An Ancient Red Cedar Woodland in the Oklahoma Cross Timbers

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By

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Abstract

Eastern Red Cedar (*Juniperus virginiana*) is the most widely distributed conifer in the eastern United States of North America. This species is commonly thought to be invasive due to its early successional status and ability to rapidly dominate the vegetation of disturbed areas. It is believed this species has dramatically increased in abundance along with the increasing human footprint on the native landscape.

This research looks at the native ecological niche of this species, the rocky fire-protected escarpments where it has survived in natural stands for hundreds of years. The Keystone Ancient Forest Preserve of Osage County, Oklahoma, is an outstanding example of this native habitat. Here a unique opportunity is presented to study eastern red cedar living under its natural conditions, rather than the disturbed environments it so often dominates. Results from this study suggest that this relatively undisturbed post oak forest is fairly resilient to the massive cedar invasion seen elsewhere in this region. Age structure data collected reveals that eastern red cedar has continuously recruited over the last 300 years and can live for over 500 years at this site. Annual ring width was found to have an unusual growth response to warm moist conditions in later winter that may take advantage of high solar radiation during the dormant leaf-off period of post oak. A 360-year long tree-ring chronology developed from the annual growth rings of eastern red cedar has potential to be doubled in length with a greater collection of remnant wood. False rings were found to cross-date amongst samples and these events were found to be correlated with drastic weather reversals in the mid-to-late growing season (May-July) where an extended cool pluvial event would relieve weeks of very hot and dry conditions.

<u>Introduction</u>

Eastern red cedar (*Juniperus virginiana*) is the most widely distributed native conifer of the eastern United States (Little, 1971; Figure 1). Red cedar is an early successional species and has become a problematic invader of grassland and forest as a result of over-grazing, logging, fire suppression, and the self-enhancing effect of "seed rain" (fertilized cedar seeds in bird droppings) due to the exploding populations of the species in the wake of human disturbance. Many research efforts involving eastern red cedar investigate the invasive problem presented by this plant (Rykiel 1983; Smeins and Merrill 1988; Engle et al. 2000). Historically, eastern red cedar is thought to have filled a smaller ecological niche restricted to limestone flats, rock outcrops, and steep, rocky, fire-protected terrain. Undisturbed forests with old-growth eastern red cedar trees are extremely rare today due to the heavy exploitation of this species for timber.

The Cross Timbers of Oklahoma have been found to preserve perhaps the most extensive remaining stands of ancient eastern red cedar in all its native range (Stahle et al. 1996). The Cross Timbers forms an ecotone between the eastern deciduous forest and the grasslands of the southern Great Plains. This forest ecosystem is believed to be one of the least disturbed forest types in the eastern U.S., due to the noncommercial nature of its slow-growing, drought stressed trees (Stahle et al. 1996; Therrell and Stahle 1998). Eastern red cedar is most common as an early colonizer but centuries-old red cedar are also found on rocky, fire-protected terrain in the Cross Timbers along with ancient post oaks (*Quercus stellata*) and blackjack oaks (*Quercus marilandica*). The Keystone Ancient Forest Preserve (KAFP) located in southern Osage County, Oklahoma, includes over 1600 acres of outstanding old-growth Cross Timbers forest. Extensive stands of ancient red cedar surrounded by an undisturbed old-growth post oak forest are present at the KAFP. This site presents a unique opportunity to study the longevity, recruitment, and growth response of red cedar to weather and climate in its natural ecological setting.

This study focuses on an undisturbed ancient eastern red cedar stand. All red cedar trees ≥5 cm diameter at breast height (dbh) growing in fixed plots covering a total area of 1 hectare (ha) were cored to document the age structure for red cedar in this stand. All trees (≥ 5cm dbh) were mapped with sub-meter accuracy in a selected 0.25- ha fixed plot and an accurate stem map was prepared. This map provides an interesting baseline for the study of vegetation change in an old-growth oak-red cedar woodland. Cores collected for age data were used along with cores from selected older cedars and remnant wood to establish the first cedar tree-ring chronology for Oklahoma and to investigate its potential for the reconstruction of weather and climate extremes.

Background

Eastern Red Cedar

There is scarcely another tree of the eastern United States that exhibits greater indifference to soil and climate than eastern red cedar (Mohr 1901). This species is found from New Brunswick to Georgia in the East and from eastern North Dakota to eastern Texas in the West. Eastern red cedar is not a true cedar, but a juniper that belongs to the *Cupressaceae* family. This family of trees includes some of the most magnificent tree species on Earth including: coast redwood (*Sequoia sempervirens*), giant sequoia (*Sequoiadendron giganteum*), and bald cypress (*Taxodium distichum*). In the southeastern United States, eastern red cedar reached heights of 25-30 m, with a dbh of

1 m (Mohr 1901). Tree-ring studies in Missouri and West Virginia have indicated that this species can reach maximum ages of over 800-years (E. R. Cook and R.P. Guyette, personal communications). The resistance of red cedar to rot and decay and its softness has made this tree a valued timber species. By the turn of the 20th century, many historic accounts of red cedar claimed that only in the highly broken and rocky lands, too remote for ready transportation, did tracts of virgin timber escape the axe (Mohr 1901). Cedar wood uses include shipbuilding, fence posts, cabinetry, furniture, and pencils.

Birds feeding upon the fruit of female eastern red cedars assist in scattering the seed (Mohr 1901: Rykiel 1983: Holthuijzen and Sharik 1984, 1985). Seedlings and saplings are commonly seen growing in a halo around hardwood trees. This is known as the "perch effect," where birds eat the cedar seeds, which pass through the body unharmed, and excrete fertilized seed pellets around the base of the hardwood. Seeds eaten by birds often germinate promptly. Previous analysis indicates that juniper establishment occurs preferentially beneath trees as opposed to more open grasslands (Fontenyn et al.1988).

Fires are disastrous to red cedar due to its thin bark, shallow root system, and flammability (Mohr 1901: Rykiel 1983: Smeins and Merrill 1988: Clark 2005). In presettlement times this fire-sensitive species was usually confined to ravines and limestone outcrops where it was protected from fires. Fire suppression favors the dominance of juniper, and this is exacerbated by grazing, since deer and livestock preferentially select forbes, then grasses, then hardwoods, eating juniper only under the most severe conditions (Fontenyn et al. 1988). Grazing also reduces the frequency and severity of fire.

Invasion by juniper may be the natural course of ecological succession in the absence of fire (Smeins and Merrill 1988). Eastern red cedar is a highly adaptive early successional species, which means it is often the first and most effective colonizer of disturbed sites. This plant has been demonstrated to be increasing in its natural abundance along with the increasing human footprint on the landscape. Human activity, particularly overgrazing and fire suppression, have led to an evident increase in this species, especially on the southern Great Plains (Smeins and Merrill 1988; Engle et al. 2000). In many circumstances this plant is regarded as a noxious invasive weed.

Remnants of the historic native niche of eastern red cedar are scarce today. Small stands of sparsely scattered old trees can be found on cliff faces and rock ledges (Guyette 1991). However, few large, undisturbed sites remain where ancient red cedar can still be found growing in its natural setting.

Cross Timbers

The development of hundreds of tree-ring chronologies in the eastern United States indicates that many relatively undisturbed ancient forest remnants still exist, even though presettlement forest were heavily logged (Therrell and Stahle 1998). Ancient forest relics tend to survive today on noncommercial sites which were not economic for logging (Stahle 1996b: Larson et al. 2000). The Cross Timbers is an ecotone between the eastern deciduous forest and the grasslands of the southern Great Plains (Rice and Penfound 1959). Extensive dendrochronological research by the University of Arkansas Tree-Ring Laboratory indicates that large intact tracts of ancient forest remain in this region, and that this biogeographical province may in fact be one of the least disturbed forest types remaining in the eastern United States. Tree growth in the Cross Timbers is typically very slow due to relatively low rainfall and because the soils are often low in fertility. This entire forest ecosystem is essentially non-commercial for timber production (Rossen 1994; Therrell and Stahle 1998).

The Cross Timbers stretch from central Texas, across Oklahoma, into southeastern Kansas, with a small component extending into western Arkansas. This transition zone is characterized as savannah woodland, dominated by a post oak-blackjack oak overstory and a grassy understory (Rice and Penfound 1959, Kuchler 1964). This ecosystem preserves some of the best remnant samples of true savannah in the eastern United States. Fine verses coarse-textured soils often account for the alternating patterns of prairie, savannah, and woodland vegetation cover. Eastern red cedar was a relatively minor species of the Cross Timbers, typically restricted to rocky fire-protected habitats. But red cedar is the oldest tree species in the Cross Timbers, with some individuals over 500 years old.

The valleys and flat hill tops of the Cross Timbers have often been developed for agriculture, but the rocky slopes have been left mostly undisturbed. From observations in the field, the University of Arkansas Tree-Ring Laboratory has found that places with steep slopes, rocky soils, and forest cover are still relatively undisturbed throughout the Cross Timbers (e.g., Griffin et al. 2005). These parameters were used in a GIS predictive modeling effort to find remaining old-growth forest in this region (Figure 2: Therrell 1997; Bayard 2003; Peppers 2004). One of the best examples of an old-growth Cross Timbers forest was found on the rugged uplands near the confluence of the Arkansas and Cimarron Rivers in Osage County, Oklahoma (Stahle et al. 1996). This site includes extensive stands of ancient red cedar, and has been set aside as the Keystone Ancient Forest Preserve.

The Ancient Cross Timbers Consortium has recently been established for the research, conservation, education, and recreational opportunities presented by the relatively pristine woodlands in this ecosystem (www.uark.edu/xtimber). One of the primary goals of the Ancient Cross Timbers Consortium is to establish a network of research natural areas throughout this ecosystem. The recent protection of the Keystone Ancient Forest Preserve has been a great success for the Consortium, the Oklahoma Nature Conservancy, and the city of Sand Springs, Oklahoma. The permanent fixed plots, stem map, and tree-ring data developed for this research project will contribute to the research and education goals of the Consortium.

Study Area

The Keystone Ancient Forest Preserve is located in the dissected uplands above the confluence of the Arkansas and Cimarron Rivers in southern Osage County, Oklahoma (Stahle et al. 1996; Therrell and Stahle 1998: Figure 3). The KAFP protects some of the highest quality and most extensive tracts (1600 acres; 650 ha) of remaining undisturbed old-growth forest in the entire Cross Timbers. The oldest known post oak and eastern red cedar ever found in Oklahoma have both been documented with dendrochronology to survive at this site (Figure 4). The integrity of the vegetation at this site extends from the soil level to forest canopy (Stahle et al. 1996).

The Keystone Ancient Forest Preserve lies in the northern range of the Cross Timbers ecosystem. Elevation ranges from approximately 250-300 meters. A series of rocky drainages dissect this significant headland exposing sandstone bluffs and shale layers. The areas included in this study were located on a relatively flat bench with very shallow and rocky soil, a small bluff line (3-5 m vertical) with large boulders at the base, and a larger bluff line (5-10 m vertical) that is cut by a steep, rocky drainage (Figure 5). All three study sites have a western aspect.

Average annual precipitation at the Keystone Ancient Forest Preserve is 105 cm, mostly occurring from April-June. The average daily winter temperature is 5.5 ºC and average daily summer temperature is 26.7 ºC (www.ncdc.noaa.gov/oa/ncdc.html). Several extreme weather events can occur in this region including severe thunderstorms, straight-line winds, hail storms, tornadoes, and ice storms.

The Keystone Ancient Forest Preserve offers the unique opportunity to study eastern red cedar growing under natural conditions and surrounded by undisturbed old-growth. Disturbance at this site has been primarily confined to the flat hill tops where there has been grazing and the development of dirt roads and clearings associated with oil exploration. This site has been the location of several previous research efforts. Therrell and Stahle (1998) found this site as a result of some of the first predictive modeling efforts in the Cross Timbers and were instrumental in its conservation as a biopreserve. Roe (1998) conducted a survey of the vascular flora. Clark (2005) looked extensively at forest age structure and regeneration, and reconstructed the fire history. The evidence indicates that the KAFP historically experienced a moderate fire event every 8 years, and the fire interval may have increased slightly over the last 100 years since European development (Clark 2005).

Research Methods

Four permanent 0.25 hectare fixed plots were established at the study site (Figure 5) using a distance tape, hand compass, Laser Atlanta Advantage GPS system, and a Trimble GPS total station (Figure 6). Two 50m x 50m plots (HOT-1 and HOT-2) were established on the bench. The third plot (HOS, 83.3m x 30m) was established downslope of the bench along a rocky outcrop, and the fourth plot (HOR, 83.3m x 30m) was established to the south in a steep, rocky drainage. The corners of the fixed plots were permanently marked with metal stakes and GPS points were taken with the Trimble GPS to allow repeat studies in the future (Table 1). A stem map was surveyed at plot HOT-1 using the Laser Atlanta Advantage GPS system, Trimble GPS, distance tape, and stadia rod. Because of the densely wooded nature of the plot, several measurement stations in the interior of HOT-1 were used (each located with GPS, Figure 6, Appendix A). Tree bearing and distance was then recorded relative to these fixed stations using the Laser Atlanta Advantage GPS Mapping System and 30m-distance tape. All trees ≥5 cm dbh were located, identified to species, and measured for diameter with a diameter tape. These data were all compiled in ArcGIS 9.0 to construct a stem map with sub-meter accuracy. The number of trees and diameter were used to estimate the frequency of stems ≥ 5 cm dbh and basal area for each species in the 0.25 ha study plot.

All eastern red cedar trees ≥ 5 cm dbh located within the fixed plots were given an identification tag and cored with a Swedish increment borer (Figure 7). A total of 96 red cedar trees were cored in the total 1.0-hectare sampling area of the four plots. Cores were taken low to the ground to get the best estimate of true age when possible. Due to the often convoluted growth form of old red cedar at the site, cores were sometime taken from higher up on the stem. At least two cores were taken from each tree to aid in the difficult cross-dating often presented by this species. Trees with no pith date or poor cross-dating were cored again on a return trip to try and provide the best possible age estimates and tree-ring data. All cores were cross-dated against a master chronology established for this site. If cores could not be precisely dated, the age of living trees was based only on ring counts.

Cores from selected old cedar at the KAFP and samples from remnant wood were used with the 96 cedar trees on the fixed plots to develop the first eastern red cedar tree-ring chronology for Oklahoma. A master chronology was established prior to this study from a collection made by Stahle and Therrell (1996) to get age estimates for ancient juniper at the KAFP. All samples collected for this study were cross-dated against the master chronology. Ring width on the dated samples was measured with a stage micrometer to 0.001mm.

The cross-dating was quality checked using COFECHA correlation analyses among all specimens in the computer program (Holmes 1983). The detrended and standardized tree-ring chronology was developed using the computer program ARSTAN (Cook 1985). Intra-annual events (false rings, frost rings, fire scars) recorded in the ring anatomy were also noted and compiled. Significant events were determined based on the binomial distribution (Stahle 1990).

Results and Discussion

The preferred way to directly measure ecological succession is to make repeated observations over time at permanent plots on a given site (Smeins and Merrill 1988). The high-resolution stem map (Figure 8) constructed at this site will serve as baseline empirical data for future long-term ecological studies at this important research natural area. Post oak dominates this fixed plot, but eastern red cedar and blackjack oak are present as the two major secondary species (Table 2). In terms of the relative frequency of the stems, blackjack oak is the second most important species (at 19.12%, Table 2). But in terms of relative dominance (basal area of one species / basal area of all species) red cedar is the second most important species (at 19.07%, Table 2).

All eastern red cedars reaching breast height were also mapped to illustrate the perch effect. The "perch effect" of red cedar regeneration can be seen around the larger post oaks and blackjack oaks. The stem map also illustrates the grassy and rocky glade on the eastern side of the plot (Figure 8).

