031   1934  -.024   1995  -.020  Higher   1968   .077   1973   .020   1967   .018   1985
.018

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 wrd005a   1932 to  2001      70 years
Series  76

 [B] Entire series, effect on correlation (  .534) is:
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      Lower    1957  -.042   1934  -.032   1940  -.030   1939  -.021  Higher    1954   .063   1968   .026   1985   .022   1975
.014

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 wrd006a   1930 to  2000      71 years
Series  77

 [B] Entire series, effect on correlation (  .499) is:
      Lower    1985  -.022   1972  -.018   2000  -.017   1950  -.014  Higher    1968   .030   1967   .028   1940   .027   1994
.022

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 wrd006b   1946 to  2001      56 years
Series  78

 [B] Entire series, effect on correlation (  .661) is:
      Lower    1959  -.034   1955  -.031   1948  -.024   1984  -.016  Higher    1968   .026   2000   .024   1985   .022   1954
.020

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 wrd007a   1936 to  2000      65 years
Series  79

 [B] Entire series, effect on correlation (  .578) is:
      Lower    1939  -.043   2000  -.030   1980  -.029   1989  -.013  Higher    1968   .086   1954   .030   1991   .022   1985
.021

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 wrd007b   1928 to  2000      73 years
Series  80
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 [B] Entire series, effect on correlation (  .508) is:
     Lower   2000  -.032   1997  -.027   1976  -.020   1974  -.019  Higher   1954   .064   1968   .034   1940   .024   1991
.017

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 wrd008a   1928 to  2001      74 years
Series  81

 [B] Entire series, effect on correlation (  .637) is:
     Lower   1939  -.033   1974  -.027   1979  -.015   2000  -.011  Higher   1968   .049   1928   .017   1967   .011   1994
.009

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 wrd009a   1930 to  1982      53 years
Series  82

 [B] Entire series, effect on correlation (  .617) is:
     Lower   1930  -.125   1952  -.011   1955  -.008   1933  -.007  Higher   1968   .029   1940   .024   1967   .012   1974
.010

 [C] Year-to-year changes diverging by over 4.0 std deviations:
     1930 1931   4.2 SD

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
     1930 -5.5 SD

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 wrd009b   1927 to  2001      75 years
Series  83

 [B] Entire series, effect on correlation (  .546) is:
     Lower   1956  -.020   1946  -.018   1963  -.018   1944  -.015  Higher   1927   .017   1929   .016   1968   .015   2000
.014
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 wrd011a   1935 to  2001      67 years
Series  84

 [B] Entire series, effect on correlation (  .494) is:
      Lower   1992  -.031   1999  -.021   1938  -.020   1980  -.018  Higher   1968   .097   1974   .014   1939   .012   1946
.012

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 wrd011b   1929 to  2001      73 years
Series  85

 [B] Entire series, effect on correlation (  .420) is:
      Lower   1988  -.020   1992  -.019   1934  -.019   1942  -.016  Higher   1940   .028   1968   .021   1929   .019   2001
.017

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 wrd012a   1937 to  2001      65 years
Series  86

 [B] Entire series, effect on correlation (  .413) is:
      Lower   1993  -.029   1946  -.019   1996  -.016   1964  -.016  Higher   1968   .032   1967   .028   1991   .024   1973
.020

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 wrd015a   1937 to  2001      65 years
Series  87

 [B] Entire series, effect on correlation (  .590) is:
      Lower   1959  -.048   1939  -.031   1940  -.022   1990  -.020  Higher   1954   .051   1968   .042   1985   .021   1991
.020
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 wrd015b   1935 to  2001      67 years
Series  88

 [B] Entire series, effect on correlation (  .576) is:
       Lower   1939  -.067   1959  -.016   1940  -.014   1948  -.012  Higher   1968   .115   1954   .029   1955   .012   1985
.012

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 wrd016a   1938 to  1997      60 years
Series  89

 [B] Entire series, effect on correlation (  .506) is:
       Lower   1958  -.053   1980  -.020   1970  -.020   1939  -.017  Higher   1954   .102   1985   .030   1964   .014   1975
.010

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 wrd016b   1941 to  2001      61 years
Series  90

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
    ---------  ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
    1960 1999   -1   -.11 -.22 -.14 -.08  .12 -.31 -.09 -.05  .04  .52* .52|-.02 -.13    -    -    -    -    -    -    -    -

 [B] Entire series, effect on correlation (  .476) is:
       Lower   1969  -.042   1950  -.033   2000  -.030   1985  -.028  Higher   1968   .153   1954   .057   1973   .019   2001
.018
     1960 to 1999 segment:
       Lower   1969  -.064   1985  -.048   1982  -.033   1976  -.033  Higher   1968   .255   1973   .027   1994   .015   1970
.012

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
       1969 -4.9 SD
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 wrd017b   1943 to  1993      51 years
Series  91

 [B] Entire series, effect on correlation (  .471) is:
       Lower   1943  -.050   1946  -.046   1959  -.022   1990  -.022  Higher   1968   .054   1954   .051   1964   .018   1967
.014

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 wrd018a   1946 to  1995      50 years
Series  92

 [B] Entire series, effect on correlation (  .657) is:
       Lower   1975  -.029   1979  -.027   1991  -.026   1982  -.015  Higher   1968   .055   1994   .019   1954   .013   1946
.013

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 wrd018b   1950 to  1996      47 years
Series  93

 [B] Entire series, effect on correlation (  .734) is:
       Lower   1952  -.029   1980  -.024   1951  -.017   1984  -.017  Higher   1968   .088   1985   .020   1994   .013   1954
.012

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 wrd020b   1937 to  2001      65 years
Series  94

 [B] Entire series, effect on correlation (  .581) is:
       Lower   1982  -.051   1950  -.025   2000  -.016   1959  -.013  Higher   1968   .062   1954   .029   1940   .022   1985
.022
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 wrd021a   1928 to  2001      74 years
Series  95

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
    ---------  ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
    1962 2001    0   -.16 -.33 -.03  .04 -.21  .13 -.15 -.17 -.09  .26  .36*   -    -    -    -    -    -    -    -    -    -

