

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

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DEDICATION

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

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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 pestalocide (Lee *et al.*, 1995). Pestalocide 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 their 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 to 1918 (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 CO₂ 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 catastrophic, 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 convective 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 “tallahasseees” 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.

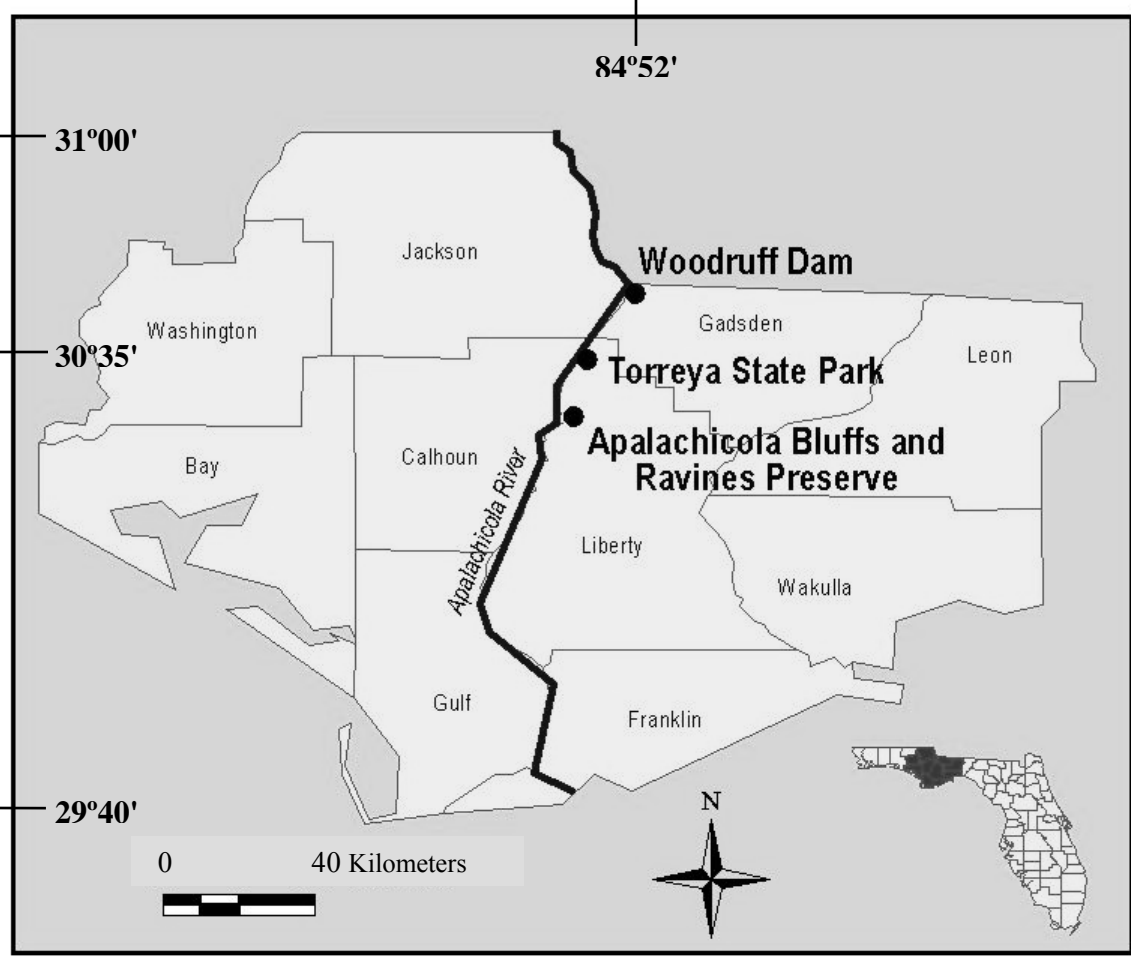


Figure 5.1 Map of collection sites along the Apalachicola River.



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, $500\text{--}595\mu\text{m}$ to ANSI 400-grit, $20.6\text{--}23.6\mu\text{m}$) 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. 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 (Schothauer 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
Torrey State Park	59	1890–2001	0.57
ABRP	41	1887–2001	0.54