Clark (2005) collected extensive age structure data for blackjack oak and post oak at this site. However, eastern red cedar was only a minor component in her sampling. The age data for eastern red cedar from the fixed plots (Figure 9c) is compared with Clark's data for post oak and blackjack oak (Figure 9a and 9b) to provide an estimate of the age structure for these three important species at the KAFP. Eastern red cedar was found to be the longest-lived species at the site (Figure 9c). The red cedar age profile at this site is consistent with an uncut forest with a continuous history of canopy recruitment (e.g., Figure 10). The lack of a large increase in cedar recruitment in the late 20th century indicates that the KAFP is not experiencing the massive cedar invasion seen elsewhere in the region.

Red cedar has recruited continuously at this site over the past 300 years, but there is an interesting gap in cedar recruitment in the early 20th century (Figure 9c). This recruitment gap might be an artifact of sampling, but appears to coincide with the extended period of reduced cedar growth seen in the ring-width chronologies from approximately 1880-1910 (Figure 9d). This period of below-average growth is followed by some 25 years of above average growth (seen best in the eastern red cedar chronology) that roughly coincides with the return of cedar recruitment, allowing for a lag of several years between the onset of wetness, red cedar germination, and finally recruitment to the 5 cm dbh sampling minimum. A large recruitment pulse is also evident in Clark's data for post oak and blackjack oak at this site following this apparently wetter period (Figure 9a and 9b). These comparisons suggest that red cedar recruitment at the KAFP may be inhibited by severe and sustained drought. In fact, the recent drought of 2004-2005 appears to have had a profound effect on the mortality of many cedar seedlings and saplings at the site based on subjective field observations.

A 360-year long tree-ring chronology was developed from the annual growth rings of selected eastern red cedar at the site (Figure 9d, Appendix B). These data indicate that red cedar annual ring width is weakly and positively correlated with February-June precipitation and with January-February temperature (not shown). Red cedar ring width is also weakly and negatively correlated with April-June temperature. The precipitation and temperature correlations during the growing season (April-June) are the classic tree growth response to drought and wetness. The unusual cedar growth response to warm conditions in the late winter may reflect a growth response to high solar radiation during warm late-winter days while the overstory oaks are still in leaf-off conditions. Previous studies have indicated that a major amount of carbon dioxide fixation occurs in understory red cedar during periods when overstory trees are leafless and air and soils temps are low but above freezing (Lassoie et al. 1983).

Widespread drought in the Great Plains can have a large impact on farming and economy in this region. The most notable droughts of the last 100 years are the 1890's, 1930's, and 1950's (Meko and Stockton 1983). The 1890's drought appears to have had the most severe impact on the standard ring width chronology developed from eastern red cedar at the KAFP. Other significant periods of reduced cedar growth at this site include 1785-1795, the 1760's, and from 1704-1711. The smallest annual growth rings of the last 300 years are 1704, 1855, and 1895.

The most interesting weather or climate related feature of the red cedar data from the KAFP may be the numerous false rings, intra-annual bands of latewood formation that can greatly complicate the dendrochronology of this species (Figure 11). Eastern red cedar is often avoided for dendrochronology because of its reputation for high numbers of false and missing rings (Butler 1988), but false rings can provide valuable intra-annual climate data (Kuo and McGinnes 1973; Bertaudière et al. 1999; Meko and Baisan 2001). Development of false rings in conifers involves the interaction of both water stress and hormonal response by the tree (Zahner 1963; Kuo and McGinnes 1973). There are a larger number of false rings in the early growth of conifers because of the proximity of the cambium to the apical meristem (Zahner 1963). Kuo and McGinnes (1973) found the longitudinal variation of false ring development in an eastern red cedar to be controlled by rainfall conditions in several ways. Only a long dry spell followed by a long wet spell was found to produce a false ring throughout all height levels analyzed.

Most of the long tree-ring series dated at this site contained only a small number of false rings, but many of these events were found to cross-date among trees (Figure 11; Table 3). A false ring chronology was developed to explore the weather and climate conditions during these unusual years. A list of false ring events was compiled from all samples at the site. A statistical test was used to identify false ring years exceeding the theoretical background frequency of false ring occurrence in the entire population of dated rings from each site, assuming that false rings occur randomly with respect to year (Stahle 1990). Background frequency was calculated as the ratio of false rings to the number of dated rings. This ratio is small and false rings can be expected to occur in any given year at this approximate frequency if their inter-annual occurrence is entirely random. Confidence interval levels were calculated using the binomial distribution, where the width of the intervals is a function of the significance level (in this case $P \leq 0.05$) and $\pm$ 1.0 standard deviation based on the total number of dated rings available during each false ring year. The false ring event was determined to be statistically significant when the lower confidence interval level attached to the proportion of false rings observed in a given year exceeded the background frequency ratio for the site. A total of 103 years with false rings were identified to occur in at least two trees at the KAFP, but only 8 years had a significant number of false rings (Stahle 1990; Figure 12).

Daily instrumental weather data are available for the three most recent events: 1948, 1958, and 1996 (Figure 13). These three false ring events all show a similar and dramatic late-growing season weather reversal that could explain false ring formation

(Figure 14). In all three cases, a mid-growing season drought developed, including high maximum average temperatures with little or no rainfall, creating a huge evapotranspiration demand on these trees (Figure 13). This heat wave was followed by an extended and drastic weather reversal with much lower temperatures and heavy rainfall. A composite average of these three events clearly illustrates the heat wave and drought conditions that stimulated the formation of latewood, followed by the cool and extremely wet weather reversal that stimulated more earlywood growth and false ring formation in red cedar (Figure 14).

Three large-scale weather systems seem capable of causing the extraordinary weather associated with false rings at the KAFP. Slow-moving or stalled frontal boundaries, a Mecoscale Convective Complex (MCC), or conceivably an early season tropical system, could explain the heavy rain and possibly the temperature reversal seen in the 20th century false ring events. MCCs are self-enhancing thunderstorm complexes that cover a huge area, orders of magnitude greater than the spatial coverage of typical thunderstorms (Maddox 1980).

The 1948 event was a particularly significant rainfall event and weather reversal. In late June, 1948 a stationary front developed into a MCC over the Southern Plains. Historic accounts of this 1948 event indicate that 9-inches of rainfall were recorded near the KAFP in Tulsa, Oklahoma (Anonymous 1948). As many as 18-inches of rainfall were recorded over a 48-hour period to the southwest near Hydro, Oklahoma, where 9 people drowned trying to cross Deep Rock Creek on Route 66 (Figure 15). A reported

21-inches fell in approximately 48-hours during this same meteorological event in Del Rio, Texas, where the flooding Devil's River was photographed pouring over Lake Walk Dam (Figure 16).

Conclusion

The Keystone Ancient Forest Preserve protects outstanding remnants of old-growth Cross Timbers forest including some of the best remaining stands of eastern red cedar found anywhere in the wide range of this native conifer. This site is an important research natural area and an excellent venue for paleoclimatic and long-term ecological research. The fixed plots and stem map produced for this study provide baseline ecological data and the opportunity for repeat studies to monitor changes in this ecosystem that might result from the increasing human impact on the surrounding landscape or even from larger-scale phenomena like global warming.

Age structure data collected for this study suggests that eastern red cedar has experienced continued recruitment in this old-growth forest site over the last 300 years and that this site has not witnessed the massive cedar invasion seen elsewhere in this region.

The eastern red cedar tree-ring chronology constructed from both living and dead trees at this site demonstrates decadal-scale climate variability. Preliminary analysis confirms that this record correlates with both seasonal climate and the existing post oak chronology from this site. This research proves that eastern red cedar from Oklahoma can be precisely dated and may be useful for climate reconstruction.

False rings, which are generally considered a nuissance in dendrochronology, were found to cross-date among cedars sampled at this site. These false ring events offer the opportunity to reconstruct the history of large magnitude storms in the late-growing season, where typically annual growth rings reflect the seasonal rainfall average. The false ring composite from red cedar at this site includes eight significant events over the past 300 years. These events reflect highly unusual late-growing weather reversals that had a major impact on this region.

There is potential to extend this red cedar chronology by utilizing dead standing trees and remnant wood found at this site. One cross-section cut from relic wood has over 500 rings and appears to date to the mid-14th century. However, further collections are needed for better replication to ensure proper chronology development. If additional false ring chronologies can be developed from red cedar in the region, then we may be able to reconstruct the history of large magnitude weather reversals over the past 300+ years. Longer chronologies and collections from multiple sites in this region will help further this investigation.

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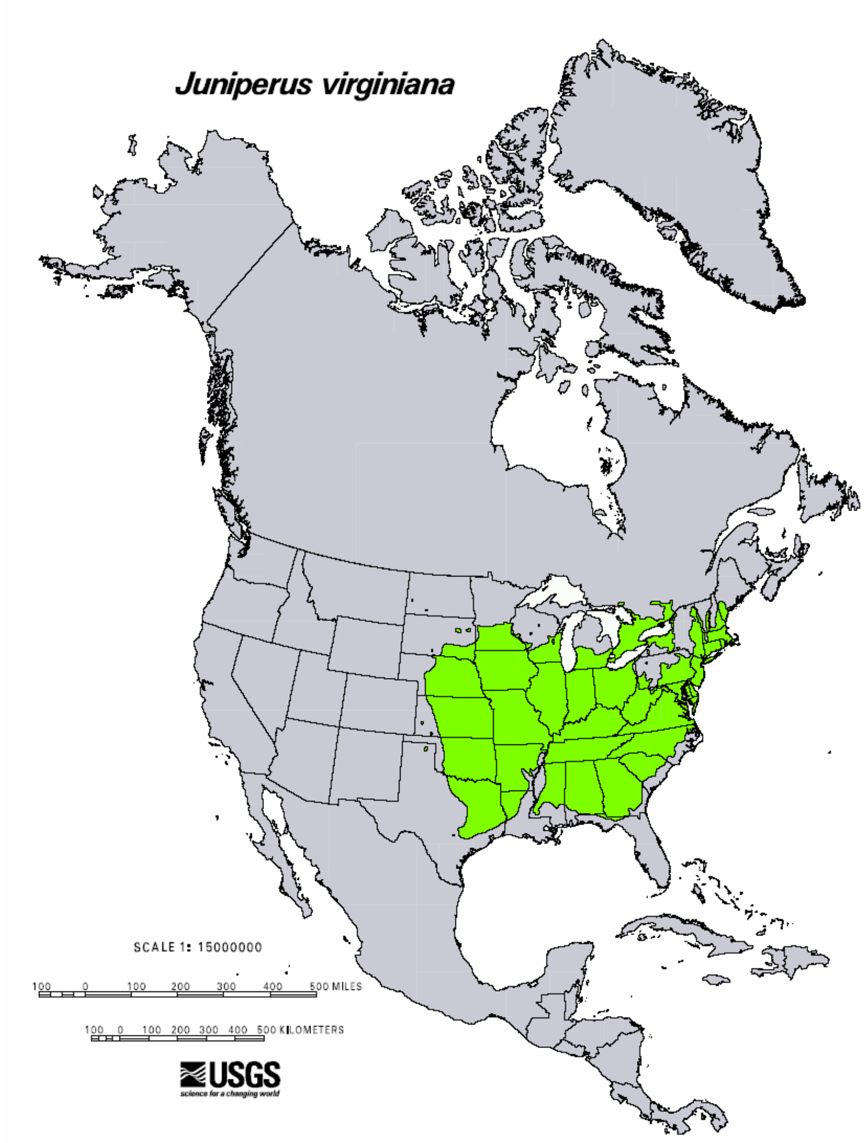


Figure 1. This is the distribution map of eastern red cedar (*Juniperus virginiana*) compiled by Little (1971). Eastern red cedar is the most widely distributed native conifer of the eastern United States.

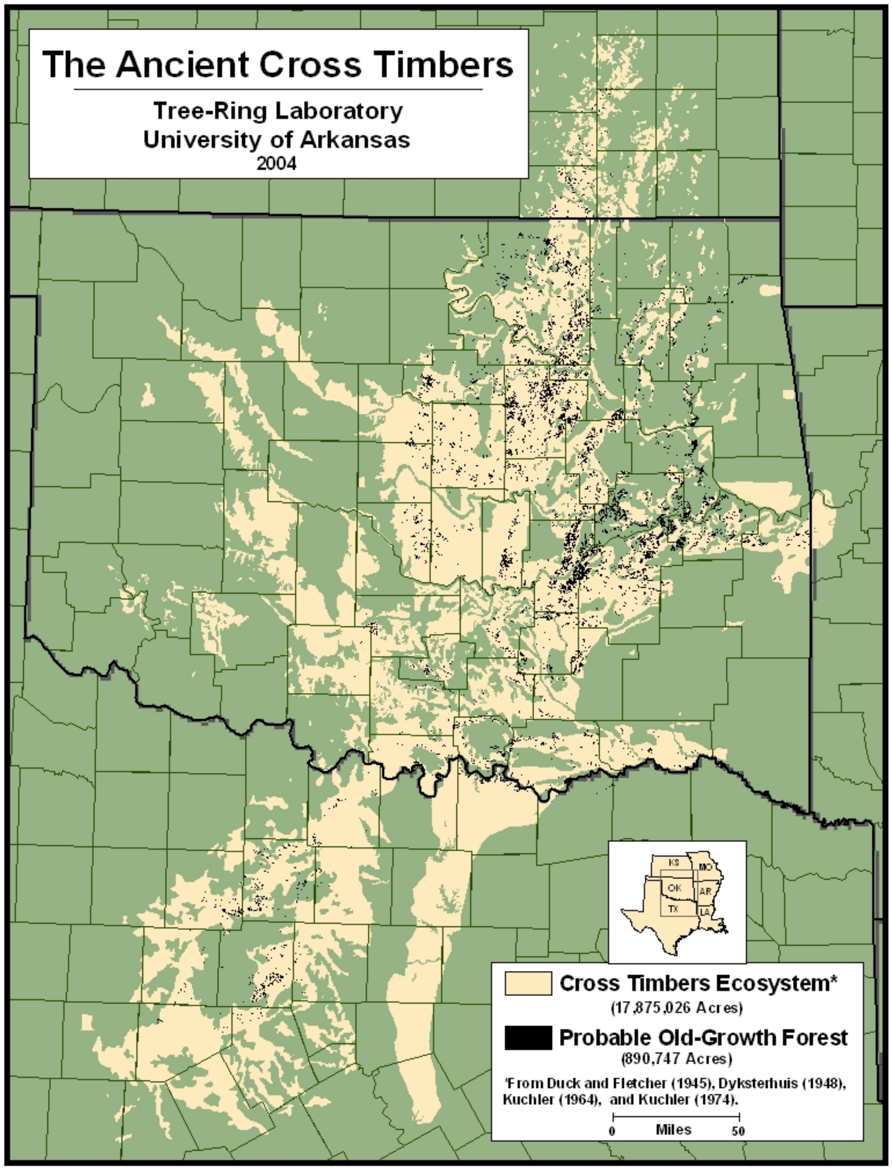


Figure 2. This is a map of the Cross Timbers ecosystem which stretches from north-central Texas, across Oklahoma, and into southeast Kansas (yellow pattern). The Cross Timbers is an ecotone between the eastern deciduous forest and the grasslands of the southern Great Plains. This western margin of eastern tree growth produces slow-grown, drought-stressed trees that are almost entirely noncommercial for lumber production. The University of Arkansas Tree-Ring Laboratory (UA-TRL) has found through years of extensive research that steep, rocky, forested slopes in this region still retain a surprising amount undisturbed old-growth. Predictive modeling efforts by the UA-TRL estimate that 890,747 acres (~360,000 ha) may still remain in this ecosystem (black polygons).