 [B] Entire series, effect on correlation (  .440) is:
      Lower   1973  -.032   1932  -.023   1976  -.017   1974  -.015  Higher   1954   .082  1967   .027  1968   .027  1991
.017
     1962 to 2001 segment:
      Lower   1973  -.061   1976  -.032   1974  -.029   1969  -.025  Higher   1968   .076  1967   .060  1991   .045  1994
.036

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 wrd021b   1930 to  2001      72 years
Series  96

 [B] Entire series, effect on correlation (  .424) is:
      Lower   1993  -.051   1988  -.023   1939  -.020   1997  -.014  Higher   1968   .053  1954   .033  1946   .021  1985
.018

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
      1993 -4.8 SD

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 wrd024a   1946 to  2001      56 years
Series  97

 [B] Entire series, effect on correlation (  .596) is:
      Lower   1975  -.027   1955  -.020   1964  -.016   1954  -.015  Higher   1968   .052  2000   .027  1985   .019  1967
.018
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 wrd024b   1946 to  2000      55 years
Series  98

 [B] Entire series, effect on correlation (  .452) is:
      Lower   1955  -.037   1991  -.026   2000  -.024   1993  -.022  Higher   1954   .048   1967   .039   1968   .030   1946
.021

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 wrd026a   1915 to  1990      76 years
Series  99

 [B] Entire series, effect on correlation (  .604) is:
      Lower   1933  -.020   1982  -.018   1943  -.016   1980  -.016  Higher   1954   .042   1927   .035   1940   .016   1985
.014

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
      1933 +3.2 SD
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====
 wrd027b   1920 to  2001      82 years
Series 100

 [B] Entire series, effect on correlation (  .478) is:
      Lower   1923  -.027   1985  -.023   1927  -.021   1940  -.020  Higher   1968   .062   1954   .043   1967   .017   1925
.016

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 wrd028a   1927 to  2001      75 years
Series 101

 [B] Entire series, effect on correlation (  .614) is:
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```
      Lower   1990  -.036   1927  -.035   1994  -.033   1955  -.016  Higher   1968   .069   2000   .018   1991   .015   1985
.011

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
      1990 +3.2 SD

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 wrd028b   1930 to  2001      72 years
Series 102

 [B] Entire series, effect on correlation (  .609) is:
      Lower   1946  -.026   1955  -.018   1979  -.018   1930  -.016  Higher   1954   .058   1968   .051   1940   .018   1994
.018

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 wrd029a   1928 to  2001      74 years
Series 103

 [B] Entire series, effect on correlation (  .615) is:
      Lower   1945  -.041   1946  -.022   1974  -.017   1955  -.011  Higher   1954   .053   1968   .030   2000   .020   1940
.018

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 wrd029b   1930 to  2001      72 years
Series 104

 [B] Entire series, effect on correlation (  .565) is:
      Lower   1996  -.032   1947  -.020   1933  -.017   1930  -.012  Higher   1954   .032   1967   .019   1991   .012   2001
.011

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 wrd030a   1929 to  2001      73 years
Series 105

 [B] Entire series, effect on correlation (  .647) is:
      Lower   1945  -.055   1937  -.015   1961  -.013   1935  -.012  Higher   1968   .058   1954   .027   1994   .015   1991
.013

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 wrd030b   1930 to  2001      72 years
Series 106

 [B] Entire series, effect on correlation (  .608) is:
      Lower   1954  -.033   1990  -.023   1930  -.016   1968  -.011  Higher   2000   .016   1973   .013   1946   .012   1967
.012

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 wrd033b   1934 to  2001      68 years
Series 107

 [B] Entire series, effect on correlation (  .567) is:
      Lower   1999  -.017   1940  -.016   1977  -.012   1974  -.012  Higher   1954   .035   1968   .030   2000   .028   1985
.026

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 wrd034b   1923 to  2001      79 years
Series 108

 [B] Entire series, effect on correlation (  .602) is:
      Lower   1974  -.038   1950  -.017   1932  -.017   1998  -.017  Higher   1954   .051   1968   .035   1991   .017   1985
.014

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 wrd037a   1950 to  2001      52 years
Series 109

 [B] Entire series, effect on correlation (  .685) is:
     Lower   2000  -.036   1950  -.035   1987  -.020   1997  -.014  Higher   1954   .048   1968   .042   1985   .022   1991
.019

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 wrd037b   1953 to  2001      49 years
Series 110

 [B] Entire series, effect on correlation (  .470) is:
     Lower   1968  -.036   2000  -.034   1970  -.025   1995  -.023  Higher   1954   .060   1991   .034   1985   .025   1956
.015

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 ght001a   1922 to  1984      63 years
Series 111

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
    ---------  ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
    1940 1979    0   -.13 -.04  .02  .12  .02 -.26 -.07 -.12 -.01  .07  .36* .08  .09 -.14 -.04  .01 -.18 -.19  .03 -.11 -.09
    1945 1984    0   -.09 -.08  .06  .01  .02 -.26 -.06 -.11 -.03  .11  .30* .09  .01 -.15 -.06  .04 -.11 -.15  .07 -.20  .00

 [B] Entire series, effect on correlation (  .434) is:
     Lower   1975  -.040   1934  -.031   1928  -.025   1963  -.022  Higher   1927   .074   1954   .032   1929   .025   1940
.024
   1940 to 1979 segment:
     Lower   1975  -.060   1950  -.035   1963  -.034   1942  -.020  Higher   1954   .060   1940   .043   1973   .032   1968
.029
   1945 to 1984 segment:
     Lower   1975  -.063   1982  -.032   1950  -.032   1963  -.032  Higher   1954   .077   1968   .049   1973   .033   1955
.030
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 ght002a   1900 to  2001     102 years
Series 112

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
     --------- ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
     1900 1939    0  -.20 -.03 -.25 -.19  .13  .24 -.08  .24  .23 -.35  .28*-.16  .16  .07 -.14 -.08  .05  .10 -.20  .09 -.09

 [B] Entire series, effect on correlation (  .459) is:
       Lower   1975 -.027   1914 -.018   1991 -.015   1901 -.015  Higher   1968  .036   2000  .026   1954  .020   1946
.018
      1900 to 1939 segment:
       Lower   1914 -.037   1901 -.036   1900 -.035   1922 -.033  Higher   1928  .058   1925  .054   1926  .037   1906
.035