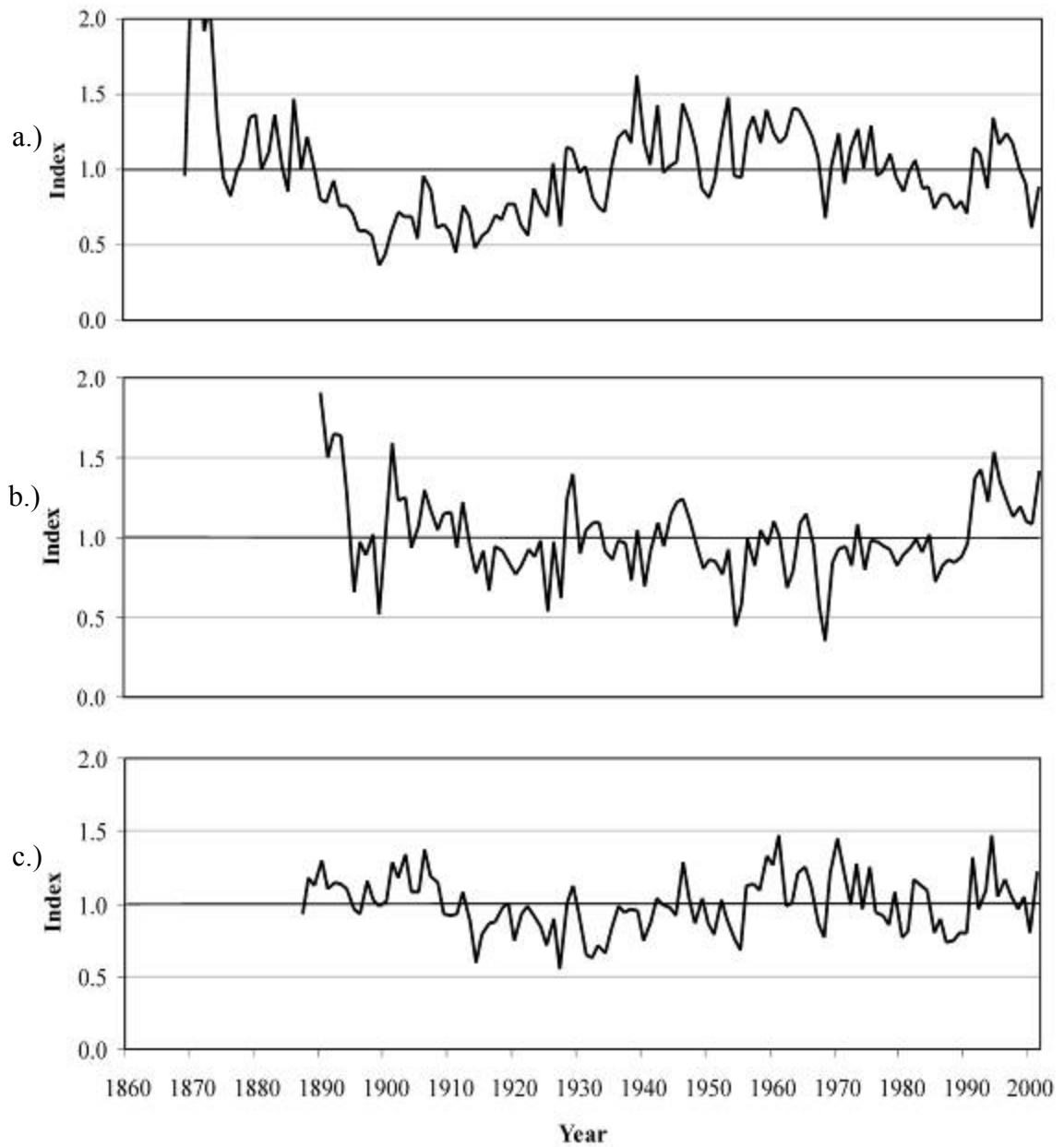


Figure 6.1 Graphs showing tree-growth within the individual site chronologies.
(a) Woodruff Dam chronology showing 19th and 20th century growth.
(b) Torreya State Park chronology showing 19th and 20th century growth.
(c) ABRP chronology showing 19th and 20th century growth.

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

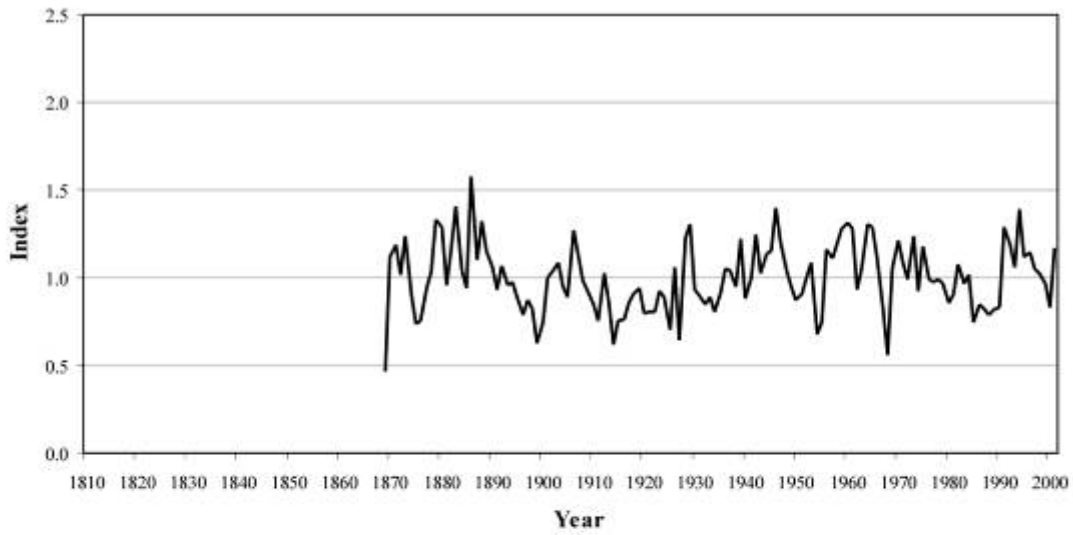
significantly higher correlations. The average mean sensitivity of the series for this site was 0.30. The mean ring width of this series was 1.7 mm, while the average standard deviation was 1.10.

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

a.)



b.)

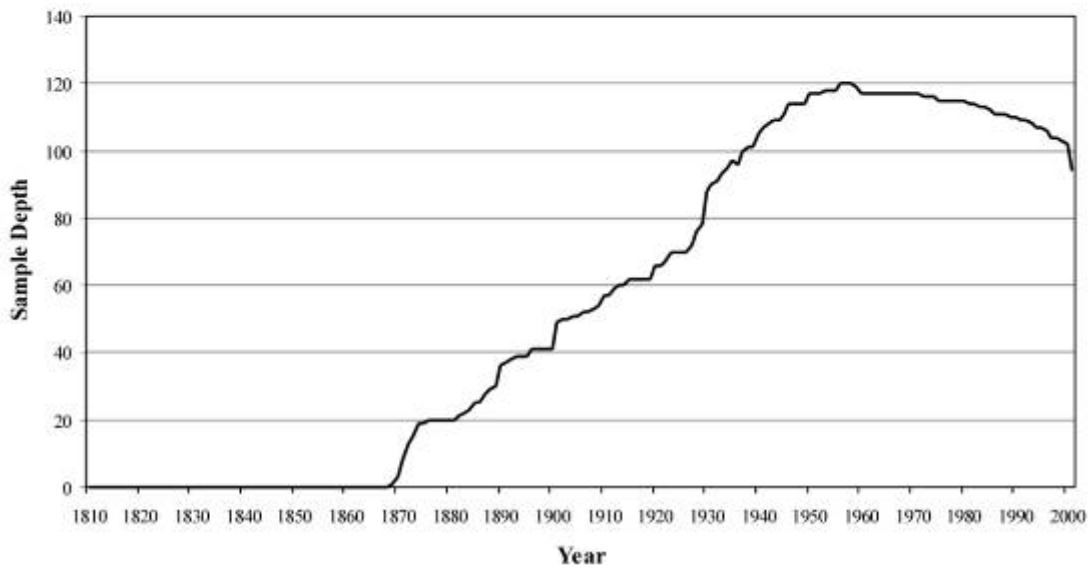


Figure 6.2 Graphs showing tree-growth and sample depth within the combined pine chronology.
(a) Combined pine chronology showing 19th and 20th century growth.
(b) Sample depth of each year within the combined pine chronology.