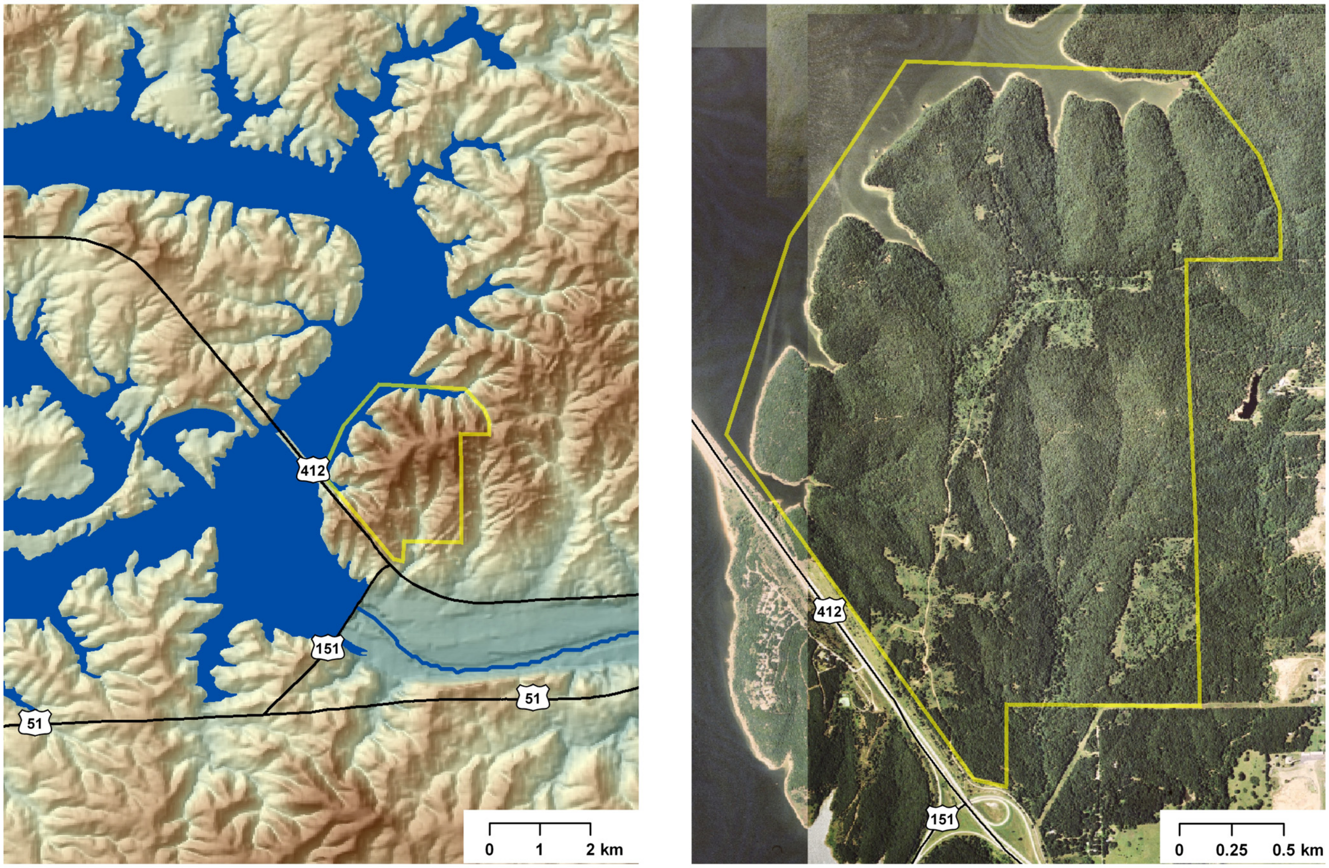


Figure 3. The boundaries of the KAFP in southern Osage County, Oklahoma are illustrated (yellow line) on the digital elevation model (left-USGS national elevation data set) and digital ortho-photo (right- 2003 Oklahoma GIS). The KAFP is a prominent headland overlooking the confluence of the Arkansas and Cimarron Rivers (impounded by Keystone Reservoir). This property is managed by the Oklahoma Nature Conservancy and the city of Sand Springs, Dept. of Parks and Recreation and protects over 1600 acres of relatively undisturbed Cross Timbers. The oldest known post oak (400 ± years) and eastern red cedar (600 ± years) of Oklahoma are both documented by dendrochronology to survive at this site.

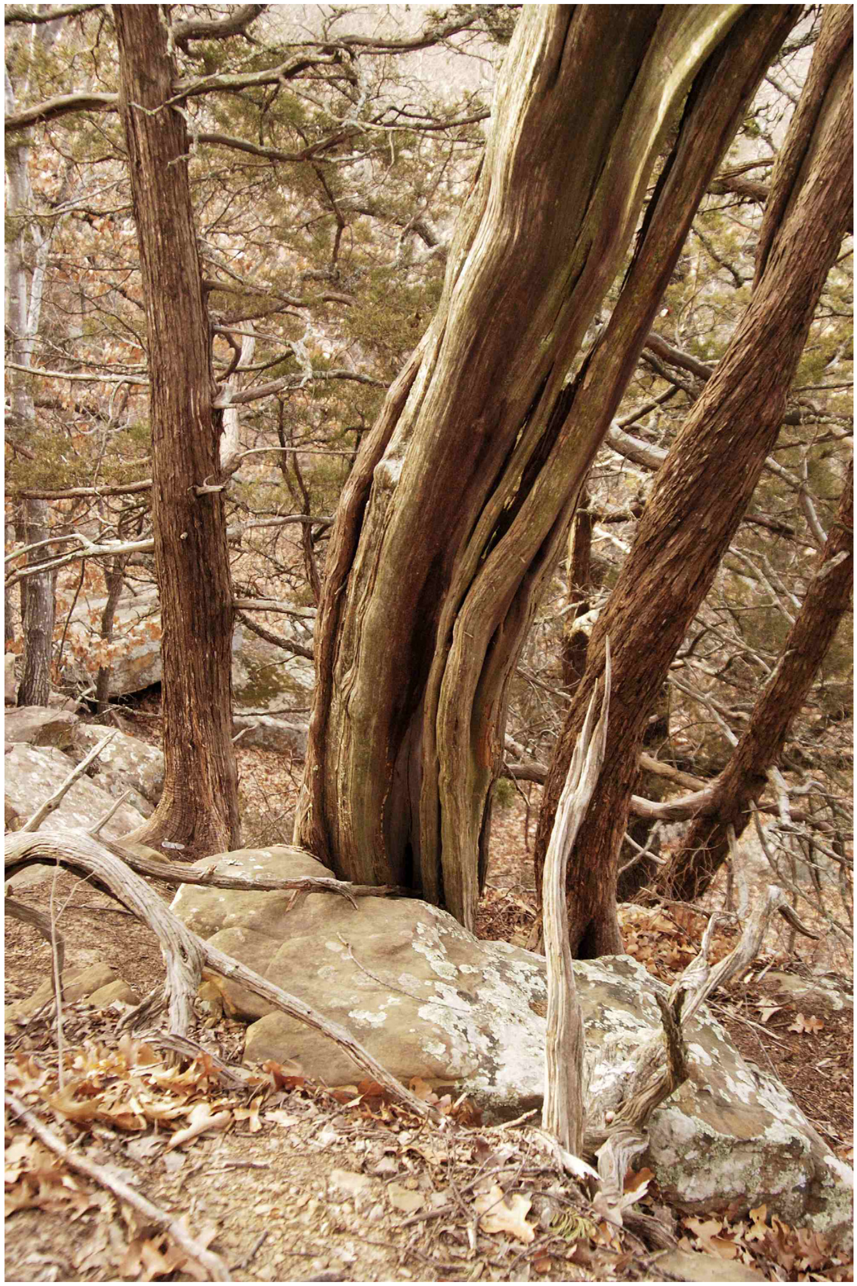


Figure 4. This photograph is a typical bluff-line view at the Keystone Ancient Forest Preserve of old-growth eastern red cedar in its natural setting on steep rocky, fire-protected slopes. The large strip-bark cedar (center) includes only a thin strip of living bark and cambium (at left) connecting the canopy and root systems. The strip-bark growth form is typical of very old conifers (e.g., Schulman 1954).

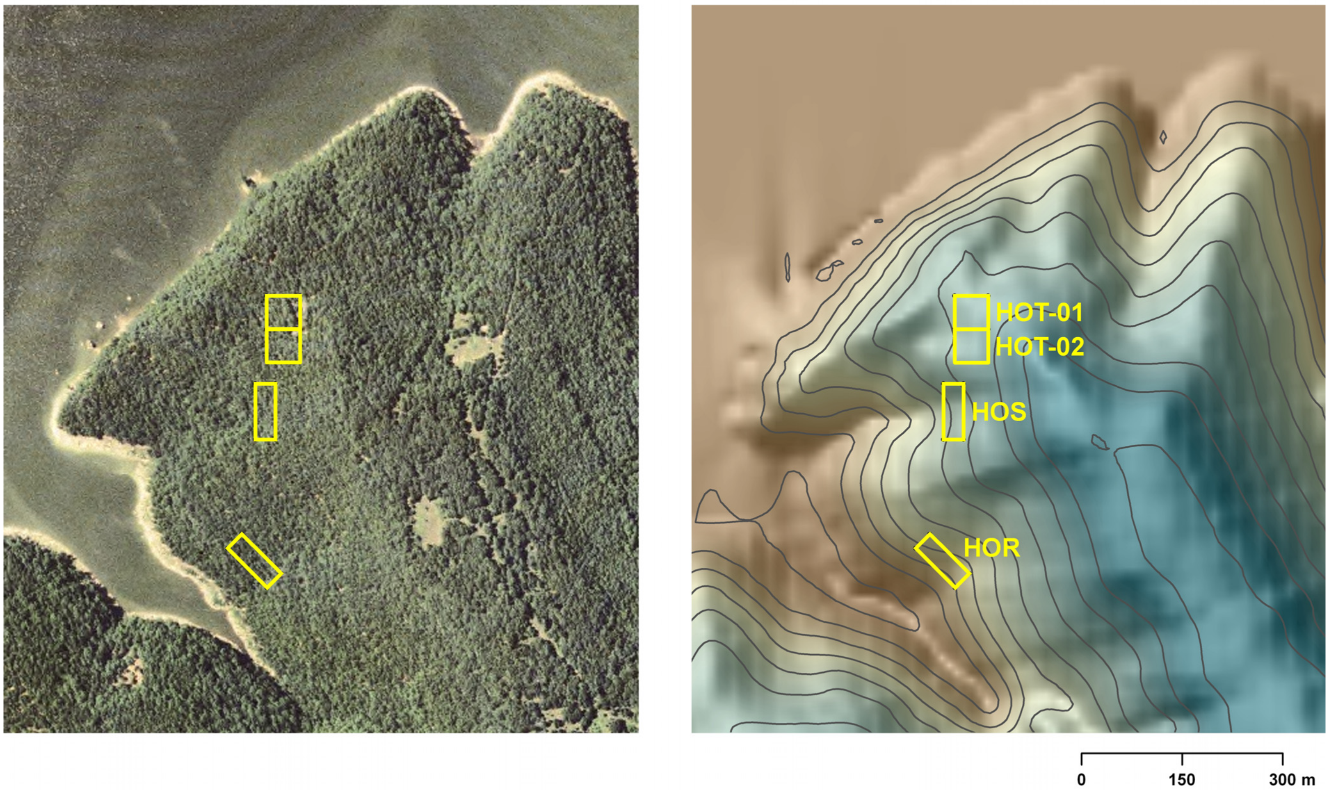


Figure 5. The digital ortho-photo (left-2003 Oklahoma GIS) and digital elevation model (right-USGS national elevation set) show the permanent fixed plots established at the Keystone Ancient Forest Preserve (4 plots, 0.25 ha each, see Table 1). The image on the left shows how the flat ridge top has been disturbed by road construction for oil exploration, but the forest slopes still remain relatively intact (this is a common scenario throughout the Cross Timbers). HOT-01 and HOT-02 are located on a relatively flat bench with shallow, rocky soil. HOS runs along a small bluff line with large sandstone boulders at the base. HOR follows a more prominent bluff line which is dissected by a rocky drainage.

Figure 6. The fixed plots and stem map were constructed using a Laser Atlanta Advantage GPS Mapping System, a Trimble GPS total station, a 30m distance tape, and a stadia rod. Fixed stations were established using the Trimble GPS total station. Tree bearing and distance was measured relative to the fixed stations using the Laser Atlanta Advantage GPS Mapping System and 30m distance tape.

Figure 7. This figure shows the author coring an old-growth eastern red cedar with a Swedish increment borer during a field trip to the Keystone Ancient Forest Preserve on November 6, 2005.

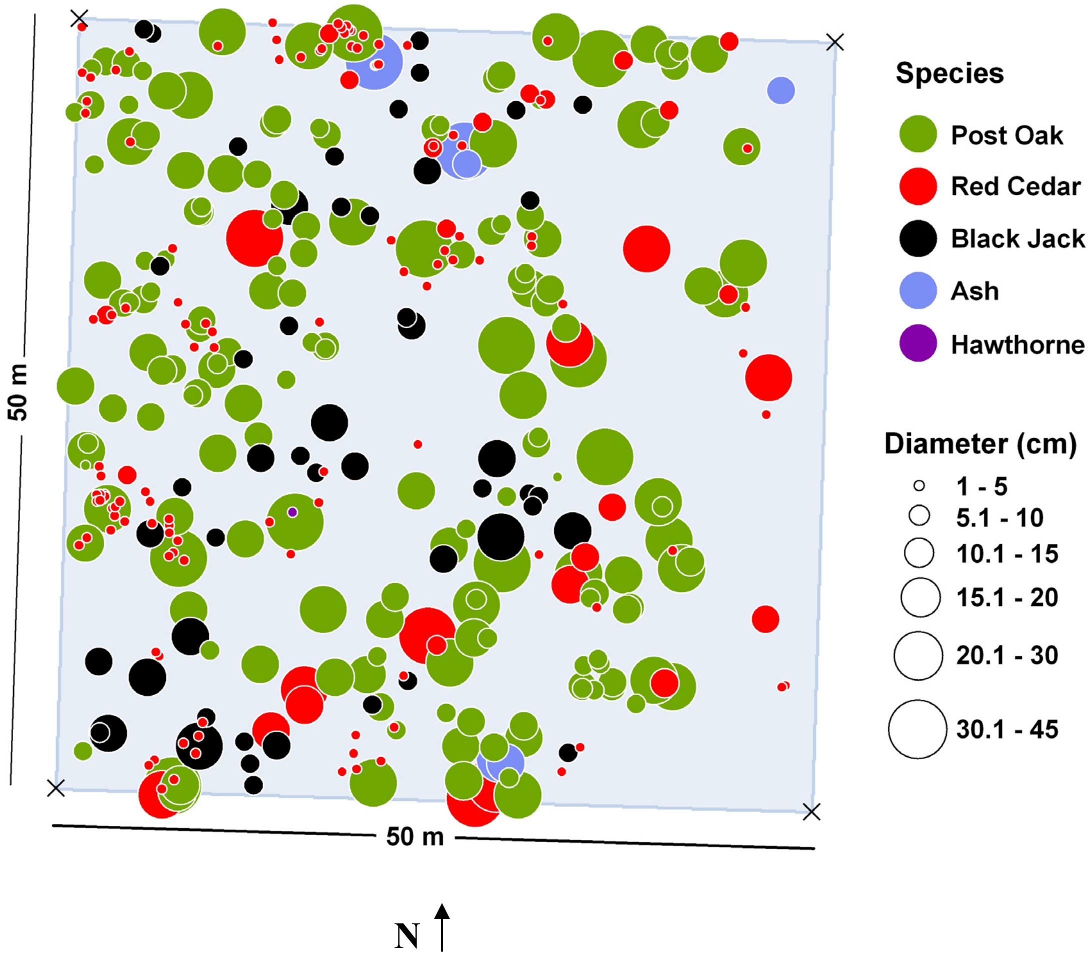


Figure 8. This 0.25-ha stem map was constructed from data collected at plot HOT-01. All trees ≥ 5 cm dbh were identified, measured for dbh, and mapped. All eastern red cedars (≤5 cm dbh) reaching breast height were also mapped to illustrate the "perch effect" of numerous young cedars establishing under larger oaks (note that post and blackjack oaks ≤5 cm dbh dominate the understory but were not mapped). The more open areas (particularly on right side of map) are natural glades. The tree diameters were exaggerated for this map.