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 ght003a   1912 to  2001      90 years
Series 113

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
     --------- ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
     1960 1999    1  -.16 -.22 -.11 -.16 -.01 -.02 -.08 -.03  .01  .07  .40| .48*-.11    -    -    -    -    -    -    -    -
     1962 2001    0  -.13 -.18 -.11 -.12  .08 -.01 -.08 -.04 -.02  .01  .34*   -    -    -    -    -    -    -    -    -    -

 [B] Entire series, effect on correlation (  .484) is:
       Lower   1968 -.037   2000 -.023   1919 -.019   1959 -.016  Higher   1954  .044   1928  .023   1925  .012   1967
.012
      1960 to 1999 segment:
       Lower   1968 -.092   1965 -.030   1962 -.025   1982 -.018  Higher   1967  .078   1994  .031   1985  .029   1974
.026
      1962 to 2001 segment:
       Lower   1968 -.072   2000 -.048   1965 -.029   1962 -.021  Higher   1967  .085   1994  .034   1985  .030   1974
.025
  [C] Year-to-year changes diverging by over 4.0 std deviations:
       1967 1968   4.0 SD
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 ght005a   1900 to  2001     102 years
Series 114

 [B] Entire series, effect on correlation (  .666) is:
      Lower   1922  -.016   1974  -.012   1902  -.009   1972  -.009  Higher   1968   .035   1954   .030   1927   .012   1967
.010

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 ght006a   1912 to  2001      90 years
Series 115

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
    ---------  ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
    1962 2001    0    .17 -.03 -.01  .00  .19 -.18  .05 -.08 -.09 -.04  .34*   -    -    -    -    -    -    -    -    -    -

 [B] Entire series, effect on correlation (  .563) is:
      Lower   1978  -.052   2000  -.034   1985  -.012   1948  -.011  Higher   1914   .030   1954   .025   1927   .014   1940
.011
     1962 to 2001 segment:
      Lower   1978  -.082   2000  -.066   1985  -.020   1991  -.014  Higher   2001   .031   1974   .030   1964   .025   1968
.024

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 ght007a   1913 to  2001      89 years
Series 116

 [B] Entire series, effect on correlation (  .523) is:
      Lower   1914  -.039   1977  -.020   1922  -.017   1942  -.014  Higher   1927   .040   1968   .021   1994   .019   1967
.019

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 ght008a   1884 to  2001     118 years
Series 117

 [B] Entire series, effect on correlation (  .557) is:
      Lower   1994  -.023   1887  -.012   1996  -.011   2000  -.010  Higher   1927   .018   1967   .012   1968   .012   1940
.010

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 ght008b   1900 to  2001     102 years
Series 118

 [B] Entire series, effect on correlation (  .539) is:
      Lower   1991  -.033   1907  -.031   1914  -.022   1903  -.020  Higher   1954   .027   1927   .019   1968   .017   1967
.015

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 ght010a   1901 to  2001     101 years
Series 119

 [B] Entire series, effect on correlation (  .532) is:
      Lower   1978  -.022   1999  -.019   2000  -.015   1906  -.014  Higher   1927   .034   1968   .025   1991   .016   1928
.014

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 ght015a   1950 to  2001      52 years
Series 120

 [B] Entire series, effect on correlation (  .606) is:
      Lower   1968  -.031   1975  -.030   1980  -.026   1955  -.021  Higher   1954   .082   1991   .018   2000   .018   1994
.016
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```
 ght016a   1901 to  2001     101 years
Series 121

 [B] Entire series, effect on correlation (  .578) is:
       Lower   1930  -.018   1968  -.015   1932  -.015   1950  -.013  Higher   1906   .020   1994   .017   1940   .013   1927
.013

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 ght016b   1896 to  2001     106 years
Series 122

 [B] Entire series, effect on correlation (  .482) is:
       Lower   2000  -.021   1988  -.015   1996  -.012   1959  -.011  Higher   1899   .034   1928   .017   1985   .016   1906
.015

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
       1899 -4.9 SD
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 ght017a   1931 to  2001      71 years
Series 123

 [B] Entire series, effect on correlation (  .709) is:
       Lower   1979  -.017   1974  -.014   2001  -.014   1955  -.011  Higher   1954   .042   1968   .022   1940   .013   1967
.012

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 ght020a   1923 to  2001      79 years
Series 124

 [B] Entire series, effect on correlation (  .594) is:
       Lower   1930  -.034   1932  -.016   1989  -.013   1923  -.012  Higher   1968   .028   1954   .024   1991   .019   1928
.017
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 ght020b   1923 to  1992      70 years
Series 125

 [B] Entire series, effect on correlation (  .701) is:
      Lower   1974  -.033   1961  -.014   1989  -.014   1955  -.010  Higher   1954   .035   1927   .032   1985   .015   1968
.014

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PART 7:  DESCRIPTIVE STATISTICS:                                        13:02  Fri 10 OCT 2003  Page
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----------------------------------------------------------------------------------------------------