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
<i>Torreya taxifolia</i>	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

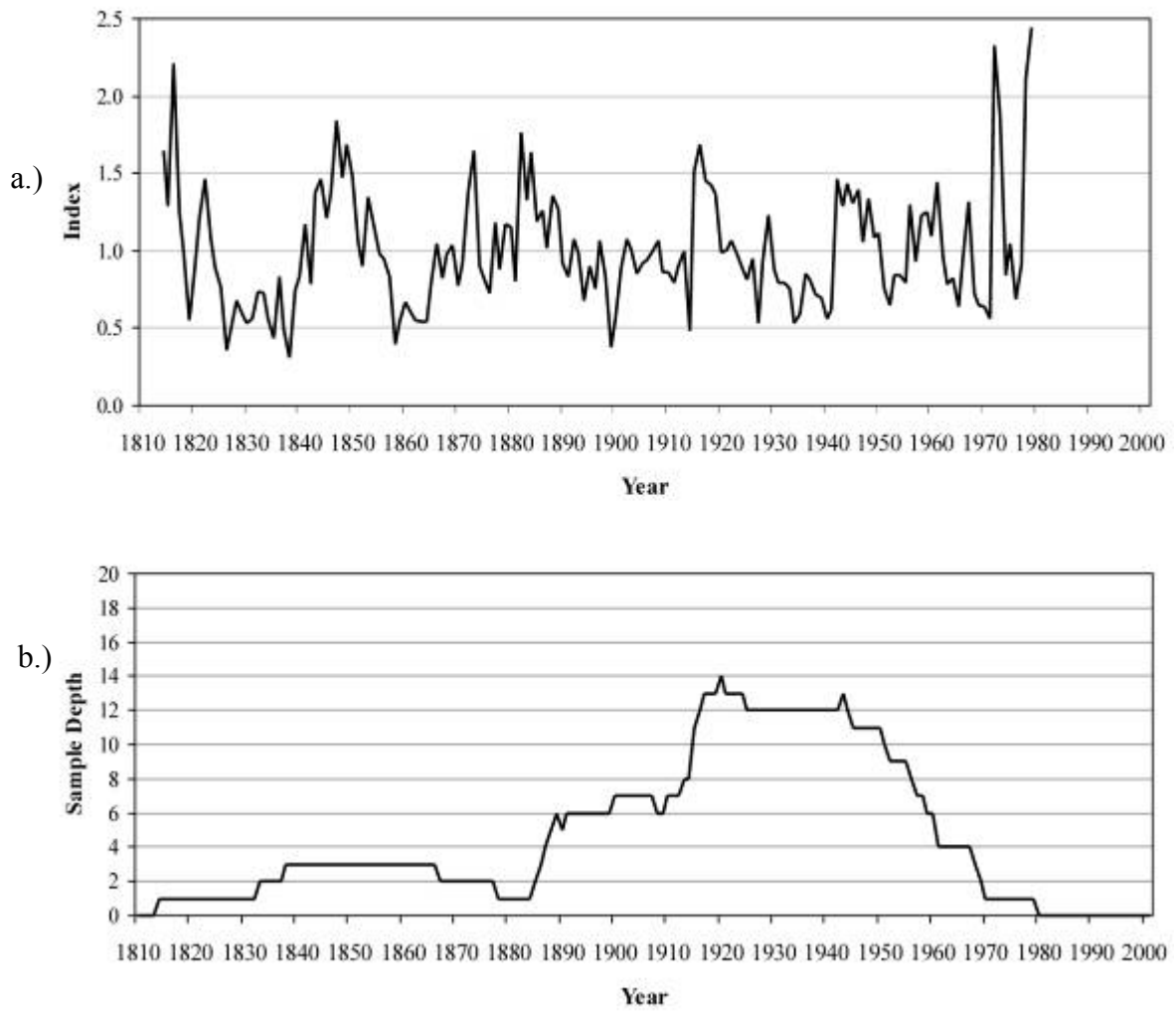


Figure 6.3 Graphs showing tree-growth and sample depth within the *T. taxifolia* chronology.
 (a) *Torreya taxifolia* chronology showing 19th and 20th century growth.
 (b) Sample depth for each year in the *T. taxifolia* chronology.

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.

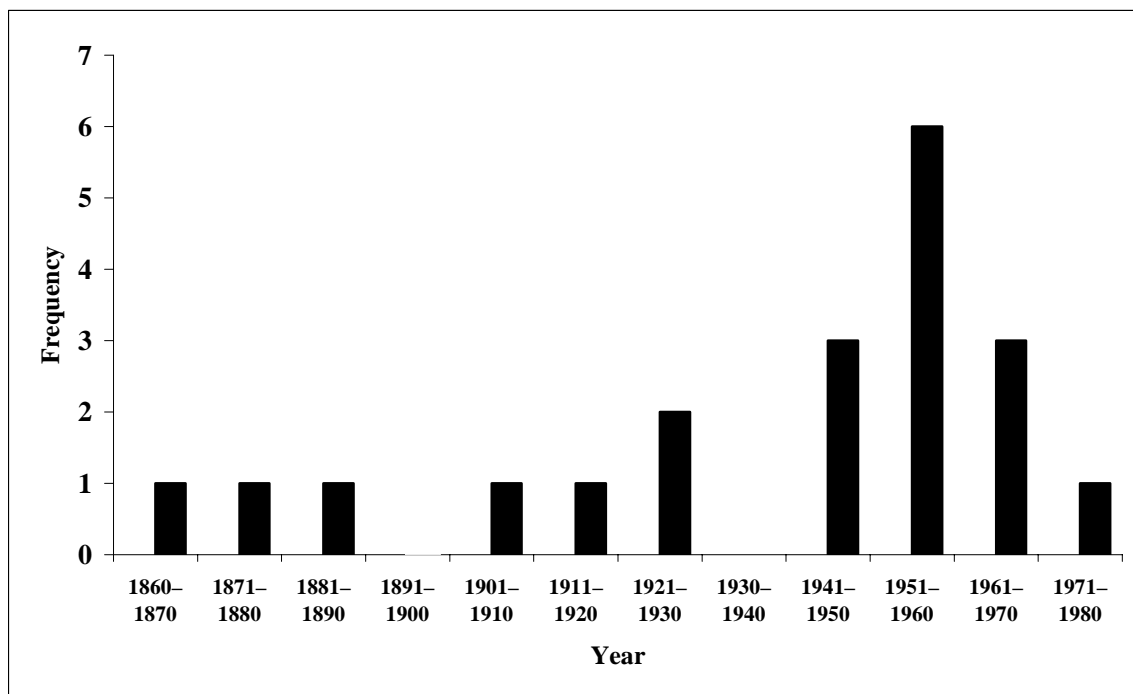


Figure 6.4 Histogram showing outside ring dates of the *T. taxifolia* cross sections.