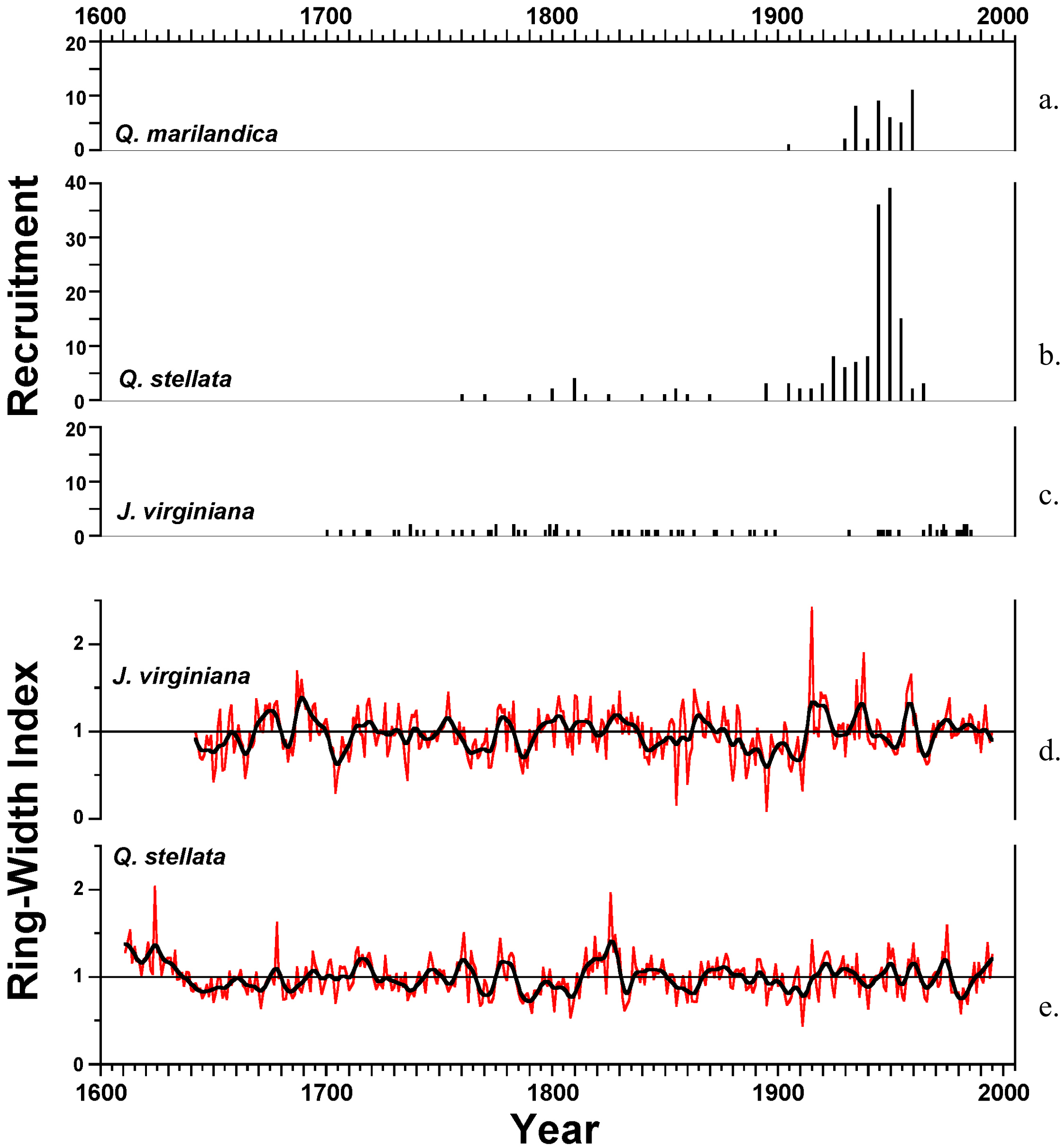


Figure 9. The age structure estimated for the three major species at the Keystone Ancient Forest Preserve, Oklahoma, is illustrated by the three recruitment plots (Figure a, b, and c). Age data for post oak (b) and blackjack oak (a) is from Clark (2005). The standard ring-width chronology for eastern red cedar (d) and post oak (e) are also included to investigate the link between recruitment and inferred climate at this. Blackjack oak is the youngest species at this site. Blackjack recruited heavily along with post oak in the mid-20th century. This recruitment event follows a period of above average growth in the 1920's and 1940's in post oak and especially eastern red cedar, which probably indicates relatively wet conditions. Eastern red cedar is the longest lived species at this site and has recruited continuously over the past 300 years. The massive cedar invasion that is seen elsewhere in this region is not evident at this site (note the lack of a large recruitment pulse in red cedar during the late 20th century).

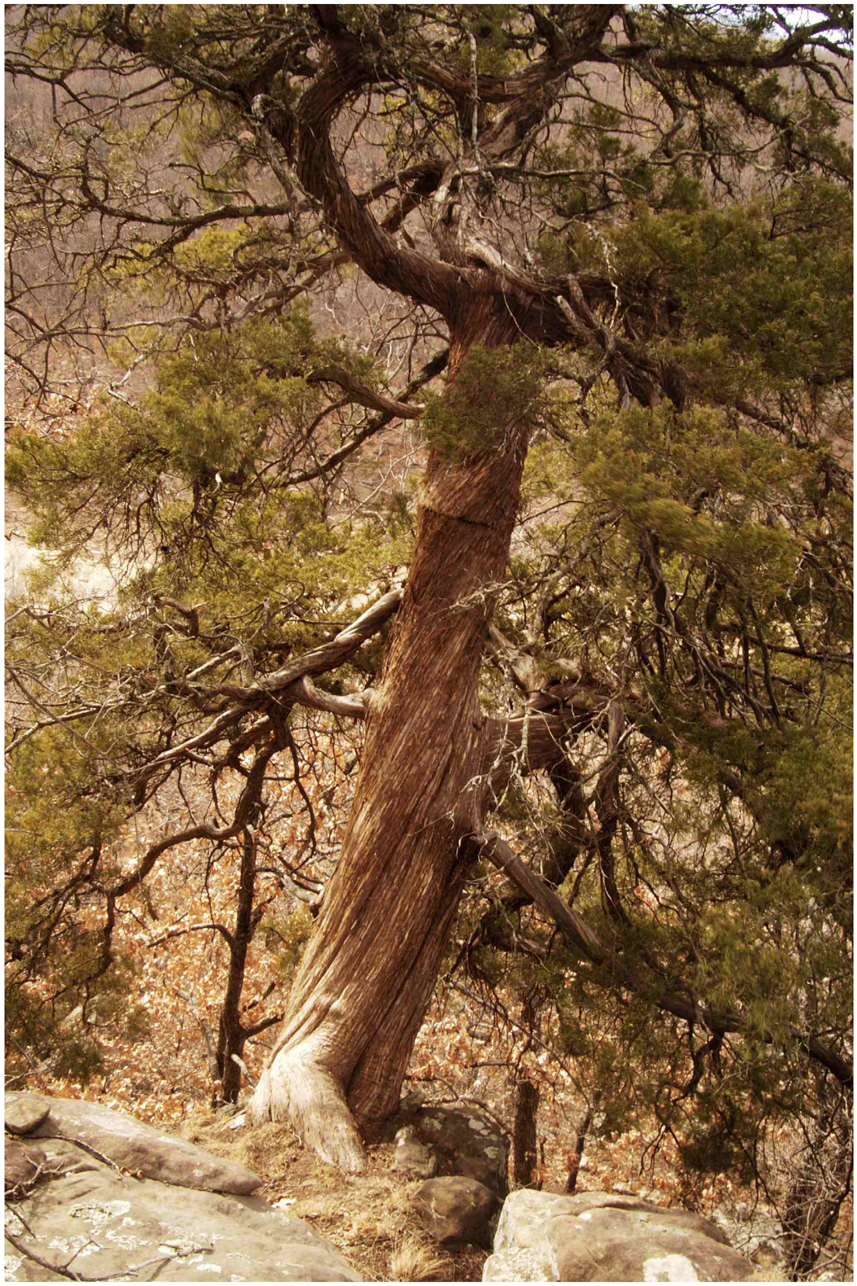


Figure 10. This handsome eastern red cedar at the bluff plot (HOR02A) recruited into the forest at the beginning of the 19th century and today is a healthy 200-year old specimen.

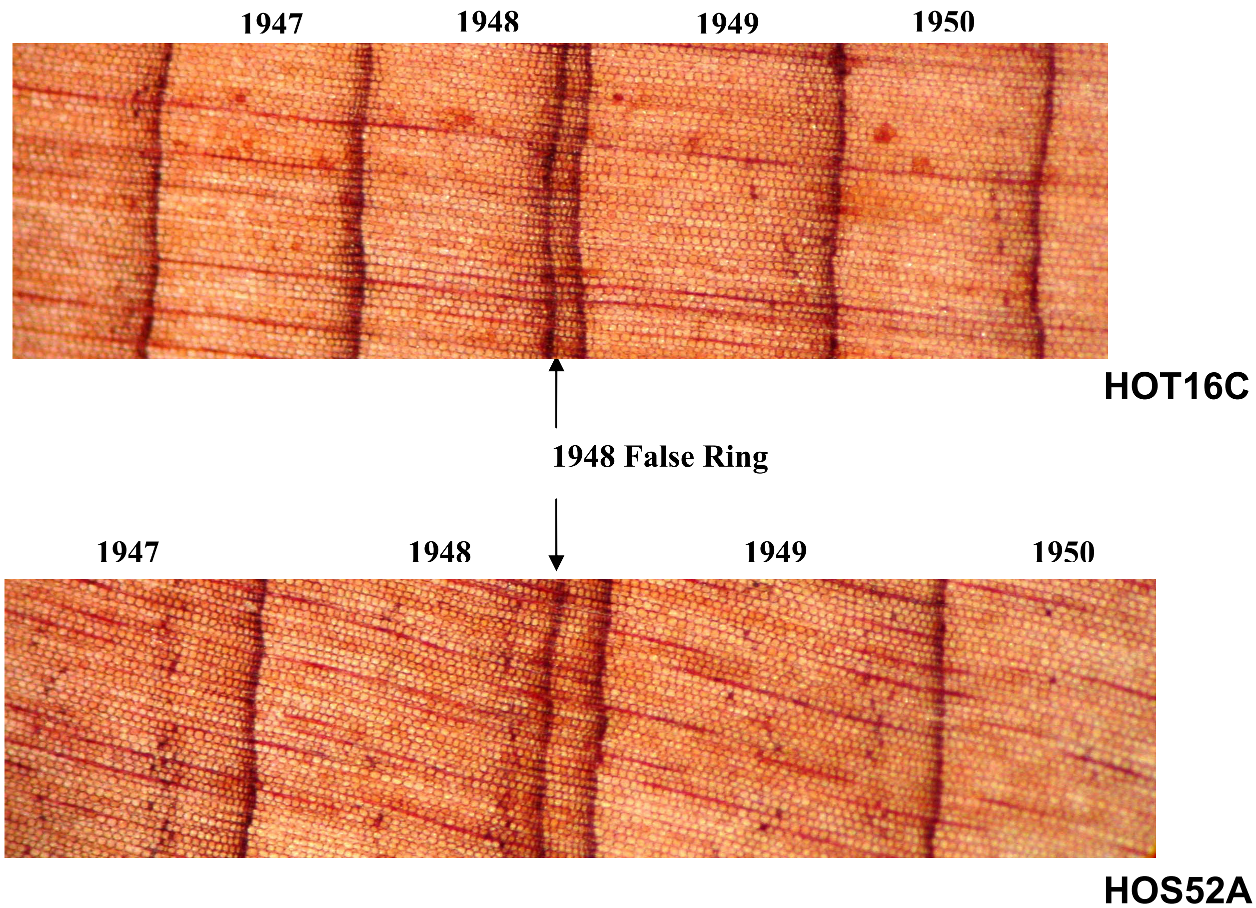


Figure 11. Photomicrograph of the 1948 false ring on sample HOT16C and HOS52A. Anatomically, false rings lack a sharp (abrupt) transition between the latewood cells of one year and the first formed earlywood cells of the following year. False rings sometimes closely mimic a true ring, but can be positively identified using the cross-dating techniques of dendrochronology (Stokes and Smiley, 1968).

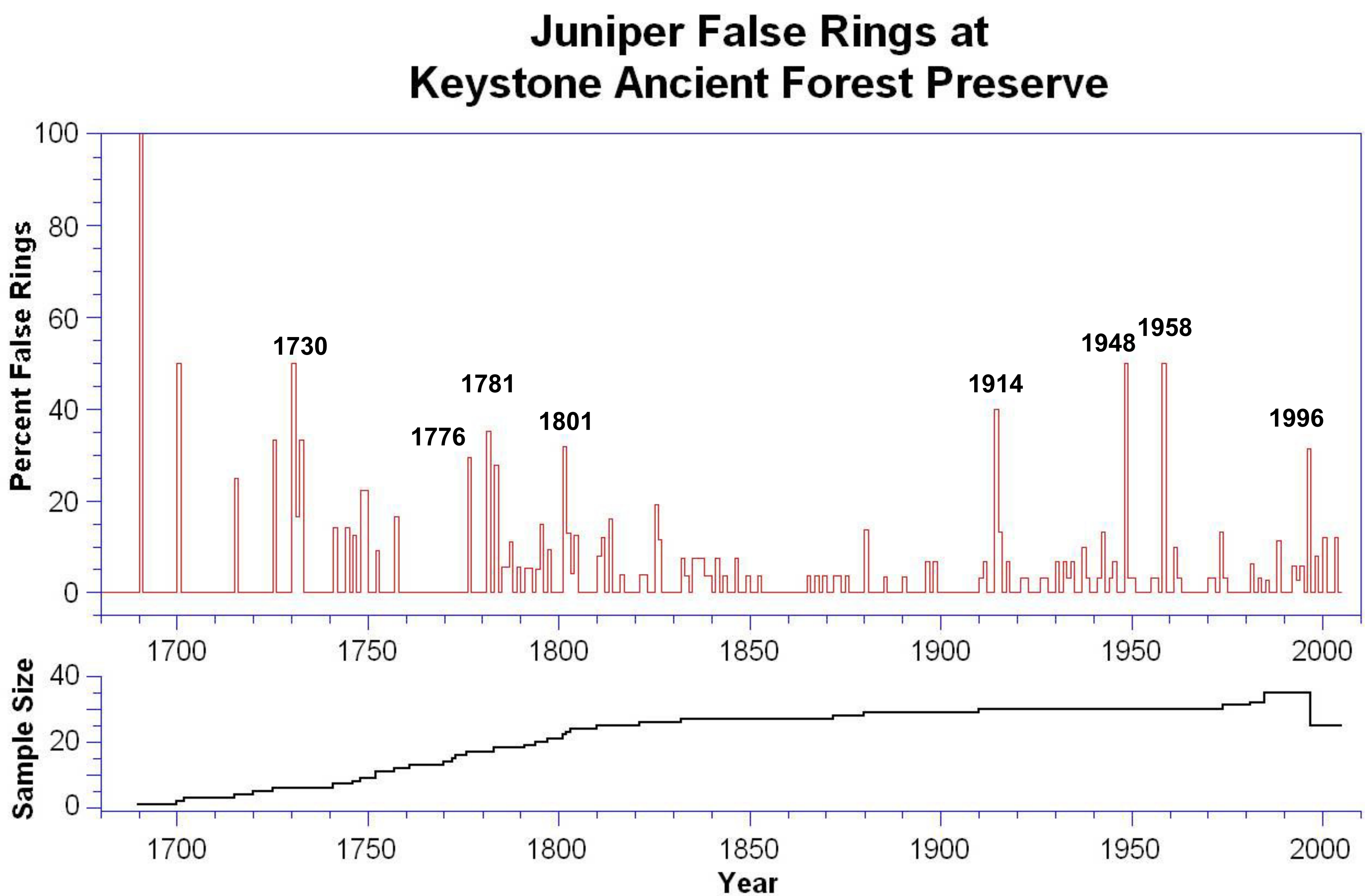


Figure 12. This false ring chronology was made of 103 false rings found in at least two eastern red cedar trees at the KAFP. The top time series shows the percentage of trees showing false rings in each year. The eight labeled years are false ring events that were found to be significant at the 95% confidence interval level (Stahle, 1990). The sample size represented in the chronology is shown below.