                                                   Corr  //-------- Unfiltered --------\\  //---- Filtered -----\\
                           No.    No.    No.       with  Mean    Max     Std   Auto   Mean   Max    Std   Auto  AR
Seq Series   Interval     Years  Segmt  Flags    Master  msmt    msmt    dev   corr   sens  value   dev   corr  ()
--- -------- ---------   -----  -----  -----    ------ -----   -----  -----  -----  -----  -----  -----  -----  --
  1 jwd003a  1870 2001     132      7      0      .526   .92    7.83  1.210   .937   .324   2.05   .320   .004   1
  2 jwd003b  1872 2001     130      7      0      .480  1.15    5.03   .906   .842   .326   2.06   .325  -.010   1
  3 jwd004a  1870 2001     132      7      2      .476  1.68   16.64  2.921   .960   .265   1.96   .306  -.044   1
  4 jwd005a  1927 2001      75      4      0      .538  1.09    2.27   .464   .617   .285   2.23   .455  -.011   1
  5 jwd006a  1887 2001     115      6      0      .589  1.12    2.88   .586   .699   .311   2.12   .413  -.029   1
  6 jwd007a  1869 2001     133      7      0      .673  2.27   19.50  2.952   .859   .309   2.02   .307   .000   1
  7 jwd008a  1871 2000     130      7      2      .538  1.26   15.15  1.606   .870   .269   2.25   .425  -.022   1
  8 jwd008b  1871 1935      65      3      0      .649  2.33   17.79  2.638   .884   .286   2.32   .422  -.066   1
  9 jwd009a  1885 1959      75      3      0      .506   .69    2.57   .431   .749   .276   2.20   .474   .057   1
 10 jwd010a  1906 2001      96      5      0      .536  2.11    4.90   .801   .695   .226   2.03   .429  -.023   1
 11 jwd010b  1920 2001      82      4      0      .575  2.28    4.40   .737   .667   .226   2.00   .398   .016   1
 12 jwd011b  1930 2001      72      4      0      .397  2.08    4.76   .788   .656   .259   1.99   .389  -.038   1
 13 jwd012a  1940 2001      62      3      0      .464  1.13    2.30   .545   .774   .288   2.04   .508  -.056   1
 14 JWD013A  1874 2001     128      7      1      .497  1.06    6.02  1.082   .886   .341   2.35   .430   .051   1
 15 JWD014A  1874 2001     128      7      1      .506  2.09   11.38  2.228   .935   .265   2.10   .331   .002   1
 16 jwd015a  1900 1999     100      4      0      .481  1.36    2.48   .458   .624   .246   1.98   .317   .059   1
 17 jwd016a  1876 2001     126      7      3      .474  1.20    3.50   .668   .790   .299   1.97   .350   .064   1
 18 jwd017a  1904 2001      98      5      2      .408   .85    2.84   .521   .815   .334   2.22   .321  -.013   1
 19 jwd018a  1872 2001     130      7      1      .517  1.22    5.89   .820   .827   .295   2.14   .330   .017   1
 20 jwd018b  1872 1996     125      6      0      .479  1.28    5.86   .863   .821   .303   2.31   .412   .050   1
 21 jwd019a  1880 1948      69      3      0      .476   .86    2.93   .405   .556   .278   2.10   .409  -.020   1
 22 jwd020a  1873 2001     129      7      0      .608  1.03    4.11   .693   .802   .324   1.97   .347  -.017   2
 23 jwd020b  1873 2001     129      7      0      .631  1.35    3.38   .709   .718   .271   2.50   .396   .039   1
 24 jwd021a  1883 2001     119      6      1      .480   .69    3.01   .559   .821   .363   1.95   .269  -.071   1
 25 jwd023a  1874 1997     124      6      0      .563   .92    3.15   .657   .829   .319   1.96   .405   .009   1
 26 jwd023b  1874 1999     126      6      0      .606   .86    2.30   .503   .820   .293   2.01   .357   .026   1
 27 jwd024a  1871 2001     131      7      0      .563   .84    7.71  1.007   .895   .274   2.12   .391  -.001   1
 28 jwd024b  1871 1927      57      3      0      .519  1.18    5.99  1.144   .853   .287   2.14   .335   .015   2
 29 jwd025a  1871 2001     131      7      0      .546  1.10    6.92   .996   .907   .322   2.04   .350  -.017   1
 30 jwd026a  1882 1974      93      4      0      .545  1.42   10.16  1.513   .725   .338   2.03   .384   .053   1
 31 jwd028a  1946 2001      56      3      0      .551  1.78    3.56   .650   .399   .330   1.86   .328   .022   2
 32 JWD029A  1872 2001     130      7      0      .527  1.54    6.70  1.327   .916   .269   2.18   .476   .007   1
 33 JWD029B  1872 1987     116      6      1      .501  1.20    5.81   .838   .850   .312   2.16   .485   .073   1
 34 jwd030b  1930 2001      72      4      0      .467  1.52    3.43   .768   .824   .262   2.16   .390  -.012   1
 35 arb001a  1909 1958      50      2      0      .514  4.12   10.22  2.059   .549   .355   2.17   .538  -.107   2
```

36	arb004b	1890	1985	96	5	0	.466	1.67	7.93	1.294	.878	.325	2.18	.414	.005	1
37	arb005a	1890	2001	112	6	0	.575	1.66	4.77	1.095	.898	.271	2.03	.372	.005	2
38	arb005b	1908	2001	94	5	0	.498	1.16	2.46	.499	.650	.263	1.91	.309	-.058	1
39	arb007a	1891	2001	111	6	0	.552	1.95	8.84	1.960	.939	.272	1.93	.401	-.031	1
40	arb007b	1896	2001	106	6	2	.443	1.31	5.39	1.312	.945	.282	2.25	.512	-.015	1
41	arb008a	1892	2001	110	6	1	.443	2.02	7.86	1.531	.891	.314	2.09	.405	.011	1
42	arb008b	1893	1980	88	5	2	.517	2.12	6.87	1.562	.909	.280	1.93	.327	.020	1
43	arb009b	1889	1980	92	5	0	.462	1.84	8.10	1.862	.910	.301	1.99	.320	-.019	1
44	arb011b	1890	2001	112	6	0	.448	1.64	6.31	1.367	.919	.335	2.03	.391	-.021	1
45	arb013a	1887	2001	115	6	0	.526	2.27	7.57	2.065	.947	.275	2.07	.416	-.056	1
46	arb013b	1887	2001	115	6	0	.476	2.31	8.95	2.027	.927	.236	2.02	.395	-.011	1
47	arb016a	1940	2001	62	3	0	.608	2.21	5.52	1.441	.780	.324	1.94	.313	-.007	2
48	arb016b	1940	2001	62	3	0	.519	2.17	6.76	1.521	.829	.288	2.07	.385	.101	1