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
Torrey 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

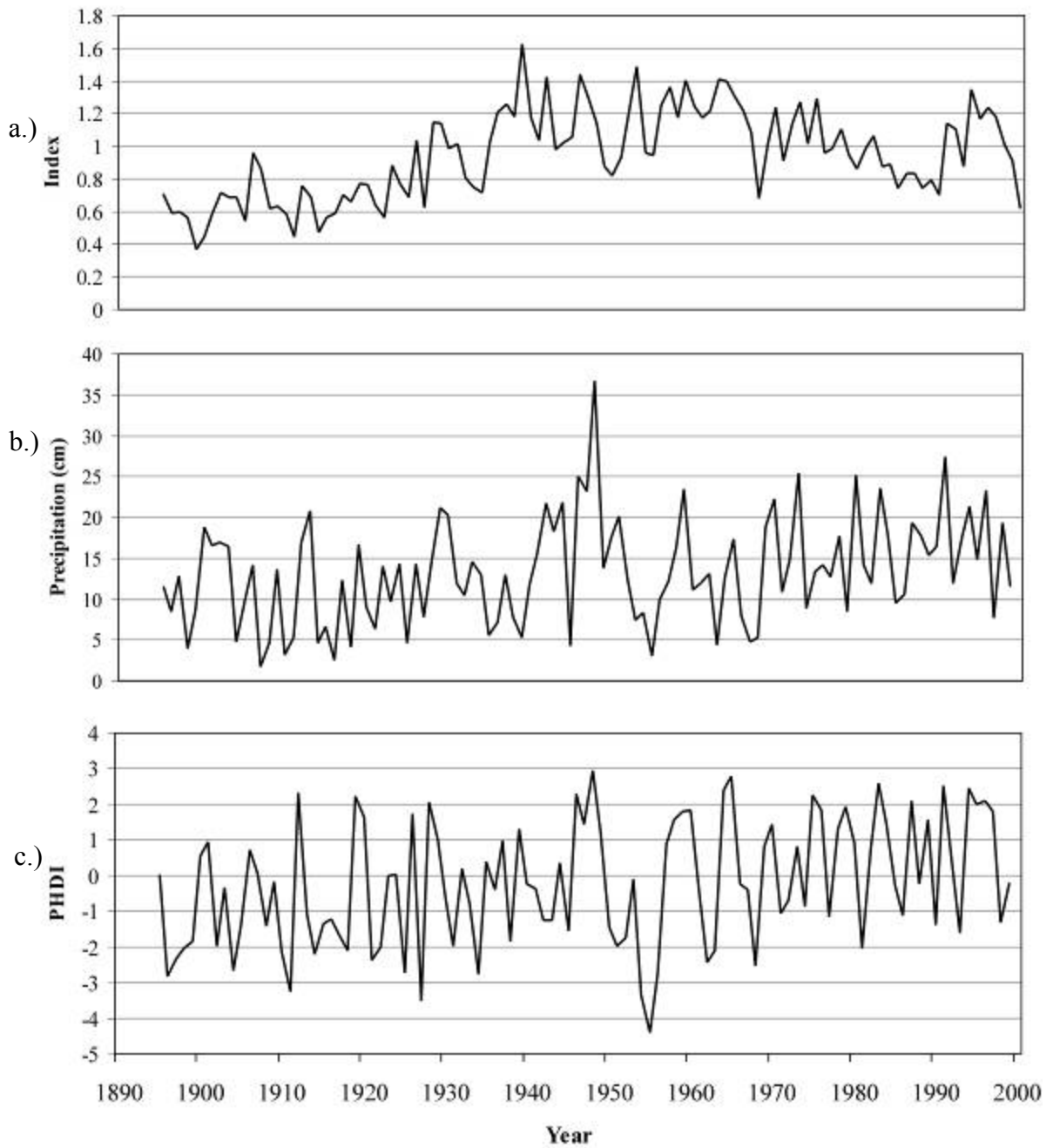


Figure 6.5 Graphs showing tree-growth and climate response at Woodruff Dam.

(a) Woodruff Dam chronology showing 20th century growth.

(b) 20th century March precipitation trends.

(c) 20th century April–September PHDI trends.