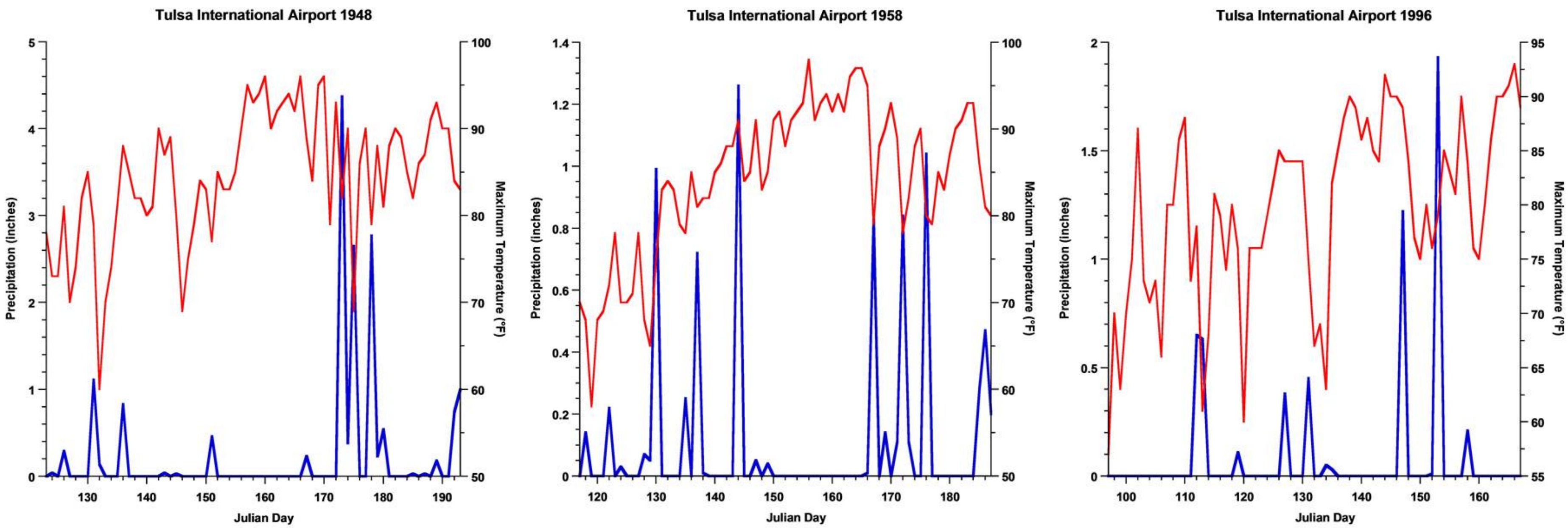


Figure 13. Daily instrumental weather data from the Tulsa International Airport for 50 days before and 20 days after the 1948, 1958, and 1996 false ring events (plotted for Julian day of the year). Precipitation is shown in blue and maximum daily temperature is shown in red. All three events show a heat wave/drought followed by much wetter and cooler conditions. This dramatic weather reversal appears to explain the significant number of false rings formed in red cedar during these three years.

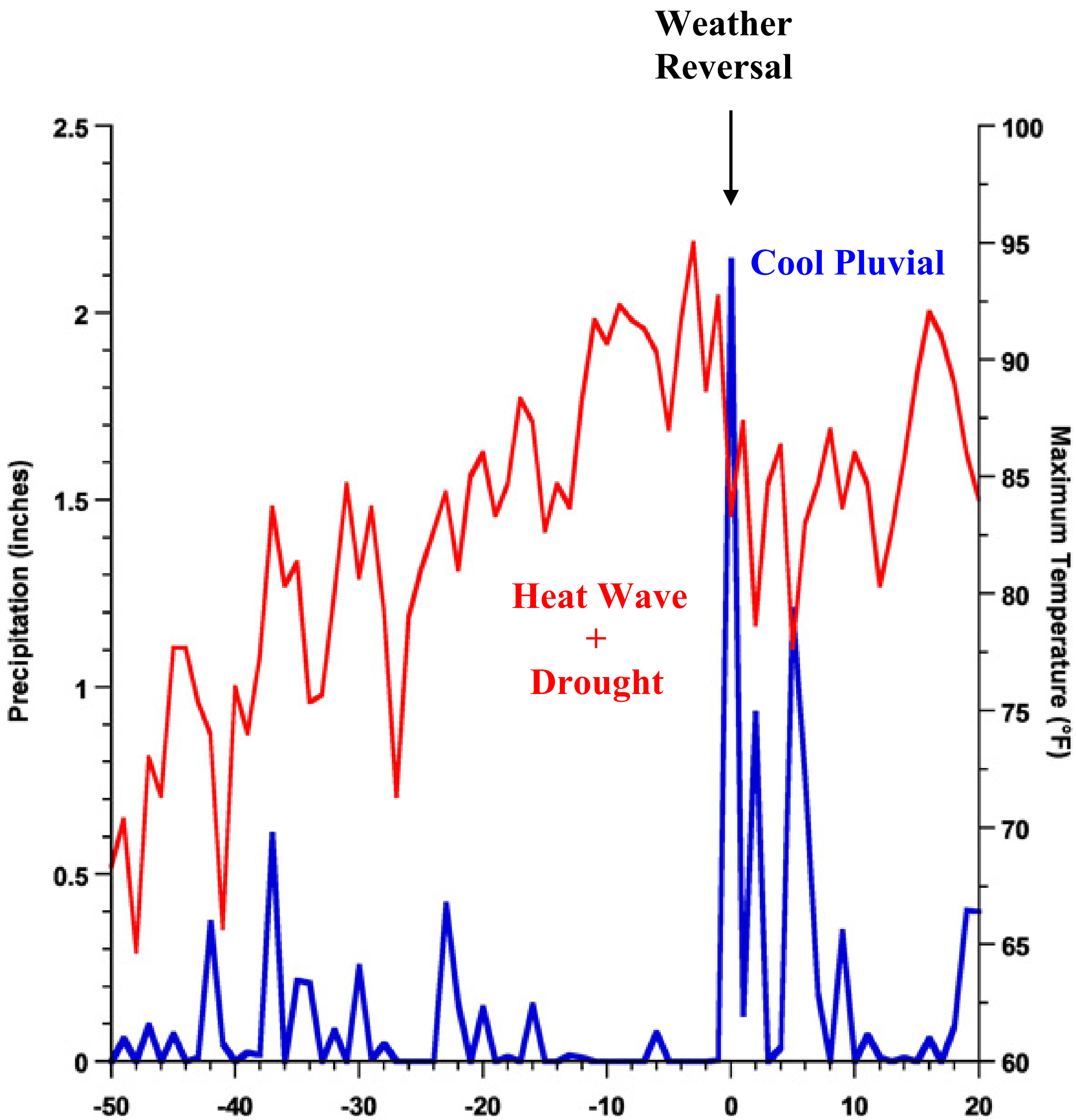
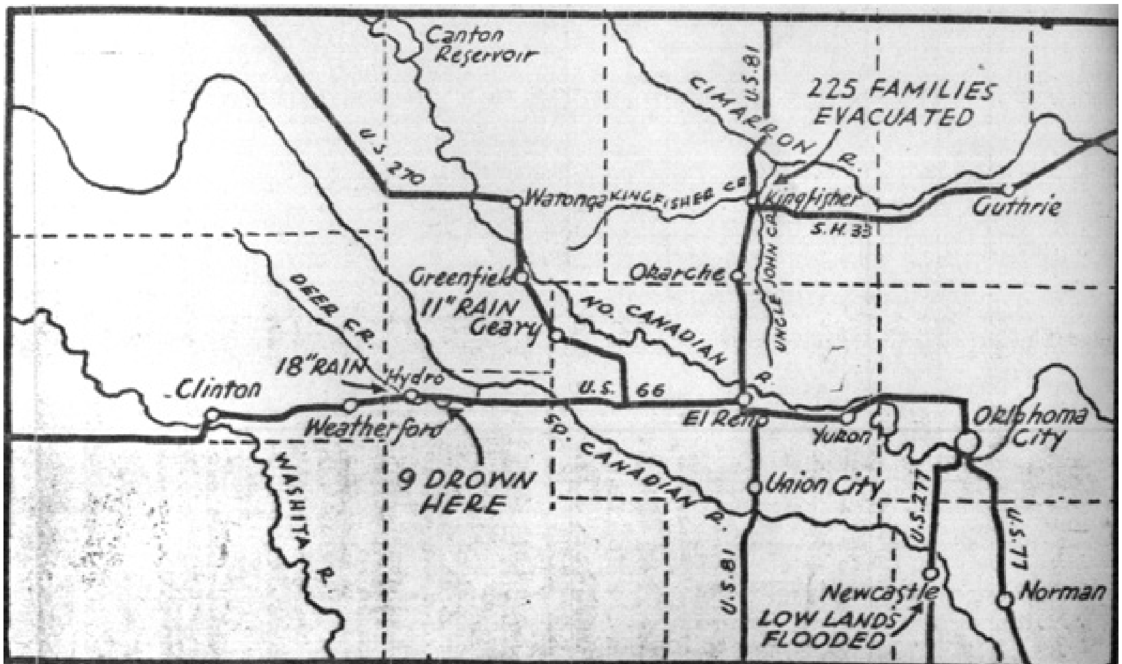


Figure 14. This is a composite average of the daily instrumental weather data from Tulsa International Airport for the 1948, 1958, and 1996 false ring events. This composite clearly illustrates the late-growing season weather reversal that appears to explain false ring formation. A mid-growing season drought developed, including high temperatures with little rainfall, creating a large evapotranspiration demand on the trees. This was followed by a drastic weather reversal with an extended period of lower temperatures and heavy precipitation.

Route 66 Flood of 1948 in Oklahoma



State Flood Area Nine persons were swept to their deaths just east of Hydro Wednesday when Deep Rock creek was swelled to a raging torrent by 19 inches of rain. At Kingfisher, continued heavy rains sent two small creeks out of their banks and forced 225 families from their homes. Others were evacuated at Wewoka, Weleetka and Henryetta. Geary reported 11 inches of rain, combining with Hydro's fall to push the long dry South Canadian river out of its banks near Newcastle. Flood conditions existed on the North Canadian above and below Oklahoma City. Flood stage exists on the Arkansas, Cimarron, Verdigris and Grand rivers, plus creeks in east and north central areas not shown.

Figure 15. Flood map from the Daily Oklahoman on June 22, 1948, after heavy rainfall from slow moving cold front and mesoscale convective complex (Anonymous 1948).

Devil's River Flood of 1948 near Del Rio, Texas

Figure 16. On June 24, 1948, the Devils River is seen pouring over Lake Walk Dam near Del Rio, Texas (Photo from Breeding 1948, USGS 61). Peak discharge was measured at over 441,000 cfs after nearly 21" of rainfall fell in this region in a 48 hour period.

Plot ID	Latitude, Longitude WGS 84	Plot Dimensions	Number of eastern red cedar trees ≥ 5cm dbh
HOT-01	36.18658 N, 96.24701 W	50m x 50m	31
	36.18669 N, 96.24758 W		
	36.18577 N, 96.24771 W		
	36.18571 N, 96.24715 W		
HOT-02	36.18577 N, 96.24771 W	50m x 50m	25
	36.18571 N, 96.24715 W		
	36.18575 N, 96.24769 W		
	36.18570 N, 96.24714 W		
HOS	36.18542 N, 96.24746 W	80m x 31.3m	15
	36.18548 N, 96.24783 W		
	36.18472 N, 96.24794 W		
	36.18466 N, 96.24755 W		
HOR	36.18341 N, 96.24809 W	80m x 31.3m	25
	36.18323 N, 96.24836 W		
	36.18283 N, 96.24771 W		
	36.18293 N, 96.24744 W		

Table 1. Four permanent 0.25-ha fixed plots were established at the site (see Figure 5). The plots were selectively located to sample good populations of old-growth red cedar. Corners of the fixed plots were permanently staked with rebar and a GPS point was taken at each corner (WGS84 = World Geodetic System of 1984). All eastern red cedar in these plots ≥ 5cm diameter at breast height (dbh) were cored with a Swedish increment borer to establish the age structure of the species, and to develop the tree-ring chronology.

Species	Frequency	Relative frequency	Basal Area	Relative Dominance
Post Oak	664	66.14	15.17 m²	67.97
Blackjack	192	19.12	1.84 m²	8.23
Eastern Red Cedar	124	12.35	4.25 m²	19.07
Ash	20	1.99	1.05 m²	4.71
Hawthorne	4	0.39	0.008 m²	0.03

Table 2. Species composition data collected from the stem map of plot HOT-01 (Appendix A). Frequency and basal area were extrapolated for 1 hectare based on our observations for the 0.25 fixed plot. Post oak dominates the overstory of this site as is seen by all measurements calculated. Blackjack oak is the most important secondary species in terms of frequency, but eastern red cedar is more important in terms of basal area and relative dominance (basal area of one species/basal area for all species).

Tree ID	Inner-Outer Ring Date	False Ring Dates
HOT01*	1793-2004	1785, 1786, 1797, 1801, 1804, 1810, 1811, 1813, 1822, 1826, 1838, 1843, 1852, 1896, 1922, 1930, 1937, 1945, 1958
HOT10*	1770-2004	1781, 1801, 1811, 1825, 1836, 1867
HOT12*	1750-2004	1752, 1776, 1781, 1791, 1956, 1958, 1981
HOT13*	1790-2004	1846, 1849, 1865, 1914, 1915, 1942, 1958, 1973
HOT15*	1900-2004	1911, 1914, 1948, 1958, 1961, 1962
HOT16*	1745-2004	1746, 1776, 1783, 1835, 1914,1948,1996
HOT18*	1767-2004	1795, 1804, 1880, 1914, 1937, 1948, 1996
HOT21*	1738-2005	1742, 1744, 1748, 1776, 1781, 1783, 1787, 1795, 1801, 1804, 1914, 1944, 1948, 1996
HOT24*	1707-2005	1795, 1801, 1880, 1915, 1948, 1949, 1958, 1973
HOT26*	1800-2005	1846
HOT27*	1720-2004	1725, 1730, 1885, 1948, 1958, 1996,
HOT28	1980-2005	1985, 1988, 1992, 1993, 1996, 1998
HOT36	1975-2005	--------------
HOT49	1980-2005	1981, 1988, 1994, 2000, 2003
HOT50	1985-2005	1988, 1994, 1996
HOS48	1870-2004	1890, 1896, 1914
HOS52*	1821-2005	1841, 1869, 1872, 1948, 1958, 1961, 1970, 1971, 1996
HOS53*	1832-2005	1832, 1833, 1880, 1911, 1915, 1917, 1934, 1955, 1958
HOR01	1985-2005	1988, 1992, 1998, 2000, 2003
HOR02*	1802-2005	1816, 1826, 1841
HOR04*	1810-2005	1810, 1825, 1832, 1873, 1875, 1898, 1914, 1917, 1926, 1938, 1942, 1948, 1974, 1996
HOR07	1985-2005	2000, 2003
HOR13	1756-2005	1880, 1910, 1914, 1930, 1941, 1942, 1958, 1973, 1996, 1997
HOR15*	1745-2005	1748, 1749, 1781, 1792, 1813, 1826, 1837, 1914, 1927, 1958
HOR19	1783-2005	1801, 1811, 1825, 1948, 1958
IRV04*	1702-1996	1715, 1725, 1730, 1732, 1958, 1948
IRV06*	1725-1996	1731, 1732, 1914, 1937, 1948, 1950, 1958, 1983
IRV08*	1694-1996	1700, 1730, 1757, 1776, 1781, 1783, 1794, 1839, 1948
IRV09*	1752-1996	1787, 1789
IRV12*	1718-1996	1749, 1757, 1776, 1783, 1802, 1958, 1996
IRV14*	1797-1996	1797, 1914, 1915, 1948
IRV15*	1761-1996	1781, 1783, 1825
IRV16*	1757-1996	1801, 1803, 1813, 1825, 1837
IRV46*	1770-1996	1802, 1835, 1836, 1958
IRV51*	1678-1996	1690, 1801, 1802, 1813, 1821, 1867, 1921, 1945, 1948, 1950, 1962

Table 3. Exactly dated false rings in eastern red cedar trees from the KAFP. Tree identification numbers are listed along with the inner and outer-most dated ring, and the dates of the false rings found in each tree. (* = included in the red cedar tree-ring chronology for Keystone Ancient Forest Preserve, Oklahoma)

Appendix A. Stem map data for HOT-01 including exact station and tree locations (UTM coordinates), range (meters) and bearing to each tree from the given station, tree identication numbers, tree species, and tree diameter.