```
 PART 7:  DESCRIPTIVE STATISTICS:                                            13:02  Fri 10 OCT 2003  Page
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                                                    Corr  //-------- Unfiltered --------\\  //---- Filtered -----\\
                               No.    No.    No.    with   Mean   Max     Std   Auto   Mean   Max    Std   Auto  AR
 Seq Series   Interval       Years  Segmt  Flags   Master  msmt   msmt    dev   corr   sens  value   dev   corr  ()
 --- -------- ---------      -----  -----  -----  ------- -----  -----  -----  -----  -----  -----  -----  -----  --
  49 arb017a  1934 2001         68      4      0    .563   2.38   6.42  1.309   .792   .280   2.19   .464  -.006   1
  50 arb017b  1931 2001         71      4      0    .591   2.23   5.62  1.244   .661   .320   1.89   .336   .028   1
  51 arb019a  1956 2001         46      3      0    .551   2.15   3.91   .735   .355   .279   2.07   .485   .080   1
  52 arb019b  1956 2001         46      3      0    .592   2.24   3.47   .661   .084   .301   2.20   .498  -.035   1
  53 arb020b  1930 2001         72      4      0    .432    .92   2.37   .496   .716   .294   2.13   .347  -.029   1
  54 arb021a  1945 2001         57      3      0    .617   2.78   6.90  1.493   .640   .336   1.91   .449   .072   1
  55 arb021b  1945 2001         57      3      0    .451   2.28   6.09  1.228   .745   .316   2.09   .428  -.040   1
  56 arb022a  1910 2000         91      5      1    .393    .81   2.10   .447   .717   .329   1.99   .326   .024   2
  57 arb022b  1910 2001         92      5      1    .471   1.42   3.79   .723   .674   .304   2.16   .378   .050   1
  58 arb023b  1910 2001         92      5      1    .509   1.71   3.39   .713   .716   .251   2.15   .486   .006   1
  59 arb024a  1900 2001        102      5      0    .454   1.84   3.79   .814   .815   .211   2.07   .348  -.033   1
  60 arb024b  1900 2001        102      5      0    .447   1.64   3.77   .745   .856   .196   1.90   .307   .011   1
  61 arb026a  1915 2001         87      5      0    .488   1.56   3.90   .651   .678   .265   1.94   .311  -.025   2
  62 arb029a  1941 2001         61      3      1    .405   1.61   5.20   .900   .530   .344   2.19   .444   .066   1
  63 arb029b  1942 2001         60      3      0    .490   2.19   6.21  1.200   .570   .356   2.22   .535  -.002   1
  64 arb030a  1940 2001         62      3      0    .477   2.04   4.14   .811   .726   .238   1.96   .372  -.056   2
  65 arb030b  1920 2001         82      4      0    .527   1.92   4.17   .867   .739   .244   2.07   .427   .026   1
  66 arb031b  1888 1989        102      5      0    .525    .97   2.70   .600   .855   .259   2.06   .352   .036   1
  67 arb032a  1920 2001         82      4      0    .536    .94   1.83   .358   .427   .307   2.15   .501   .090   1
  68 arb032b  1902 2001        100      5      0    .498   1.02   2.16   .378   .541   .297   2.06   .498   .022   1
  69 arb033a  1890 2001        112      6      1    .405   1.04   3.36   .741   .853   .300   1.95   .330   .018   1
  70 arb034a  1890 2001        112      6      1    .421   1.24   3.35   .691   .772   .307   2.14   .429   .027   2
  71 arb034b  1890 2001        112      6      0    .443   1.29   3.25   .571   .723   .271   1.91   .337  -.015   2
  72 wrd001a  1933 1993         61      3      0    .540   3.07   9.87  2.776   .902   .332   1.91   .345  -.031   1
  73 wrd001b  1933 1971         39      1      0    .527   3.50  10.26  3.069   .898   .329   2.14   .498   .040   1
  74 wrd002a  1930 2000         71      4      0    .469   2.07   4.36  1.073   .748   .270   2.13   .502  -.002   1
  75 wrd002b  1929 2000         72      4      0    .438   2.24   4.68  1.136   .660   .380   2.18   .411   .034   1
  76 wrd005a  1932 2001         70      4      0    .534   3.20  13.92  3.194   .891   .368   2.03   .432  -.014   1
  77 wrd006a  1930 2000         71      4      0    .499   2.24   4.68  1.287   .920   .256   1.92   .393   .051   1
  78 wrd006b  1946 2001         56      3      0    .661   2.96   7.58  1.614   .766   .299   2.02   .455   .013   1
  79 wrd007a  1936 2000         65      4      0    .578   3.10   7.00  1.491   .714   .308   2.01   .401   .004   1
  80 wrd007b  1928 2000         73      4      0    .508   2.02  11.64  2.299   .925   .345   2.07   .427  -.077   1
  81 wrd008a  1928 2001         74      4      0    .637   1.84   6.90  1.228   .869   .256   1.98   .330   .009   1
  82 wrd009a  1930 1982         53      3      0    .617   4.27  13.17  4.148   .928   .303   1.89   .294  -.005   1
  83 wrd009b  1927 2001         75      4      0    .546   2.48  10.86  2.865   .952   .360   1.87   .315  -.011   1
```