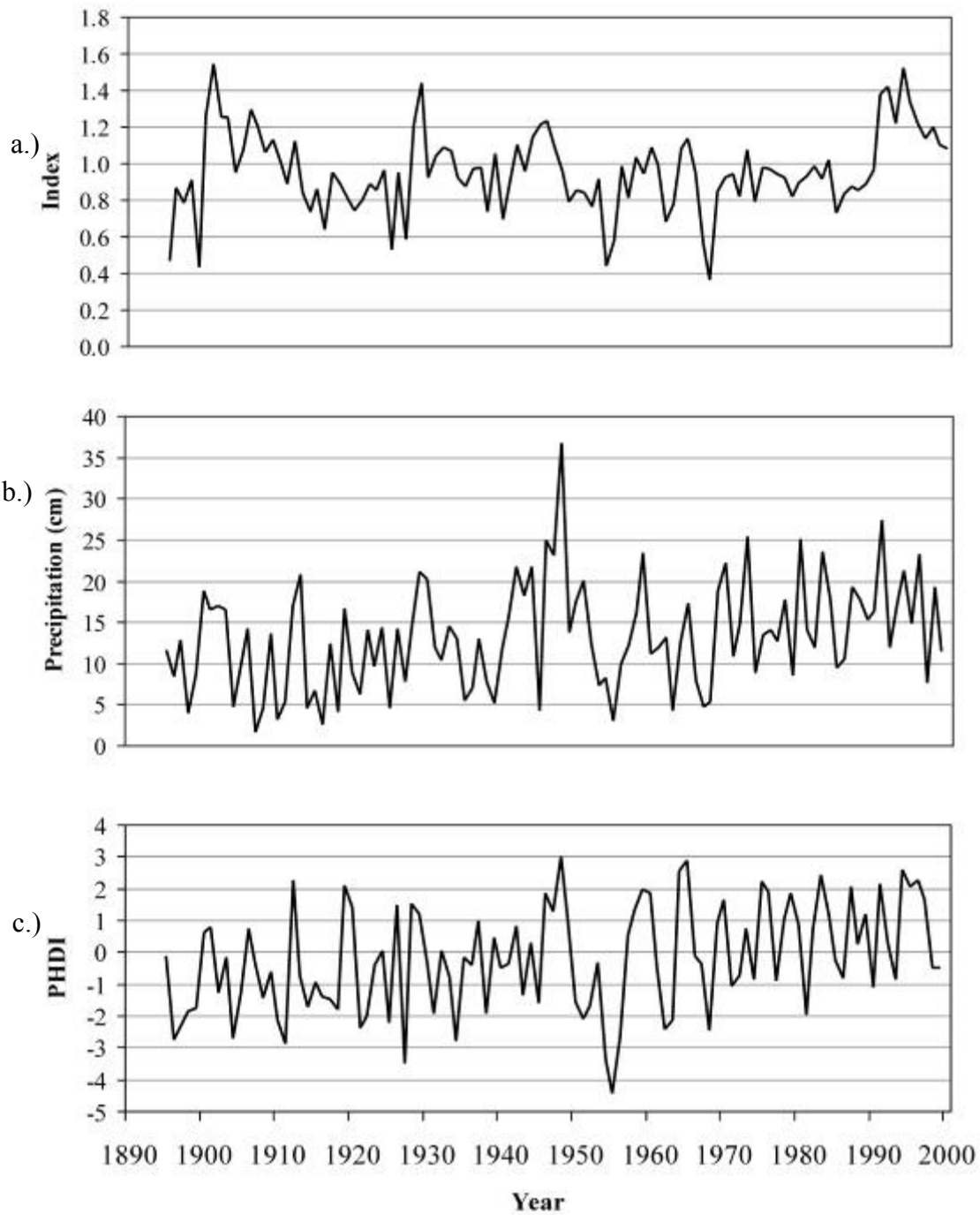


Figure 6.6 Graphs showing tree-growth and climate response at Torreya State Park.
 (a) Torreya State Park chronology showing 20th century growth trends.
 (b) 20th century March precipitation trends.
 (c) 20th century March–October PHDI trends.

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

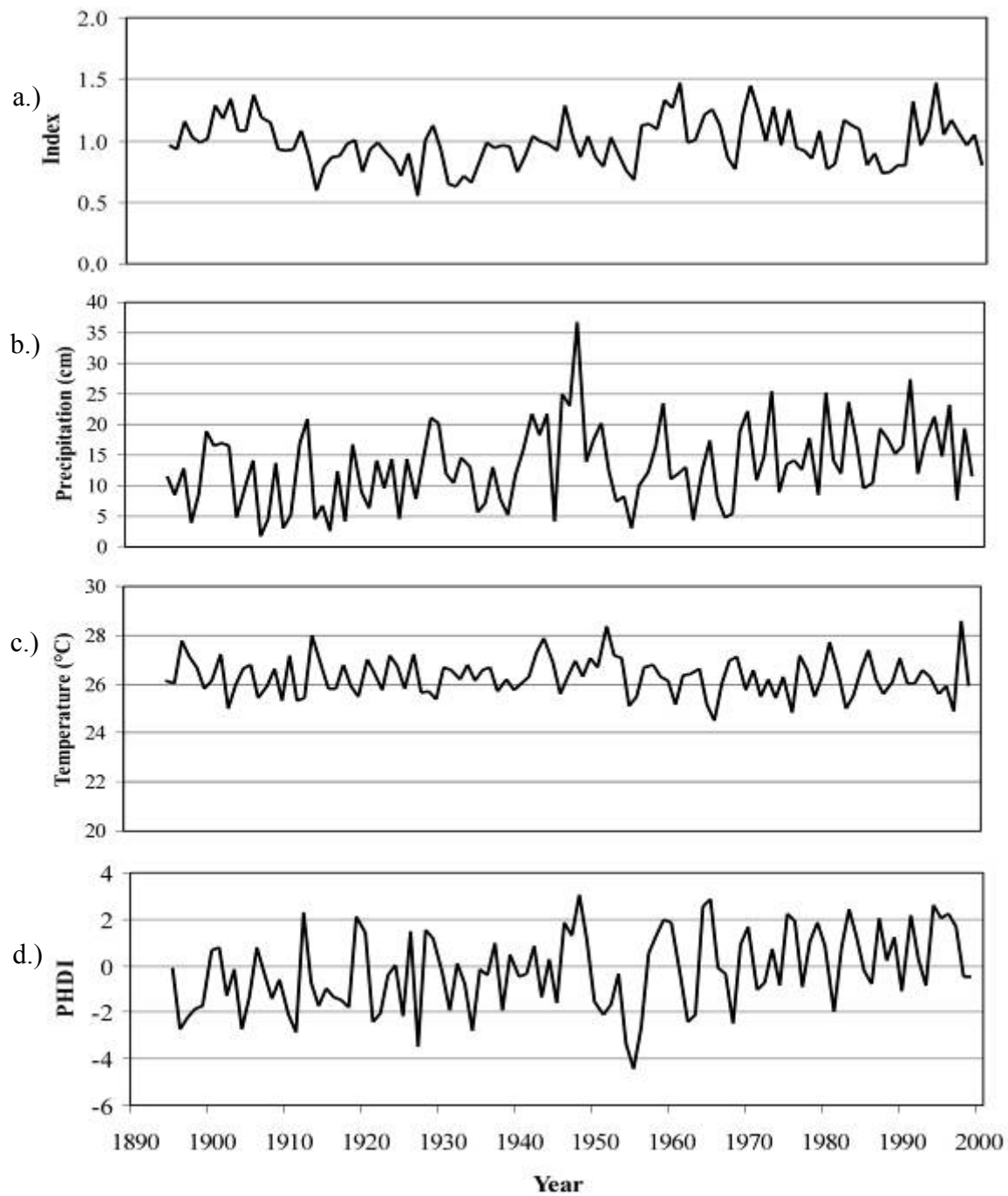


Figure 6.7 Graphs showing tree-growth and climate response at ABRP.

- (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.