STATION	X_COORD (UTM)	Y_COORD (UTM)
1	747563.7740	4008158.1010
2	747548.2074	4008147.5420
3	747530.6057	4008153.3970
4	747519.2280	4008153.8040
5	747528.7208	4008131.4410
6	747519.4421	4008112.8310
7	747535.1747	4008112.5560
8	747549.8688	4008119.5650
9	747555.4241	4008132.0710

X_COORD (UTM)	Y_COORD (UTM)	TREE #	SPECIES #	RANGE (m)	BEARING	DBH (cm)	STATION	TAG #
747560.2761	4008154.8506	1	4	4.72	227.1	11.00	1	
747557.8259	4008151.1120	2	1	9.09	220.4	17.50	1	
747558.1453	4008143.5894	3	1	15.46	201.2	21.00	1	
747558.1836	4008151.0223	4	2	9.01	218.3	2.00	1	
747552.9440	4008153.3470	5	2	11.80	246.3	5.50	1	40
747552.0795	4008152.4979	6	1	12.90	244.4	13.50	1	
747551.1155	4008152.3588	7	1	13.77	245.6	26.00	1	
747555.4955	4008157.0699	8	1	8.26	262.9	16.50	1	
747556.7859	4008157.9180	9	2	6.95	268.5	8.10	1	38
747551.7322	4008144.2972	10	2	18.20	221.1	23.60	1	37
747555.5377	4008142.0060	11	1	18.00	207.1	16.00	1	
747556.9738	4008141.5203	12	1	17.80	202.3	24.20	1	
747557.2407	4008141.5154	13	2	17.80	201.5	5.20	1	51
747558.3906	4008140.7102	14	2	18.20	197.2	1.00	1	
747553.2305	4008156.2074	15	1	9.95	30.1	13.20	2	
747553.2939	4008156.4236	16	1	10.16	29.8	15.00	2	
747553.4899	4008157.1906	17	1	10.95	28.7	10.00	2	
747552.8272	4008156.9722	18	1	10.44	26.1	12.20	2	
747551.5075	4008157.5794	19	1	10.48	18.2	17.20	2	
747549.8306	4008156.4737	20	2	9.05	10.3	5.60	2	42
747548.3175	4008156.5563	21	1	8.83	0.7	37.00	2	
747547.2193	4008153.5108	22	3	6.02	350.6	6.00	2	
747545.3025	4008157.8765	23	1	10.60	344.3	27.00	2	
747544.7706	4008157.5800	24	2	10.60	341.1	2.00	2	
747541.7910	4008155.2706	25	1	9.99	320.3	11.00	2	
747541.4816	4008155.0117	26	1	9.99	318.0	12.30	2	
747542.8209	4008153.0233	27	3	7.65	315.5	7.00	2	
747544.3834	4008153.7579	28	1	7.25	328.4	9.60	2	
747544.4059	4008153.7213	29	2	7.25	328.4	1.00	2	
747544.7863	4008153.7908	30	2	7.09	331.3	6.80	2	46
747543.6909	4008154.1136	31	2	7.94	325.5	6.80	2	44
747540.6309	4008152.2031	32	2	8.85	301.6	9.10	2	48
747541.3796	4008150.8133	33	1	7.45	295.6	24.20	2	
747539.5023	4008150.2867	34	4	8.97	287.5	31.50	2	
747539.6965	4008149.4288	35	4	8.66	282.5	11.50	2	
747538.7078	4008151.2840	36	2	10.20	291.5	2.00	2	
747537.8457	4008151.8977	37	1	11.19	292.8	10.00	2	
747537.5235	4008151.6432	38	1	11.39	291.0	10.80	2	
747539.3243	4008150.6007	39	2	9.39	289.0	1.00	2	
747537.4388	4008150.5284	40	2	11.15	285.5	5.00	2	
747537.4033	4008150.4167	41	2	11.15	284.9	6.00	2	45
747537.0745	4008148.9089	42	3	11.15	277.0	13.30	2	
747538.4693	4008145.1861	43	2	9.99	256.4	5.80	2	39
747539.3426	4008144.7469	44	2	9.29	252.5	1.00	2	
747538.4001	4008143.7773	45	2	10.50	249.0	1.00	2	
747538.9389	4008143.2003	46	2	10.23	244.9	1.00	2	

747539.4591	4008143.5367	47	1	9.55	245.4	14.31	2	
747540.7293	4008143.2245	48	2	8.63	240.0	1.00	2	
747541.4481	4008145.1351	49	1	7.10	250.4	15.00	2	
747542.0985	4008145.5924	50	1	6.37	252.3	8.50	2	
747543.9777	4008146.2084	51	1	4.38	252.5	11.00	2	
747543.9209	4008147.1896	52	3	4.27	265.3	6.20	2	
747544.8320	4008144.7397	53	1	4.30	230.3	17.40	2	
747544.1156	4008144.8644	54	2	4.88	236.8	2.00	2	
747544.1023	4008144.2532	55	2	5.25	231.3	2.00	2	
747543.7636	4008142.4837	56	1	6.69	221.3	8.60	2	
747543.5369	4008142.0348	57	1	7.16	220.3	12.20	2	
747544.1303	4008141.4746	58	1	7.23	213.9	16.00	2	
747545.4356	4008141.4879	59	1	6.60	204.6	11.70	2	
747545.3740	4008140.8344	60	1	7.22	202.9	12.30	2	
747545.1606	4008140.6013	61	1	7.52	203.7	12.00	2	
747546.2904	4008140.5345	62	2	7.26	195.3	1.00	2	
747546.5647	4008139.0117	63	1	8.63	190.9	11.40	2	
747546.8514	4008138.0140	64	2	9.52	188.1	20.80	2	4
747547.4529	4008137.0155	65	1	10.37	184.1	36.70	2	
747535.9856	4008139.3911	66	3	14.65	236.3	8.10	2	
747536.3574	4008138.8373	67	3	14.65	233.7	10.70	2	
747542.6659	4008137.7475	68	1	11.07	209.5	36.70	2	
747541.5918	4008133.4192	69	2	15.37	205.1	45.10	2	1
747543.8579	4008134.5429	70	1	13.58	198.5	25.50	2	
747558.3366	4008137.7262	71	2	14.10	134.1	1.00	2	
747535.0612	4008152.8499	72	3	4.44	97.0	9.80	3	
747536.4000	4008155.2685	73	3	6.04	72.1	9.80	3	
747536.3130	4008157.3489	74	3	6.90	55.3	8.40	3	
747535.5259	4008157.0112	75	2	6.10	53.7	1.00	3	
747533.6207	4008157.0286	76	2	4.71	39.7	2.00	3	
747533.3617	4008155.8785	77	4	3.53	48.0	35.70	3	
747533.4387	4008155.6344	78	2	3.60	51.7	2.00	3	
747533.4387	4008155.6344	79	2	3.60	51.7	2.00	3	
747533.5173	4008155.6882	80	2	3.70	51.8	1.00	3	
747533.6284	4008155.7081	81	2	3.80	52.6	1.00	3	
747531.7483	4008154.6266	82	2	1.65	42.9	5.70	3	47
747531.8284	4008156.8308	83	2	3.64	19.6	1.00	3	
747532.1891	4008156.7466	84	2	3.70	25.3	1.00	3	
747532.5968	4008157.5715	85	2	4.62	25.5	1.00	3	
747531.9438	4008157.7196	86	1	4.35	17.2	35.00	3	
747531.6405	4008157.9150	87	2	4.63	12.9	1.00	3	
747531.7587	4008157.8553	88	2	4.60	14.5	1.00	3	
747531.5831	4008157.9175	89	2	4.62	12.2	1.00	3	
747531.4335	4008158.1403	90	2	4.81	9.9	1.00	3	
747531.3453	4008157.6786	91	2	4.34	9.8	1.00	3	
747531.1246	4008158.0230	92	2	4.65	6.4	1.00	3	
747530.8795	4008158.2944	93	2	4.90	3.2	1.00	3	
747530.3333	4008157.6087	94	2	4.19	356.3	6.10	3	43
747529.7546	4008156.4869	95	2	3.20	344.6	1.00	3	
747529.8656	4008156.6283	96	2	3.31	347.1	1.00	3	

747528.9830	4008156.7838	97	1	3.62	334.4	27.10	3	
747528.5001	4008156.0346	98	2	3.37	321.4	1.00	3	
747526.5614	4008158.2340	99	2	6.30	320.1	1.00	3	
747526.5742	4008158.2186	100	2	6.28	320.1	1.00	3	
747526.8504	4008157.0873	101	2	5.26	314.5	1.00	3	
747527.0786	4008155.8302	102	2	4.28	304.6	1.00	3	
747522.9957	4008156.5959	103	2	8.25	292.8	1.00	3	
747523.2714	4008157.4960	104	1	8.26	299.2	28.40	3	
747521.2329	4008153.3316	105	1	9.24	269.6	26.60	3	
747519.7044	4008153.5873	106	1	10.82	271.0	16.60	3	
747523.8018	4008148.3256	107	1	8.40	233.3	17.20	3	
747525.8532	4008148.3361	108	1	6.89	223.2	10.50	3	
747524.5326	4008150.0996	109	3	6.87	241.5	8.10	3	
747527.0715	4008151.9619	110	1	3.75	247.9	12.90	3	
747526.8481	4008151.6448	111	1	4.08	245.0	13.20	3	
747529.8582	4008151.4699	112	1	2.02	201.2	9.40	3	
747530.3567	4008151.0276	113	1	2.32	186.0	12.50	3	
747530.9267	4008149.6532	114	3	3.71	175.1	9.50	3	
747527.6747	4008147.0826	115	1	6.91	204.9	10.30	3	
747528.0559	4008146.3145	116	3	7.45	199.8	15.50	3	
747526.9692	4008145.4907	117	1	8.66	204.7	8.50	3	
747525.8084	4008144.1814	118	2	10.20	207.5	37.90	3	? Old 79
747529.1957	4008145.0604	119	1	8.40	189.6	11.00	3	
747529.0801	4008143.3097	120	1	10.15	188.6	10.40	3	
747531.4648	4008146.4005	121	3	7.00	173.0	9.80	3	
747532.2557	4008145.4296	122	1	7.99	168.3	29.30	3	
747533.3919	4008145.8648	123	3	7.99	159.7	8.20	3	
747537.0373	4008143.8618	124	1	11.32	146.0	36.30	3	
747534.8340	4008144.3294	125	2	10.00	155.0	1.00	3	
747535.7444	4008142.3265	126	2	12.20	155.1	1.00	3	
747537.2918	4008141.4336	127	2	13.70	150.8	1.00	3	
747537.9733	4008142.8750	128	2	12.84	145.0	1.00	3	
747518.6271	4008157.2470	129	3	3.46	350.1	7.00	4	
747518.0668	4008157.5323	130	3	3.87	342.7	7.00	4	
747517.1776	4008156.0416	131	2	3.03	317.5	1.00	4	
747518.0798	4008154.8092	132	1	1.49	311.2	7.20	4	
747517.0102	4008155.2664	133	1	2.60	303.4	11.30	4	
747515.6213	4008155.3573	134	1	3.87	293.3	11.40	4	
747516.3146	4008154.8186	135	2	3.08	289.2	1.00	4	
747514.7097	4008154.8554	136	1	4.60	283.1	7.80	4	
747513.9517	4008157.5398	137	2	6.46	305.3	1.00	4	
747514.0788	4008154.5644	138	2	5.20	278.4	1.00	4	
747514.6482	4008154.2854	139	2	4.60	276.0	1.00	4	
747514.6491	4008154.2933	140	2	4.60	276.1	1.00	4	
747514.6474	4008154.2774	141	2	4.60	275.9	1.00	4	
747514.4430	4008152.7257	142	2	4.90	257.3	1.00	4	
747514.6884	4008152.5023	143	1	4.67	254.0	10.50	4	
747514.3906	4008151.9374	144	2	5.18	248.9	1.00	4	
747513.6667	4008151.9970	145	1	5.80	252.0	9.50	4	
747517.2256	4008152.5817	146	1	2.30	238.6	9.20	4	

747518.4135	4008150.6546	147	1	3.20	194.5	10.60	4	
747517.4063	4008150.2132	148	1	3.90	206.9	25.30	4	
747517.3934	4008150.1878	149	2	4.05	206.9	1.00	4	
747515.0583	4008148.6365	150	1	6.60	218.9	8.00	4	
747521.1165	4008148.4413	151	1	5.60	160.6	17.10	4	
747522.2331	4008146.1358	152	1	8.20	158.6	7.20	4	
747522.1440	4008145.7486	153	1	8.50	160.1	13.40	4	
747521.9966	4008145.8088	154	1	8.40	160.9	12.20	4	
747515.8621	4008141.1541	155	1	13.00	194.9	18.00	4	
747520.3990	4008143.3645	156	2	10.50	173.6	1.00	4	
747519.9710	4008142.6171	157	1	11.17	176.2	8.30	4	
747518.5956	4008142.4932	158	1	11.30	183.2	5.70	4	
747519.6135	4008142.1844	159	3	11.60	178.1	5.20	4	
747515.3081	4008138.6027	160	2	15.20	298.1	1.00	5	
747516.1442	4008138.9085	161	2	14.60	300.7	5.30	5	52
747516.5238	4008138.9153	162	2	14.30	301.5	1.00	5	
747517.2274	4008139.6999	163	1	14.10	305.7	10.60	5	
747517.6697	4008139.7686	164	1	13.80	307.0	7.50	5	
747517.4401	4008139.3986	165	2	13.80	305.2	1.00	5	
747518.5848	4008140.0065	166	1	13.20	310.2	14.10	5	
747519.0642	4008140.5092	167	1	13.20	313.2	9.40	5	
747520.8710	4008139.8589	168	2	11.50	317.0	2.00	5	
747521.4144	4008138.4721	169	2	10.13	313.9	2.00	5	
747522.0193	4008137.0047	170	2	8.70	309.7	2.00	5	
747523.3441	4008137.0087	171	2	7.73	316.0	2.00	5	
747522.7364	4008138.5729	172	2	9.30	320.0	2.00	5	
747523.2011	4008138.0425	173	2	8.60	320.1	1.00	5	
747522.3629	4008138.2352	174	1	9.23	316.9	15.00	5	
747522.4852	4008138.7678	175	1	9.56	319.6	12.20	5	
747524.2431	4008136.7773	176	1	6.90	320.0	13.20	5	
747525.3166	4008136.3027	177	3	5.90	325.0	7.00	5	
747523.6127	4008135.9922	178	1	6.80	311.7	8.30	5	
747523.5779	4008135.6205	179	1	6.55	309.1	15.40	5	
747518.9900	4008136.5715	180	1	10.92	297.8	16.10	5	
747519.9668	4008135.3936	181	1	9.55	294.3	11.00	5	
747520.6197	4008135.5332	182	1	9.01	296.8	13.20	5	
747522.0255	4008133.8515	183	1	7.08	289.8	7.20	5	
747522.3186	4008134.0277	184	1	6.85	292.0	11.00	5	
747525.3951	4008133.4472	185	1	3.80	301.1	16.80	5	
747526.4471	4008131.3497	186	1	2.21	267.7	13.10	5	
747523.8065	4008130.1701	187	1	4.98	255.5	19.20	5	
747519.3006	4008132.3813	188	1	9.40	275.7	13.40	5	
747516.7685	4008132.8662	189	1	11.98	276.8	11.40	5	
747514.2654	4008134.2247	190	1	14.64	280.9	16.20	5	
747515.1143	4008130.0589	191	1	13.60	264.2	15.30	5	
747515.2021	4008130.5431	192	1	13.50	266.2	9.70	5	
747515.0934	4008129.1116	193	1	13.80	260.3	5.00	5	
747515.9967	4008129.0597	194	2	12.94	259.4	1.00	5	
747516.1230	4008128.4630	195	2	12.94	256.7	1.00	5	
747516.4023	4008127.2714	196	2	13.00	251.3	1.00	5	