```
 84 wrd011a  1935 2001     67       4     0   .494   3.38  11.15 2.843   .937   .276   1.92   .400   .000   1
 85 wrd011b  1929 2001     73       4     0   .420   3.46  13.69 3.518   .952   .280   2.05   .398  -.131   1
 86 wrd012a  1937 2001     65       4     0   .413   2.02   8.29 2.287   .938   .369   2.13   .414   .034   1
 87 wrd015a  1937 2001     65       4     0   .590   3.49  10.58 2.816   .927   .272   2.10   .489   .042   1
 88 wrd015b  1935 2001     67       4     0   .576   3.58   8.31 2.028   .879   .225   1.74   .298  -.052   1
 89 wrd016a  1938 1997     60       3     0   .506   2.51  10.35 2.669   .940   .261   1.89   .330  -.003   1
 90 wrd016b  1941 2001     61       3     1   .476   3.52  10.27 2.650   .925   .239   1.88   .317   .127   1
 91 wrd017b  1943 1993     51       2     0   .471   2.60   7.60 2.103   .880   .324   1.96   .348  -.049   1
 92 wrd018a  1946 1995     50       2     0   .657   2.93   7.47 1.812   .864   .242   1.94   .363  -.110   2
 93 wrd018b  1950 1996     47       2     0   .734   3.40   7.73 2.018   .869   .200   1.87   .340  -.032   1
 94 wrd020b  1937 2001     65       4     0   .581   2.05   6.68 2.048   .951   .304   2.03   .463  -.041   1
 95 wrd021a  1928 2001     74       4     1   .440   2.64   9.55 1.657   .745   .314   2.07   .377  -.020   1
 96 wrd021b  1930 2001     72       4     0   .424   2.46   7.15 1.356   .753   .292   1.84   .337   .051   1
```

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PART 7:  DESCRIPTIVE STATISTICS:                                          13:02  Fri 10 OCT 2003  Page
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                                                Corr   //-------- Unfiltered --------\\  //---- Filtered -----\\
                             No.    No.    No.   with   Mean   Max     Std   Auto   Mean   Max    Std   Auto  AR
Seq Series   Interval      Years  Segmt  Flags  Master  msmt   msmt    dev   corr   sens  value   dev   corr  ()
--- -------- ---------     -----  -----  -----  ------  -----  -----  -----  -----  -----  -----  -----  -----  --
 97 wrd024a  1946 2001        56      3      0    .596   3.07  10.25  2.562   .863   .309   2.01   .350   .021   1
 98 wrd024b  1946 2000        55      3      0    .452   3.46   8.84  2.709   .876   .288   1.93   .395  -.027   2
 99 wrd026a  1915 1990        76      4      0    .604   2.65   9.89  2.309   .891   .288   2.15   .451  -.098   1
100 wrd027b  1920 2001        82      4      0    .478   2.75   7.59  1.979   .858   .327   2.19   .477   .045   1
101 wrd028a  1927 2001        75      4      0    .614   2.48  15.19  2.861   .949   .292   2.09   .367  -.066   1
102 wrd028b  1930 2001        72      4      0    .609   2.32   8.61  1.609   .896   .285   2.04   .386  -.079   1
103 wrd029a  1928 2001        74      4      0    .615   3.20  11.92  2.179   .937   .213   1.93   .395  -.053   2
104 wrd029b  1930 2001        72      4      0    .565   2.78   7.81  1.396   .794   .225   1.99   .409  -.025   1
105 wrd030a  1929 2001        73      4      0    .647   2.07   9.83  1.678   .932   .246   1.98   .430  -.006   1
106 wrd030b  1930 2001        72      4      0    .608   1.74   8.87  1.496   .903   .323   1.87   .333   .023   1
107 wrd033b  1934 2001        68      4      0    .567   2.39   7.17  2.048   .945   .299   1.92   .382  -.035   1
108 wrd034b  1923 2001        79      4      0    .602   2.97   8.30  2.101   .902   .261   2.08   .356   .019   1
109 wrd037a  1950 2001        52      3      0    .685   3.87   7.53  1.443   .464   .301   2.10   .494   .008   1
110 wrd037b  1953 2001        49      3      0    .470   2.73   4.85  1.047   .491   .320   2.07   .452  -.012   2
111 ght001a  1922 1984        63      3      2    .434   1.07   3.57   .791   .667   .451   2.07   .425   .008   1
112 ght002a  1900 2001       102      5      1    .459   3.07  18.40  3.089   .942   .211   2.10   .320   .010   1
113 ght003a  1912 2001        90      5      2    .484   3.14  11.25  1.950   .785   .334   1.90   .293  -.072   2
114 ght005a  1900 2001       102      5      0    .666   2.35   7.63  1.422   .854   .277   1.97   .411   .039   1
115 ght006a  1912 2001        90      5      1    .563   1.44   3.42   .744   .576   .367   1.90   .370  -.017   1
116 ght007a  1913 2001        89      5      0    .523   1.76   4.03   .898   .591   .359   2.07   .430   .003   1
117 ght008a  1884 2001       118      6      0    .557   2.80  16.19  3.101   .941   .307   2.03   .274   .005   1
118 ght008b  1900 2001       102      5      0    .539   1.71   5.45  1.090   .756   .369   2.16   .508   .011   1
119 ght010a  1901 2001       101      5      0    .532   1.58   9.36  1.368   .860   .343   2.10   .400  -.007   1
120 ght015a  1950 2001        52      3      0    .606   3.83   7.21  1.261   .514   .263   1.86   .324  -.047   1
121 ght016a  1901 2001       101      5      0    .578   2.41   7.24  1.671   .901   .267   2.12   .376  -.006   4
122 ght016b  1896 2001       106      6      0    .482   1.92   6.43  1.656   .887   .318   1.77   .239  -.046   1
123 ght017a  1931 2001        71      4      0    .709   3.26  11.29  2.701   .840   .380   1.99   .390   .000   1
124 ght020a  1923 2001        79      4      0    .594   1.62   6.77  1.502   .920   .329   2.03   .353  -.039   1
125 ght020b  1923 1992        70      3      0    .701   2.11   5.70  1.519   .905   .355   1.99   .414  -.004   1
--- -------- ---------     -----  -----  -----  ------  -----  -----  -----  -----  -----  -----  -----  -----  --
Total or mean:             10697    562     33    .525   1.90  19.50  1.403   .808   .296   2.50   .385  -.002

                                    - = [  COFECHA COMBICOF  ] = -
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A-5. *Torreya taxifolia* COFECHA output.

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  PART 5:  CORRELATION OF SERIES BY SEGMENTS:                                                       13:05  Fri 19 SEP 2003
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-----
 Correlations of  40-year dated segments, lagged  20 years
 Flags:  A = correlation under   .3665 but highest as dated;  B = correlation higher at other than dated position

 Seq Series   Time_span   1820 1840 1860 1880 1900 1920 1940
                          1859 1879 1899 1919 1939 1959 1979
 --- -------- ---------  ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
   1 ghs002    1916 1960                      .59  .61  .58
   2 ghs003    1926 1969                           .41  .36A
   3 ghs004    1920 1960                           .50  .48
   4 ghs005    1886 1925                 .50
   5 ghs006    1910 1979                      .54  .48  .46
   6 ghs007    1915 1967                      .57  .54  .42
   7 ghs008    1915 1951                      .62
   8 ghs009    1915 1950                      .60
   9 ghs010    1889 1946                 .44  .54  .52
  10 ghs011    1814 1867  .40
  11 ghs013    1838 1889  .43  .42  .52
  12 ghs014    1891 1924                 .39
  13 ghs017    1900 1943                      .50  .51
  14 ghs018    1887 1955                 .61  .46  .44B
  15 ghs020    1917 1956                      .50
  16 ghs021    1833 1877  .38  .41
  17 ghs022    1944 1968                                .50
  18 ghs023    1888 1908                 .71
  19 ghs025    1885 1920                 .50
  20 abc012    1913 1958                      .59  .57
```