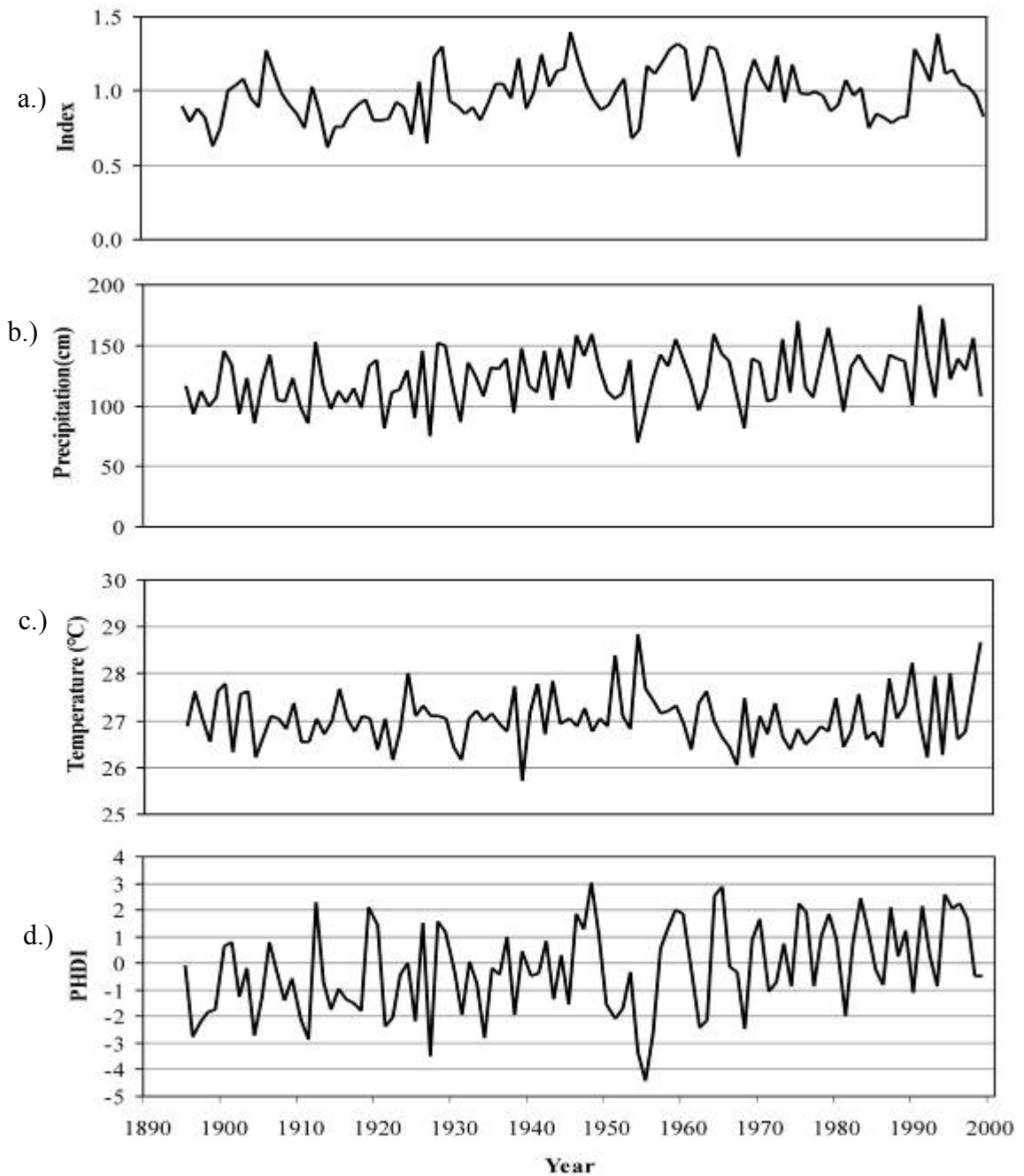


Figure 6.8 Graphs showing tree-growth and climate response for the combined pine series.

- (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
<i>Pinus spp.</i>	January–September $r = 0.65$ $p < 0.0001$	August $r = -0.22$ $p = 0.03$	March–October $r = 0.60$ $p < 0.0001$
<i>Torreya taxifolia</i>	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 a 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