747516.4542	4008127.1212	197	2	13.00	250.6	1.00	5	
747516.0887	4008127.2633	198	2	13.30	251.7	1.00	5	
747515.8914	4008127.2229	199	2	13.50	251.8	1.00	5	
747515.9282	4008126.8101	200	2	13.60	250.1	1.00	5	
747516.1162	4008126.8782	201	2	13.40	250.1	1.00	5	
747516.2918	4008126.9663	202	2	13.20	250.2	2.00	5	
747516.8819	4008124.9325	203	2	13.50	241.2	2.00	5	
747517.7912	4008125.5314	204	2	12.42	241.6	1.00	5	
747517.1181	4008125.9068	205	2	12.85	244.5	1.00	5	
747516.9463	4008126.3701	206	2	12.81	246.7	2.00	5	
747517.1351	4008126.4754	207	2	12.60	246.8	1.00	5	
747517.4205	4008126.8295	208	2	12.20	247.8	1.00	5	
747516.6413	4008126.3384	209	1	13.00	247.1	22.60	5	
747515.2215	4008124.0504	210	1	15.30	241.3	18.00	5	
747514.8267	4008123.8971	211	2	15.80	241.5	2.00	5	
747515.3425	4008124.4172	212	2	15.10	242.3	2.00	5	
747519.4397	4008126.8942	213	2	10.33	243.9	1.00	5	
747517.8684	4008128.5534	214	2	11.20	255.1	6.00	5	53
747519.0803	4008127.5264	215	2	10.40	247.9	1.00	5	
747519.5855	4008125.4858	216	2	10.90	236.9	1.00	5	
747520.7087	4008125.7891	217	2	9.80	234.8	1.00	5	
747520.7581	4008125.3751	218	2	10.00	232.7	2.00	5	
747520.7475	4008125.3890	219	2	10.00	232.8	2.00	5	
747520.7578	4008124.9001	220	2	10.30	230.6	1.00	5	
747521.3429	4008124.3905	221	2	10.20	226.3	1.00	5	
747521.0700	4008123.6282	222	2	10.93	224.4	1.00	5	
747520.7970	4008123.3777	223	2	11.30	224.5	1.00	5	
747521.4149	4008123.2698	224	1	10.80	221.8	32.20	5	
747519.5104	4008124.7982	225	3	11.30	234.2	11.20	5	
747521.7899	4008123.1518	226	2	10.80	219.9	1.00	5	
747525.8072	4008124.6431	227	1	7.30	203.2	19.20	5	
747523.8481	4008124.6848	228	3	8.30	215.8	6.00	5	
747521.1045	4008125.9883	229	1	9.28	234.4	17.40	5	
747521.5170	4008127.8650	230	3	8.00	243.6	8.50	5	
747526.6560	4008129.9353	231	3	2.50	233.9	11.10	5	
747527.3582	4008125.8085	232	2	5.79	193.6	1.00	5	
747528.8284	4008123.7368	233	2	7.70	179.2	1.00	5	
747529.0525	4008125.8583	234	1	5.40	176.6	38.50	5	
747528.8764	4008126.4884	235	5	4.93	178.2	5.00	5	
747534.5069	4008114.1483	236	3	18.20	161.5	7.00	5	
747536.8114	4008115.7658	237	3	17.60	152.7	8.00	5	
747536.5340	4008116.1068	238	2	17.20	153.0	2.00	5	
747530.5770	4008127.1721	239	2	4.65	156.5	1.00	5	
747530.8581	4008129.1887	240	2	3.10	136.5	1.00	5	
747530.3572	4008129.1040	241	3	2.82	145.0	6.60	5	
747529.2613	4008130.1425	242	3	1.36	157.4	9.30	5	
747532.9017	4008129.5970	243	3	4.50	113.8	13.90	5	
747531.1236	4008132.3682	244	3	2.50	68.9	15.10	5	
747528.1922	4008135.0646	245	1	3.62	351.7	8.40	5	
747529.7974	4008137.5468	246	1	6.15	10.0	10.00	5	

747530.6988	4008137.1532	247	1	6.00	19.1	9.00	5	
747530.6961	4008137.3105	248	1	6.14	18.6	10.60	5	
747528.2719	4008138.5754	249	3	7.10	356.4	9.70	5	
747526.7840	4008140.7936	250	1	9.46	348.3	18.20	5	
747527.3493	4008142.4524	251	1	11.05	352.9	9.30	5	
747528.4303	4008140.6859	252	1	9.18	358.2	13.90	5	
747530.2640	4008138.8929	253	2	7.60	11.7	2.00	5	
747536.9936	4008128.1321	254	1	8.82	111.8	18.00	5	
747537.0207	4008131.1512	255	2	8.30	92.0	1.00	5	
747542.8207	4008123.5608	256	1	16.00	119.2	30.50	5	
747539.2696	4008124.5905	257	1	12.50	123.0	15.60	5	
747538.9274	4008123.7498	258	3	12.72	127.0	12.00	5	
747540.3602	4008125.7641	259	1	12.90	116.0	10.00	5	
747535.1655	4008119.7182	260	1	13.30	151.2	15.50	5	
747516.3681	4008116.4048	261	3	4.64	319.3	14.80	6	
747515.5105	4008110.5428	262	1	4.50	239.8	9.80	6	
747517.1299	4008111.7675	263	3	2.45	245.3	19.00	6	
747516.5752	4008111.7932	264	3	3.01	250.1	7.80	6	
747519.8807	4008109.7874	265	2	3.07	171.8	1.00	6	
747520.2402	4008110.1367	266	2	2.80	163.5	2.00	6	
747521.5565	4008108.9041	267	2	4.45	151.7	2.00	6	
747520.7673	4008108.2696	268	2	4.74	163.8	2.00	6	
747520.8044	4008107.8852	269	2	5.00	164.6	26.00	6	16
747521.4759	4008108.4893	270	1	4.64	154.9	30.90	6	
747521.9795	4008108.5575	271	1	4.89	149.3	16.00	6	
747521.8112	4008108.1000	272	1	5.20	153.4	18.20	6	
747522.1197	4008111.2788	273	2	3.09	120.1	1.00	6	
747522.1143	4008111.2695	274	2	3.09	120.3	1.00	6	
747522.9361	4008110.6477	275	2	4.11	122.0	2.00	6	
747523.1237	4008111.7753	276	2	3.82	106.0	2.00	6	
747523.3378	4008112.6473	277	2	3.89	92.7	2.00	6	
747523.1843	4008111.1256	278	3	4.00	114.5	22.50	6	
747523.5740	4008113.0042	279	3	4.11	87.6	5.10	6	
747519.6138	4008115.4860	280	3	2.58	3.7	16.10	6	
747520.3343	4008116.8891	281	2	4.15	12.4	1.00	6	
747520.1084	4008117.1347	282	2	4.35	8.8	1.00	6	
747522.3705	4008118.2021	283	3	6.04	28.6	15.50	6	
747522.1799	4008119.9261	284	1	7.51	21.1	19.00	6	
747523.6705	4008117.3496	285	1	6.15	43.1	7.70	6	
747527.0168	4008116.5582	286	1	8.35	63.8	18.40	6	
747530.0107	4008115.0004	287	2	10.65	78.4	27.80	6	10
747530.0506	4008114.0022	288	2	10.59	83.7	16.60	6	13
747527.8865	4008112.2405	289	2	8.37	94.0	19.00	6	8
747526.1558	4008111.5017	290	3	6.81	101.2	6.80	6	
747526.5605	4008110.0842	291	3	7.60	111.1	6.00	6	
747526.8366	4008108.6983	292	3	8.44	119.2	6.20	6	
747528.2706	4008111.3219	293	3	8.89	99.7	13.30	6	
747532.0013	4008115.8694	294	1	12.83	76.4	18.30	6	
747531.0980	4008120.2281	295	1	13.66	57.6	29.00	6	
747533.4855	4008112.1598	296	2	1.73	256.8	1.00	7	

747533.3912	4008110.9725	297	2	2.38	228.4	1.00	7	
747533.6122	4008109.9658	298	2	3.02	211.1	1.00	7	
747532.6719	4008109.7567	299	2	3.75	221.8	1.00	7	
747534.7485	4008109.0846	300	1	3.37	187.0	25.50	7	
747535.1994	4008110.5312	301	2	2.02	179.3	1.00	7	12
747541.4957	4008108.3085	302	2	7.41	123.9	41.10	7	
747540.7056	4008109.4140	303	1	6.28	119.6	16.20	7	11
747542.8726	4008109.3043	304	2	8.17	112.9	37.30	7	
747544.3362	4008108.6104	305	1	9.87	113.3	21.00	7	
747543.7025	4008109.7026	306	1	8.96	108.5	6.50	7	
747543.4715	4008110.6405	307	4	8.43	103.0	17.00	7	
747543.0886	4008110.9459	308	4	7.96	101.5	23.20	7	
747542.6421	4008111.6391	309	1	7.45	97.0	14.70	7	
747535.0579	4008114.0404	310	1	1.43	355.5	11.80	7	
747534.1129	4008116.0952	311	1	3.60	343.3	19.00	7	
747544.6079	4008112.3255	312	1	9.34	91.4	19.20	7	
747544.5566	4008113.0970	313	1	9.34	86.7	11.50	7	
747540.4650	4008111.6517	314	1	5.28	99.7	17.40	7	
747541.0640	4008113.2791	315	1	5.88	83.0	10.70	7	
747539.4132	4008113.7954	316	1	4.39	73.7	5.20	7	
747536.1607	4008112.5508	317	1	0.95	90.3	7.20	7	
747536.0047	4008112.7614	318	2	0.85	76.1	1.00	7	
747534.7584	4008117.3148	319	1	4.74	355.0	7.40	7	9
747538.0519	4008118.7261	320	2	6.60	25.0	41.60	7	6
747538.6571	4008118.1289	321	2	6.53	32.0	8.30	7	
747539.5792	4008117.0381	322	1	6.14	44.5	28.80	7	
747535.8265	4008121.2250	323	1	8.63	4.3	12.70	7	
747547.5397	4008111.4423	324	3	8.40	196.0	10.00	8	
747547.1800	4008110.1879	325	2	9.75	196.0	1.00	8	
747548.3508	4008111.8275	326	2	7.88	191.1	1.00	8	
747548.4130	4008117.1422	327	1	2.79	211.0	7.30	8	
747549.3499	4008117.5730	328	1	2.03	194.6	5.70	8	
747549.4823	4008117.3038	329	1	2.26	189.7	6.80	8	
747550.3524	4008116.1243	330	1	3.42	172.0	10.90	8	
747550.3284	4008115.8216	331	1	3.70	173.0	14.30	8	
747549.1572	4008115.5704	332	1	4.01	190.1	9.50	8	
747548.3550	4008115.8183	333	1	3.97	202.0	14.20	8	
747548.3617	4008115.6388	334	1	4.17	201.0	7.10	8	
747551.9542	4008114.7459	335	1	5.21	156.6	8.20	8	
747553.0689	4008116.3199	336	1	4.45	135.4	21.50	8	
747553.8090	4008116.1639	337	2	5.14	130.8	13.00	8	5
747554.3437	4008115.9542	338	1	5.64	128.9	22.00	8	
747560.3332	4008120.4989	339	2	10.45	84.9	11.20	8	20
747554.6654	4008123.6185	340	1	6.17	49.8	22.00	8	
747555.2402	4008124.1042	341	1	6.97	49.8	12.50	8	
747551.1425	4008120.8566	342	1	1.76	44.6	10.80	8	
747551.3370	4008121.0028	343	1	2.00	45.6	11.00	8	
747554.0576	4008124.7749	344	2	6.68	38.8	1.00	8	
747553.7821	4008125.4328	345	1	6.92	33.7	26.60	8	
747550.8534	4008123.0916	346	1	3.58	15.6	16.30	8	

747549.0009	4008121.8379	347	1	2.37	339.1	12.60	8	
747548.6869	4008121.5089	348	1	2.24	328.7	7.00	8	
747547.3581	4008122.3437	349	2	3.66	317.9	17.00	8	3
747547.8858	4008123.0699	350	1	3.91	330.5	23.40	8	
747548.2838	4008124.1683	351	2	4.80	341.0	13.70	8	2
747542.6780	4008125.3053	352	3	9.10	308.6	20.20	8	
747545.2358	4008124.2304	353	2	6.57	315.2	1.00	8	
747541.1702	4008121.2086	354	1	8.81	280.7	8.50	8	
747541.2171	4008120.8426	355	1	8.60	278.4	29.10	8	
747541.1223	4008118.6920	356	1	8.71	264.3	16.00	8	
747542.0190	4008118.7122	357	1	7.85	263.8	9.20	8	
747549.1740	4008120.9169	358	2	1.51	332.8	2.00	8	
747549.1458	4008120.9247	359	2	1.53	332.0	2.00	8	
747553.2818	4008127.6197	360	1	4.89	205.7	10.00	9	
747552.9973	4008127.9181	361	1	4.70	210.3	22.00	9	
747549.9805	4008127.4708	362	2	7.06	229.8	13.40	9	7
747547.4072	4008125.8524	363	3	10.07	232.2	15.20	9	
747545.0907	4008128.0422	364	3	11.06	248.7	6.20	9	
747544.7241	4008127.3740	365	3	11.66	246.3	5.10	9	
747544.4553	4008128.1652	366	3	11.61	250.4	6.70	9	
747542.9653	4008127.9506	367	1	13.08	251.7	8.50	9	
747541.3720	4008128.4107	368	3	14.48	255.4	8.20	9	
747542.2562	4008130.3842	369	3	13.20	262.7	15.10	9	
747544.9527	4008131.8882	370	1	10.44	269.0	6.60	9	
747544.8352	4008131.4604	371	1	10.54	266.7	13.30	9	
747546.2961	4008129.3151	372	1	9.51	253.2	5.00	9	
747549.4021	4008130.7028	373	1	6.00	257.2	35.10	9	
747559.9597	4008133.8030	374	2	4.85	69.1	1.00	9	
747560.0631	4008136.1753	375	2	6.07	48.5	24.80	9	17
747561.7873	4008116.2421	376	2	17.05	158.1	2.00	9	
747561.5414	4008116.1348	377	2	17.06	159.0	2.00	9	

species codes

1 = post oak

2 = eastern red cedar

3 = blackjack oak

4 = ash

5 = hawthorne

DBH

1 = <5cm dbh

2 = <5cm dbh, >1m tall

Appendix B. The tree-ring chronologies and the sample size data developed for selected eastern red cedar trees at the KAFP.