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 PART 6:  POTENTIAL PROBLEMS:                                                              13:05  Fri 19 SEP 2003  Page
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 For each series with potential problems the following diagnostics may appear:

 [A] Correlations with master dating series of flagged  40-year segments of series filtered with  32-year spline,
     at every point from ten years earlier (-10) to ten years later (+10) than dated

 [B] Effect of those data values which most lower or raise correlation with master series

 [C] Year-to-year changes very different from the mean change in other series

 [D] Absent rings (zero values)

 [E] Values which are statistical outliers from mean for the year
========================================================================================================================

 ghs002    1916 to  1960      45 years
Series   1

 [B] Entire series, effect on correlation (  .579) is:
       Lower   1949  -.063   1960  -.023   1918  -.016   1954  -.013  Higher   1927   .058   1942   .031   1956   .026   1940
.022

========================================================================================================================

 ghs003    1926 to  1969      44 years
Series   2

 [A] Segment    High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
   ---------    ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
   1930 1969      0    .03 -.42 -.14 -.14  .27  .15 -.06  .33  .29  .01  .36* .30 -.17 -.01 -.25 -.17  .01 -.27 -.21 -.02 -.09

 [B] Entire series, effect on correlation (  .395) is:
       Lower   1934  -.044   1966  -.037   1949  -.031   1937  -.020  Higher   1929   .037   1940   .026   1967   .023   1946
.022
     1930 to 1969 segment:
       Lower   1934  -.057   1966  -.046   1949  -.035   1955  -.023  Higher   1940   .035   1967   .031   1946   .030   1961
.027
```

```
 [E] Outliers     2   3.0 SD above or -4.5 SD below mean for year
       1949 +4.4 SD;    1966 +3.6 SD

=====================================================================================================================================

 ghs004    1920 to  1960      41 years
Series   3

 [B] Entire series, effect on correlation (  .475) is:
       Lower   1938  -.042   1932  -.035   1942  -.028   1960  -.027  Higher   1927   .034   1929   .033   1956   .026   1948
.020

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
       1938 +3.1 SD

=====================================================================================================================================

 ghs005    1886 to  1925      40 years
Series   4

 [B] Entire series, effect on correlation (  .497) is:
       Lower   1896  -.046   1911  -.033   1890  -.031   1925  -.030  Higher   1899   .120   1914   .053   1888   .016   1889
.013

=====================================================================================================================================

 ghs006    1910 to  1979      70 years
Series   5

 [*] Later part of series cannot be checked from 1970 to 1979 -- not matched by another series

 [B] Entire series, effect on correlation (  .476) is:
       Lower   1922  -.060   1968  -.029   1943  -.024   1955  -.023  Higher   1914   .045   1942   .030   1929   .028   1956
.024

=====================================================================================================================================

 ghs007    1915 to  1967      53 years
Series   6

 [B] Entire series, effect on correlation (  .483) is:
```

```
       Lower   1959  -.037   1962  -.035   1948  -.030   1933  -.020  Higher   1927   .096   1942   .029   1934   .019   1946
.018

==========================================================================================================================

 ghs008    1915 to  1951      37 years
Series   7

 [B] Entire series, effect on correlation (  .618) is:
       Lower   1932  -.046   1935  -.031   1918  -.029   1923  -.028  Higher   1927   .096   1942   .034   1916   .021   1940
.021

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
       1932 +3.5 SD

==========================================================================================================================

 ghs009    1915 to  1950      36 years
Series   8

 [B] Entire series, effect on correlation (  .604) is:
       Lower   1933  -.086   1941  -.021   1915  -.019   1942  -.019  Higher   1927   .082   1934   .059   1940   .027   1946
.011

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
       1933 +3.9 SD

==========================================================================================================================

 ghs010    1889 to  1946      58 years
Series   9

 [B] Entire series, effect on correlation (  .451) is:
       Lower   1899  -.044   1941  -.026   1922  -.020   1913  -.017  Higher   1927   .067   1934   .038   1914   .028   1945
.012

 [E] Outliers     4   3.0 SD above or -4.5 SD below mean for year
       1897 +3.1 SD;    1899 +4.5 SD;    1934 -4.5 SD;    1941 +3.1 SD

==========================================================================================================================
```

```
 ghs011    1814 to  1867      54 years
Series  10

 [*] Early part of series cannot be checked from 1814 to 1832 -- not matched by another series

 [B] Entire series, effect on correlation (  .404) is:
       Lower   1833  -.043   1862  -.041   1845  -.029   1851  -.020  Higher   1838   .048   1853   .026   1837   .020   1849
.015

 [E] Outliers     2   3.0 SD above or -4.5 SD below mean for year
       1847 +3.0 SD;    1858 +4.3 SD

================================================================================================================================

 ghs013    1838 to  1889      52 years
Series  11

 [B] Entire series, effect on correlation (  .455) is:
       Lower   1870  -.068   1847  -.049   1871  -.040   1888  -.027  Higher   1858   .151   1882   .036   1881   .019   1884
.015

 [E] Outliers     2   3.0 SD above or -4.5 SD below mean for year
       1870 +3.8 SD;    1871 +4.5 SD

================================================================================================================================

 ghs014    1891 to  1924      34 years
Series  12

 [B] Entire series, effect on correlation (  .395) is:
       Lower   1895  -.048   1908  -.026   1911  -.025   1896  -.024  Higher   1899   .224   1914   .061   1892   .018   1897
.017

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
       1912 +3.1 SD

================================================================================================================================

 ghs017    1900 to  1943      44 years
Series  13

 [B] Entire series, effect on correlation (  .532) is:
```

```
        Lower   1915  -.046   1925  -.031   1909  -.025   1919  -.022  Higher   1927   .113   1942   .045   1929   .034   1934
 .030
  [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
        1915 -4.7 SD
================================================================================================================================
 ghs018    1887 to  1955      69 years
Series  14

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
    ---------  ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
    1916 1955    2   -.04 -.06 -.18  .10 -.01 -.13 -.08 -.18 -.22 -.01  .44| .15  .47* .10  .13 -.26  .09 -.13 -.02 -.19 -.11