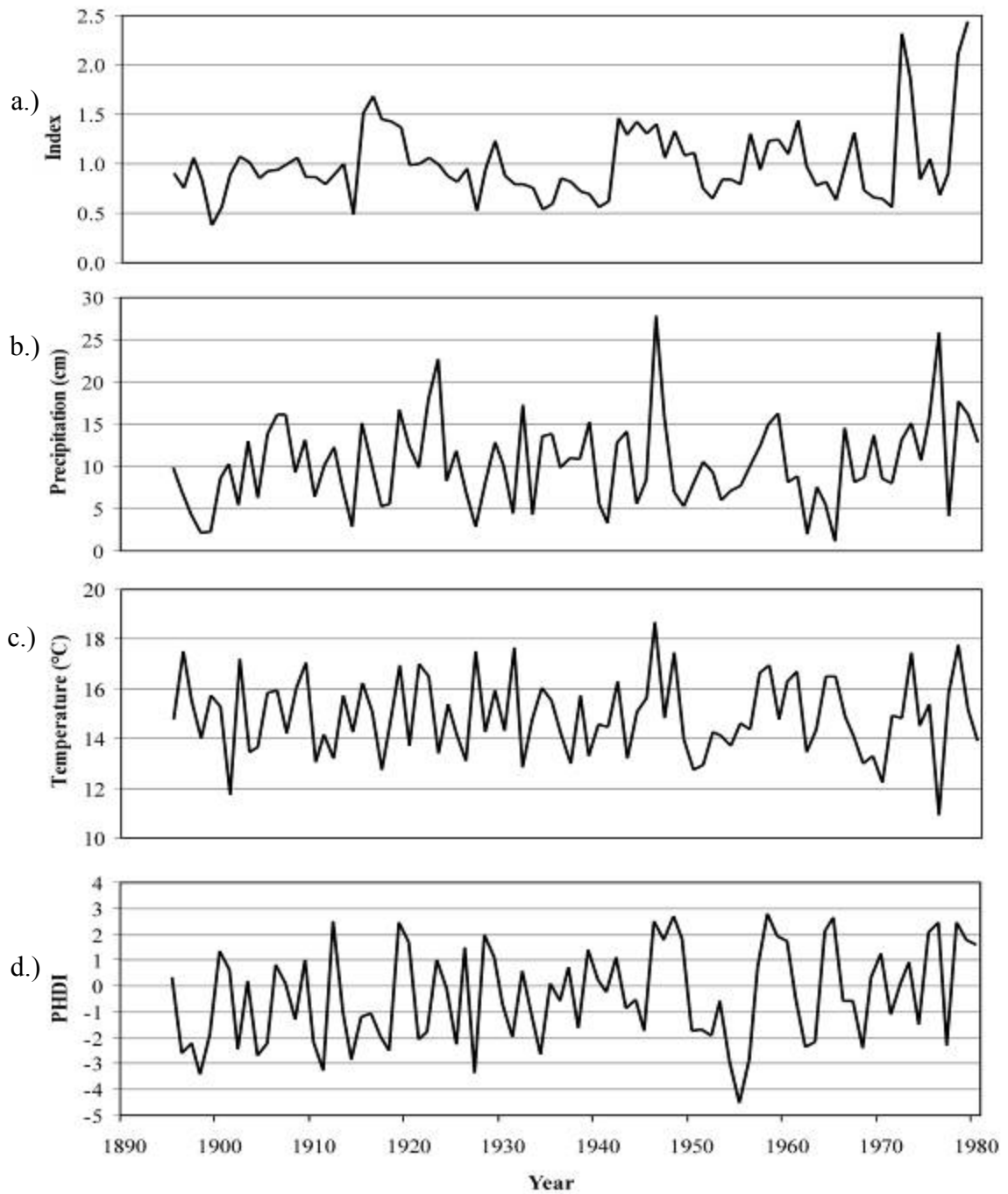


Figure 6.9 Graphs showing tree-growth and climate response for *T. taxifolia*.
 (a) *Torrey taxifolia* chronology showing 20th century growth.
 (b) 20th century May precipitation trends.
 (c) 20th century November temperature trends.
 (d) 20th century May–July PHDI trends.

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 Torrey 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 Torrey 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 predictor 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 20°C. 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 20°C. 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 20°C 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.

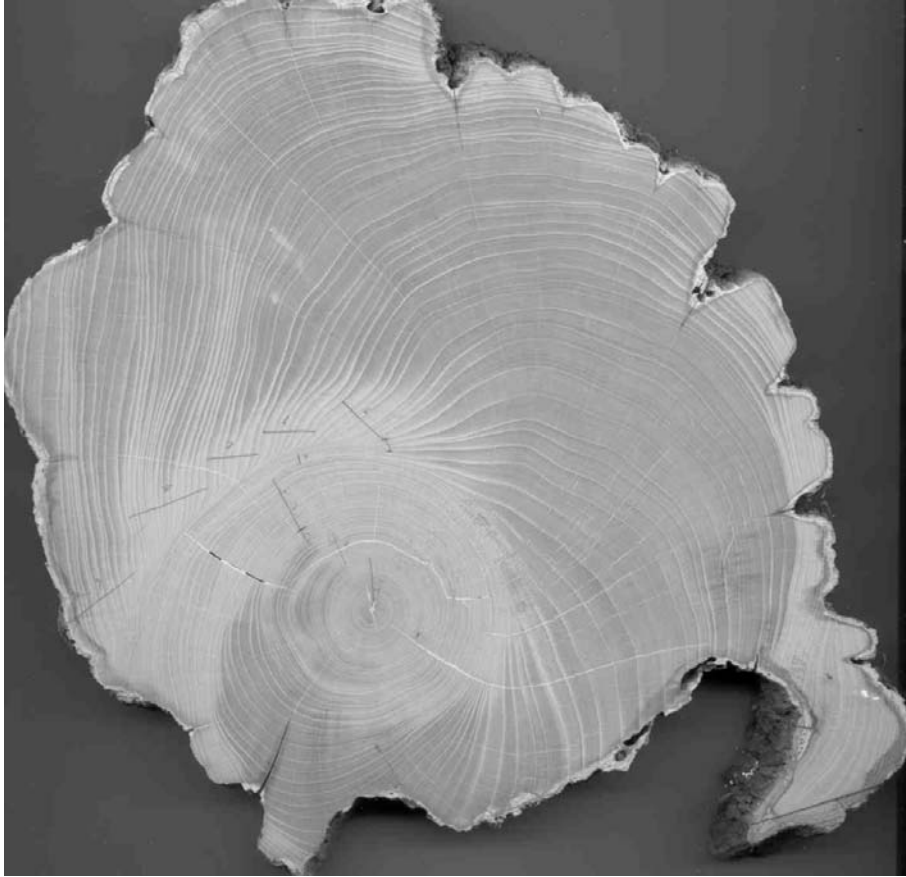
Increased runoff and erosion occur with the removal of upland vegetation as well. This overland runoff and erosion result in increased slumping of the soils in the ravines. Most of the *Torreya* cross sections possess reaction wood, illustrating the persistence of



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 ecosystems 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 phenomenon 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. 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 occurring 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

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

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

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:

1870 to 1909 segment:	Lower	1964	-.029	1996	-.022	1906	-.019	1954	-.013	Higher	2000	.018	1876	.018	1968	.016	1949	.014
1940 to 1979 segment:	Lower	1906	-.052	1884	-.041	1871	-.032	1897	-.028	Higher	1876	.089	1875	.028	1888	.028	1899	.023
	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

=====

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

=====

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:

```

Lower 1970 -.067 1982 -.039 1988 -.033 1976 -.025 Higher 1968 .049 1975 .049 1994 .038 1985 .031
=====
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
=====
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
=====
jwd005a 1927 to 2001 75 years Series 6

```

[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

=====

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

=====

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

=====

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

=====

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

=====
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

=====
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
=====

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
=====

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
=====

jwd012a  1940 to 2001      62 years                                     Series 16

```

[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

=====
 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

=====
 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

=====
 JWD014A 1874 to 2001 128 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
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

=====
 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

=====
 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

=====

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

=====

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

=====

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
=====

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
=====

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
=====
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
=====
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
=====
jwd023b  1874 to 1999    126 years                                     Series 31

```

[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

=====
 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

=====
 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

=====
 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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=====
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

=====
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

=====
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

=====

```

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

=====

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

=====

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

=====

PART 7: DESCRIPTIVE STATISTICS:

Seq	Series	Interval	No. Years	No. Segmt	No. Flags	Corr	//----- Unfiltered -----\\					//----- Filtered -----\\			
						with Master	Mean msmt	Max msmt	Std dev	Auto corr	Mean sens	Max value	Std dev	Auto corr	AR
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

 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	

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

=====

wrd006b 1946 to 2001 56 years Series 7

[B] Entire series, effect on correlation (.688) is:

Lower 1948 -.036 1959 -.018 1960 -.018 1984 -.015 Higher 1985 .035 1968 .024 1991 .015 1967 .014

```

=====
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

=====

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

=====

```

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

=====

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

=====

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

=====
 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

=====
 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

=====
 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

=====

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

=====

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

=====

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:

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

=====
 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

=====
 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

=====
gh002a 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

=====
gh003a 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

=====
gh004b 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

=====
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

=====
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

=====
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

=====
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

=====
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

=====

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

=====

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

=====

Seq Series	Interval	No. Years	No. Segmt	No. Flags	Corr	Unfiltered					Filtered				AR ()
					with Master	Mean msmt	Max msmt	Std dev	Auto corr	Mean sens	Max value	Std dev	Auto 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

Seq Series	Interval	No. Years	No. Segmt	No. Flags	Corr	//----- Unfiltered -----\\				//---- Filtered ----\\				
					with Master	Mean msmt	Max msmt	Std dev	Auto corr	Mean sens	Max value	Std dev	Auto corr	AR
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

 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
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
39	arb033a	1890	2001	.48	.64	.41B	.50	.66
40	arb034a	1890	2001	.55	.51	.51	.64	.69
41	arb034b	1890	2001	.50	.56	.68	.58	.66

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

=====
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

=====
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

=====

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

=====

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

=====

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

=====

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

=====
 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

=====
 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

=====

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

=====

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

=====

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:

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

=====

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

=====
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

=====
arb016a 1940 to 2001 62 years Series 14

[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

=====
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

```

=====
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

=====

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

=====

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

=====

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

=====

arb020b  1904 to 2001      98 years                                     Series 20

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[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

=====
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

=====
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

=====
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

=====
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

=====

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

=====

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

=====

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

=====

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

=====

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

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

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

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

=====

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

=====

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

=====

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

=====

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

=====

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

=====
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

=====
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

=====
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

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
-------	------	-------	------	-------	------	-------	------	-------	--------	------	------	------	------	------	------	------	------

=====

Corr		//----- Unfiltered -----\\					//---- Filtered ----\\								
Seq	Series	Interval	No. Years	No. Segmt	No. Flags	with Master	Mean msmt	Max msmt	Std dev	Auto corr	Mean sens	Max value	Std dev	Auto corr	AR
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

 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	

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
=====

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
=====

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
=====

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

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

=====

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

=====

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

=====

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

=====

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

=====

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

=====

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

=====

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

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

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

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

=====

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

=====

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

=====

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

=====

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

=====

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

=====

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

=====

jwd020b 1873 to 2001 129 years Series 23

[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

=====

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

=====

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

=====

jwd023b 1874 to 1999 126 years Series 26

[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

=====

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

=====

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

=====

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

=====

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

=====

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

=====

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

=====

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

=====

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

=====

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
=====

```

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

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

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

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

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
-------	------	-------	------	-------	------	-------	------	-------	--------	------	------	------	------	------	------	------	------

=====

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

=====

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

=====

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

=====

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

=====

arb017a 1934 to 2001 68 years Series 49

[B] Entire series, effect on correlation (.563) is:

Lower 1972 -.032 1998 -.014 1938 -.014 1988 -.012 Higher 1994 .025 1991 .019 1967 .017 1975 .013

=====
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

=====
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

=====
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

=====
arb020b 1930 to 2001 72 years Series 53

[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

=====
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

=====
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

=====
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

=====
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

=====

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

=====

arb024a 1900 to 2001 102 years Series 59

[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
-------	------	-------	------	-------	------	-------	------	-------	--------	------	------	------	------	------	------	------	------

=====

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

=====

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

=====

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

=====

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

=====

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

=====

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

=====

arb031b 1888 to 1989 102 years Series 66

[B] Entire series, effect on correlation (.525) is:

Lower 1940 -.025 1954 -.021 1892 -.017 1960 -.017 Higher 1914 .029 1968 .028 1928 .019 1985 .018

=====

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

=====

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

=====

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

[C] Year-to-year changes diverging by over 4.0 std deviations:

1891 1892 -4.2 SD

=====

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

=====

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

=====

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

=====

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

=====

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

=====
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

=====
wrd005a 1932 to 2001 70 years Series 76

[B] Entire series, effect on correlation (.534) is:

Lower 1957 -.042 1934 -.032 1940 -.030 1939 -.021 Higher 1954 .063 1968 .026 1985 .022 1975 .014

=====
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

=====
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

=====

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

=====

wrd007b 1928 to 2000 73 years Series 80

[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

=====

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

=====

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

=====
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

=====
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

=====
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

=====
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

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

=====

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

=====

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

=====

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

=====
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

=====
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

=====
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

=====
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

=====

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

=====

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

=====

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
-------	------	-------	------	-------	------	-------	------	-------	--------	------	------	------	------	------	------	------	------

=====

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

=====

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

=====

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

=====

wrd028a 1927 to 2001 75 years Series 101

[B] Entire series, effect on correlation (.614) is:

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

=====

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

=====

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

=====

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

=====

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

=====

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

=====
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

=====
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

=====
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

=====
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

=====

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

=====

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

=====

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

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
-------	------	-------	------	-------	------	-------	------	-------	--------	------	------	------	------	------	------	------	------

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

=====

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

=====

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

=====

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

=====

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

=====

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

=====

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

=====

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

=====

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

=====

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

=====

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

=====

Seq Series	Interval	No. Years	No. Segmt	No. Flags	Corr	//----- Unfiltered -----\\					//---- Filtered ----\\			
					with Master	Mean msmt	Max msmt	Std dev	Auto corr	Mean sens	Max value	Std dev	Auto corr	AR
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

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Corr //----- Unfiltered -----\\ //---- Filtered -----\\
with Mean Max Std Auto Mean Max Std Auto
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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-----
                Corr //----- Unfiltered -----\\ //---- Filtered -----\\
                with Mean Max Std Auto Mean Max Std Auto
Seq Series Interval No. No. No. 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] = -

A-5. *Torreya taxifolia* COFECHA output

 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	

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

=====

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

=====

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

=====

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

=====

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-----\\
//----- Unfiltered -----\\ //---- Filtered -----\\
Corr 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

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- = [COFECHA LAST COF] = -

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”.