 [B] Entire series, effect on correlation (  .554) is:
       Lower   1897  -.017   1920  -.015   1896  -.013   1915  -.013  Higher   1899   .094   1914   .031   1944   .016   1916
 .013
     1916 to 1955 segment:
       Lower   1920  -.027   1954  -.021   1921  -.020   1940  -.018  Higher   1944   .038   1916   .030   1942   .028   1929
 .027

================================================================================================================================
 ghs020    1917 to  1956      40 years
Series  15

 [B] Entire series, effect on correlation (  .498) is:
       Lower   1928  -.048   1920  -.041   1950  -.039   1929  -.033  Higher   1934   .061   1927   .049   1956   .027   1942
 .025

================================================================================================================================
 ghs021    1833 to  1877      45 years
Series  16

 [B] Entire series, effect on correlation (  .388) is:
       Lower   1870  -.071   1842  -.057   1871  -.046   1833  -.032  Higher   1858   .202   1838   .043   1873   .019   1837
 .018

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
```

```
       1842 +3.7 SD
=========================================================================================================================================

 ghs022    1944 to  1968      25 years
Series  17

 [B] Entire series, effect on correlation (  .505) is:
       Lower   1957  -.083   1962  -.074   1950  -.025   1953  -.019  Higher   1944   .036   1967   .033   1961   .027   1958
.027

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 ghs023    1888 to  1908      21 years
Series  18

 [B] Entire series, effect on correlation (  .711) is:
       Lower   1897  -.119   1895  -.021   1894  -.018   1904  -.017  Higher   1899   .291   1888   .020   1889   .014   1908
.008

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 ghs025    1885 to  1920      36 years
Series  19

 [B] Entire series, effect on correlation (  .501) is:
       Lower   1903  -.085   1916  -.053   1911  -.038   1900  -.022  Higher   1899   .218   1914   .066   1888   .021   1897
.013

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 abc012    1913 to  1958      46 years
Series  20

 [B] Entire series, effect on correlation (  .495) is:
       Lower   1914  -.070   1955  -.031   1956  -.026   1954  -.020  Higher   1927   .089   1934   .027   1916   .023   1942
.020

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
       1914 +3.6 SD
```

```
 PART 7:  DESCRIPTIVE STATISTICS:                                                    13:05  Fri 19 SEP 2003  Page
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                                          Corr   //-------- Unfiltered --------\\  //---- Filtered -----\\
                     No.    No.    No.    with   Mean    Max     Std   Auto   Mean   Max    Std   Auto  AR
Seq Series   Interval  Years  Segmt  Flags  Master  msmt    msmt    dev   corr   sens  value   dev   corr  ()
--- -------- ---------  -----  -----  -----  ------ -----   -----  -----  -----  -----  -----  -----  -----  --
  1 ghs002   1916 1960     45      3      0   .579   1.26    3.59   .756   .501   .469   2.19   .513  -.056   1
  2 ghs003   1926 1969     44      2      1   .395   1.02    2.46   .402   .377   .269   2.37   .602   .014   1
  3 ghs004   1920 1960     41      2      0   .475   1.30    2.56   .581   .650   .327   2.09   .456   .029   1
  4 ghs005   1886 1925     40      1      0   .497   1.18    2.00   .405   .527   .306   1.90   .489  -.034   1
  5 ghs006   1910 1979     70      3      0   .476    .62    1.56   .371   .565   .396   2.26   .465   .024   1
  6 ghs007   1915 1967     53      3      0   .483   1.63    4.60   .958   .794   .341   2.02   .453   .022   1
  7 ghs008   1915 1951     37      1      0   .618   1.06    2.89   .704   .772   .282   2.14   .509  -.036   1
  8 ghs009   1915 1950     36      1      0   .604   2.65    6.52  1.804   .757   .391   2.13   .514   .042   1
  9 ghs010   1889 1946     58      3      0   .451    .76    3.27   .675   .779   .347   2.29   .422   .085   1
 10 ghs011   1814 1867     54      1      0   .404    .55    1.86   .404   .804   .296   2.12   .439   .014   1
 11 ghs013   1838 1889     52      3      0   .455   1.83    4.49  1.048   .811   .283   1.87   .311  -.022   1
 12 ghs014   1891 1924     34      1      0   .395    .87    2.54   .519   .515   .507   1.96   .514   .010   1
 13 ghs017   1900 1943     44      2      0   .532   1.13    2.60   .677   .713   .342   2.18   .450   .032   1
 14 ghs018   1887 1955     69      3      1   .554   1.28    2.99   .482   .210   .358   2.09   .387   .070   1
 15 ghs020   1917 1956     40      1      0   .498    .52     .95   .209   .697   .243   1.89   .453   .001   1
 16 ghs021   1833 1877     45      2      0   .388   1.33    3.25   .668   .484   .424   1.87   .385   .037   1
 17 ghs022   1944 1968     25      1      0   .505   1.23    2.65   .716   .764   .288   2.02   .574  -.120   1
 18 ghs023   1888 1908     21      1      0   .711   2.40    3.96   .885   .216   .411   2.02   .443   .166   6
 19 ghs025   1885 1920     36      1      0   .501   1.01    1.84   .405   .532   .320   2.16   .428   .004   1
 20 abc012   1913 1958     46      2      0   .495   1.15    2.94   .890   .768   .445   2.15   .470   .025   2
--- -------- ---------  -----  -----  -----  ------ -----   -----  -----  -----  -----  -----  -----  -----  --
Total or mean:            890     37      2   .495   1.18    6.52   .658   .614   .352   2.37   .456   .018

                                      - = [  COFECHA LAST COF  ] = -
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Vita

Elizabeth A. Atchley was born in Charleston, South Carolina on July 20, 1973. She attended Pinewood Academy before moving to Corryton, TN. In 1981. There, she attended Gibbs Elementary and High School until graduating in 1991. She attended the University of Tennessee, and graduated with a B.A. in Psychology in 1995. She then enrolled at the University of Tennessee in 1998 taking courses in botany and geography before entering the Department of Geography in the fall of 2000. Her thesis is entitled "The Effects of Habitat Alterations on Growth and Vitality of *Torreya taxifolia* Arnott. in Northern Florida, U.S.A.: a Dendroecological Study".