YEAR	NUM	SEG	AGE	RAW	STD	RES	ARS
1642	1	355	1	0.4	0.996	1.005	1.008
1643	1	355	2	0.321	0.862	0.863	0.872
1644	2	305.5	2	0.53	0.716	0.762	0.716
1645	3	230.667	2.333	0.738	0.686	0.784	0.675
1646	3	230.667	3.333	0.806	0.739	0.865	0.739
1647	3	230.667	4.333	1.039	0.949	1.059	0.96
1648	3	230.667	5.333	0.495	0.848	0.987	0.976
1649	3	230.667	6.333	0.697	0.949	1.1	1.095
1650	5	218.8	4.8	0.089	0.284	0.382	0.426
1651	5	218.8	5.8	0.381	0.775	0.996	0.77
1652	5	218.8	6.8	0.81	1.054	1.402	1.315
1653	5	218.8	7.8	0.75	0.91	0.928	1.06
1654	5	218.8	8.8	0.243	0.51	0.403	0.433
1655	5	218.8	9.8	0.293	0.55	0.774	0.551
1656	5	218.8	10.8	0.621	1.272	1.44	1.265
1657	6	239	10	0.598	1.105	1.071	1.183
1658	6	239	11	0.721	1.282	1.219	1.298
1659	6	239	12	0.405	0.8	0.682	0.807
1660	6	239	13	0.477	0.883	0.97	0.898
1661	6	239	14	0.642	1.222	1.312	1.276
1662	6	239	15	0.647	1.188	1.106	1.222
1663	6	239	16	0.551	0.887	1.001	1.096
1664	6	239	17	0.126	0.372	0.375	0.42
1665	6	239	18	0.505	0.741	0.985	0.756
1666	6	239	19	0.535	1.157	1.26	1.166
1667	6	239	20	0.422	0.745	0.703	0.776
1668	6	239	21	0.454	0.832	0.894	0.809
1669	6	239	22	0.575	1.244	1.315	1.243
1670	6	239	23	0.694	1.229	1.128	1.232
1671	6	239	24	0.603	0.987	0.899	0.998
1672	6	239	25	0.69	1.039	1.002	1.006
1673	6	239	26	0.742	1.269	1.24	1.248
1674	7	229.286	23.286	0.931	1.352	1.187	1.292
1675	8	226.125	21.375	0.721	1.238	1.079	1.202
1676	8	226.125	22.375	0.563	0.914	0.815	0.902
1677	8	226.125	23.375	0.691	1.153	1.21	1.176
1678	9	236.444	21.778	0.619	1.24	1.15	1.227
1679	9	236.444	22.778	0.478	1.053	0.893	0.99
1680	9	236.444	23.778	0.583	1.015	1.041	1.042
1681	9	236.444	24.778	0.548	0.926	0.811	0.834
1682	9	236.444	25.778	0.466	0.797	0.854	0.792
1683	9	236.444	26.778	0.496	0.839	0.937	0.858
1684	9	236.444	27.778	0.449	0.799	0.766	0.715
1685	9	236.444	28.778	0.331	0.699	0.698	0.588

1686	9	236.444	29.778	0.41	0.827	0.976	0.815
1687	9	236.444	30.778	0.834	1.39	1.48	1.41
1688	9	236.444	31.778	0.7	1.278	1.125	1.296
1689	9	236.444	32.778	0.678	1.239	1.131	1.256
1690	9	236.444	33.778	0.704	1.185	1.089	1.197
1691	9	236.444	34.778	0.655	1.153	1.113	1.198
1692	10	243.3	32.3	0.76	1.32	1.269	1.354
1693	10	243.3	33.3	0.574	0.954	0.846	0.994
1694	10	243.3	34.3	0.816	1.333	1.389	1.391
1695	10	243.3	35.3	0.801	1.35	1.208	1.371
1696	10	243.3	36.3	0.694	1.246	1.05	1.205
1697	10	243.3	37.3	0.601	1.037	0.958	1.046
1698	10	243.3	38.3	0.603	1.037	1.036	1.06
1699	10	243.3	39.3	0.656	1.142	1.128	1.157
1700	10	243.3	40.3	0.589	1.143	1.105	1.174
1701	10	243.3	41.3	0.607	0.985	0.841	0.916
1702	11	248	38.545	0.508	0.82	0.823	0.794
1703	11	248	39.545	0.502	0.844	0.941	0.863
1704	11	248	40.545	0.147	0.262	0.329	0.279
1705	11	248	41.545	0.279	0.519	0.819	0.533
1706	11	248	42.545	0.423	0.682	0.892	0.709
1707	12	252.25	40	0.43	0.896	1.039	0.927
1708	12	252.25	41	0.432	0.78	0.823	0.799
1709	12	252.25	42	0.384	0.687	0.79	0.714
1710	12	252.25	43	0.272	0.56	0.683	0.573
1711	12	252.25	44	0.391	0.689	0.885	0.718
1712	12	252.25	45	0.459	1.045	1.142	1.033
1713	12	252.25	46	0.535	1.05	1.031	1.05
1714	12	252.25	47	0.668	1.256	1.227	1.253
1715	12	252.25	48	0.477	0.897	0.767	0.874
1716	12	252.25	49	0.438	0.784	0.827	0.782
1717	12	252.25	50	0.35	0.63	0.712	0.629
1718	14	256.071	43.857	0.755	1.382	1.453	1.308
1719	15	244.4	41.933	0.747	1.455	1.32	1.45
1720	16	246.938	40.312	0.664	1.236	1.057	1.243
1721	18	246.778	36.833	0.536	0.978	0.877	0.981
1722	18	246.778	37.833	0.422	0.766	0.783	0.78
1723	18	246.778	38.833	0.501	0.866	0.974	0.891
1724	18	246.778	39.833	0.56	0.946	1.015	0.976
1725	18	246.778	40.833	0.577	1.006	1.001	0.996
1726	17	256.529	39.471	0.733	1.283	1.268	1.272
1727	17	256.529	40.471	0.426	0.758	0.632	0.747
1728	17	256.529	41.471	0.498	0.886	1.012	0.915
1729	18	257.167	40.167	0.605	1.032	1.108	1.079
1730	18	257.167	41.167	0.484	0.862	0.873	0.91
1731	18	257.167	42.167	0.564	0.976	0.989	0.958
1732	18	257.167	43.167	0.697	1.248	1.262	1.251
1733	19	252.895	41.895	0.628	1.069	0.951	1.057
1734	19	252.895	42.895	0.511	0.91	0.843	0.872
1735	19	252.895	43.895	0.384	0.638	0.72	0.674

1736	19	252.895	44.895	0.37	0.632	0.759	0.633
1737	19	252.895	45.895	0.702	1.226	1.379	1.237
1738	20	253.65	44.6	0.684	1.166	1.108	1.209
1739	20	253.65	45.6	0.641	1.122	1.048	1.137
1740	20	253.65	46.6	0.612	1.173	1.117	1.178
1741	20	253.65	47.6	0.424	0.75	0.671	0.748
1742	20	253.65	48.6	0.457	0.776	0.865	0.768
1743	20	253.65	49.6	0.629	1.068	1.209	1.121
1744	20	253.65	50.6	0.567	0.997	1.038	1.092
1745	21	254	49.19	0.598	1.02	1.021	1.063
1746	22	254.273	47.955	0.634	1.098	1.059	1.09
1747	24	254.25	44.958	0.562	1.016	0.966	1.008
1748	24	254.25	45.958	0.587	1.056	1.024	1.033
1749	24	254.25	46.958	0.474	0.893	0.885	0.904
1750	28	250.5	41.25	0.579	1.034	1.066	1.032
1751	28	250.5	42.25	0.592	1.014	1.029	1.047
1752	29	250.31	41.793	0.56	1.039	1.028	1.053
1753	29	250.31	42.793	0.565	1.065	1.035	1.062
1754	29	250.31	43.793	0.78	1.304	1.266	1.296
1755	29	250.31	44.793	0.605	1.04	0.893	1.018
1756	29	250.31	45.793	0.604	1.058	1.029	1.041
1757	30	249.967	45.267	0.458	0.85	0.827	0.849
1758	30	249.967	46.267	0.521	0.896	0.982	0.927
1759	30	249.967	47.267	0.632	1.115	1.164	1.14
1760	30	249.967	48.267	0.532	0.932	0.894	0.955
1761	32	249.094	46.25	0.558	1.08	1.118	1.105
1762	32	249.094	47.25	0.42	0.799	0.784	0.832
1763	32	249.094	48.25	0.344	0.647	0.745	0.682
1764	32	249.094	49.25	0.294	0.567	0.736	0.613
1765	32	249.094	50.25	0.501	0.855	1.036	0.886
1766	32	249.094	51.25	0.539	0.959	1.031	0.99
1767	32	249.094	52.25	0.384	0.696	0.731	0.733
1768	32	249.094	53.25	0.401	0.716	0.848	0.746
1769	32	249.094	54.25	0.49	0.886	1.041	0.944
1770	34	248.029	52.059	0.518	0.87	0.959	0.942
1771	34	248.029	53.059	0.641	1.043	1.119	1.101
1772	34	248.029	54.059	0.332	0.592	0.553	0.599
1773	34	248.029	55.059	0.336	0.556	0.746	0.589
1774	34	248.029	56.059	0.416	0.76	0.955	0.795
1775	36	246.528	53.944	0.493	0.844	0.919	0.841
1776	36	246.528	54.944	0.711	1.251	1.32	1.261
1777	36	246.528	55.944	0.754	1.327	1.185	1.296
1778	36	246.528	56.944	0.663	1.196	1.048	1.173
1779	36	246.528	57.944	0.686	1.253	1.167	1.242
1780	37	245.838	57.378	0.44	0.786	0.7	0.803
1781	38	245.053	56.868	0.671	1.226	1.302	1.228
1782	38	245.053	57.868	0.547	0.968	0.868	0.966
1783	39	244.487	57.385	0.88	1.411	1.406	1.398
1784	40	243.7	56.95	0.433	0.779	0.549	0.715
1785	40	243.7	57.95	0.486	0.85	0.927	0.818

1786	40	243.7	58.95	0.381	0.661	0.743	0.675
1787	40	243.7	59.95	0.289	0.521	0.68	0.554
1788	40	243.7	60.95	0.449	0.796	1.009	0.835
1789	40	243.7	61.95	0.361	0.616	0.704	0.642
1790	40	243.7	62.95	0.557	0.979	1.162	1.023
1791	40	243.7	63.95	0.449	0.761	0.767	0.781
1792	41	240.512	63.39	0.542	0.949	1.05	0.967
1793	42	239.833	62.881	0.484	0.837	0.863	0.855
1794	42	239.833	63.881	0.725	1.291	1.374	1.321
1795	42	239.833	64.881	0.563	1.02	0.891	1.026
1796	42	239.833	65.881	0.582	1.032	1.009	1.025
1797	43	238.907	65.349	0.615	1.05	1.036	1.051
1798	43	238.907	66.349	0.663	1.142	1.107	1.133
1799	43	238.907	67.349	0.644	1.109	1.041	1.1
1800	44	241	64.977	0.634	1.149	1.096	1.142
1801	44	241	65.977	0.431	0.824	0.769	0.832
1802	44	241	66.977	0.628	1.194	1.241	1.178
1803	45	240.133	66.489	0.759	1.37	1.286	1.363
1804	45	240.133	67.489	0.685	1.279	1.096	1.248
1805	46	239.283	67.022	0.657	1.227	1.123	1.228
1806	46	239.283	68.022	0.495	0.932	0.832	0.929
1807	46	239.283	69.022	0.44	0.818	0.862	0.838
1808	46	239.283	70.022	0.539	0.989	1.077	1.017
1809	46	239.283	71.022	0.392	0.717	0.708	0.72
1810	46	239.283	72.022	0.749	1.451	1.583	1.475
1811	46	239.283	73.022	0.746	1.406	1.23	1.427
1812	46	239.283	74.022	0.487	0.905	0.741	0.918
1813	46	239.283	75.022	0.57	1.085	1.141	1.114
1814	46	239.283	76.022	0.494	1.024	0.994	1.045
1815	46	239.283	77.022	0.575	1.096	1.075	1.098
1816	46	239.283	78.022	0.519	1.086	1.04	1.085
1817	47	238.213	77.362	0.699	1.342	1.312	1.352
1818	47	238.213	78.362	0.461	0.881	0.751	0.899
1819	47	238.213	79.362	0.496	0.954	0.985	0.949
1820	49	236.061	77.122	0.379	0.76	0.783	0.768
1821	50	235.04	76.58	0.485	0.899	1.013	0.925
1822	50	235.04	77.58	0.576	1.106	1.123	1.098
1823	50	235.04	78.58	0.556	1.043	1.017	1.062
1824	50	235.04	79.58	0.36	0.699	0.677	0.707
1825	50	235.04	80.58	0.622	1.218	1.366	1.253
1826	50	235.04	81.58	0.57	1.099	1.018	1.125
1827	50	235.04	82.58	0.704	1.312	1.231	1.287
1828	50	235.04	83.58	0.611	1.164	1.018	1.139
1829	51	233.725	82.941	0.576	1.095	1.024	1.085
1830	51	233.725	83.941	0.754	1.468	1.444	1.484
1831	51	233.725	84.941	0.497	0.963	0.737	0.938
1832	52	232.577	84.308	0.497	0.987	0.977	0.957
1833	52	232.577	85.308	0.588	1.149	1.15	1.138
1834	52	232.577	86.308	0.487	0.976	0.922	0.983
1835	52	232.577	87.308	0.599	1.2	1.216	1.215

1836	52	232.577	88.308	0.494	1.052	0.924	1.016
1837	52	232.577	89.308	0.491	1.011	0.962	0.973
1838	52	232.577	90.308	0.563	1.175	1.196	1.191
1839	52	232.577	91.308	0.367	0.829	0.771	0.854
1840	52	232.577	92.308	0.462	1.078	1.175	1.121
1841	52	232.577	93.308	0.328	0.7	0.66	0.714
1842	52	232.577	94.308	0.322	0.682	0.838	0.729
1843	52	232.577	95.308	0.315	0.627	0.758	0.654
1844	52	232.577	96.308	0.512	1.032	1.209	1.074
1845	51	233.784	95.843	0.357	0.729	0.709	0.744
1846	51	233.784	96.843	0.366	0.779	0.905	0.807
1847	51	233.784	97.843	0.466	0.994	1.094	1.022
1848	51	233.784	98.843	0.439	0.918	0.905	0.919
1849	51	233.784	99.843	0.33	0.706	0.71	0.682
1850	52	232.269	98.923	0.427	0.91	0.994	0.871
1851	50	233.52	95.84	0.398	0.855	0.919	0.872
1852	50	233.52	96.84	0.503	1.077	1.149	1.103
1853	50	233.52	97.84	0.509	1.121	1.105	1.152
1854	50	233.52	98.84	0.471	1.079	1.027	1.094
1855	50	233.52	99.84	0.1	0.186	0.188	0.231
1856	50	233.52	100.84	0.337	0.727	1.095	0.79
1857	50	233.52	101.84	0.528	1.218	1.347	1.268
1858	50	233.52	102.84	0.58	1.347	1.242	1.356
1859	50	233.52	103.84	0.467	1.079	0.932	1.081
1860	50	233.52	104.84	0.176	0.395	0.364	0.402
1861	51	231.765	103.784	0.33	0.746	1.025	0.788
1862	51	231.765	104.784	0.358	0.814	0.933	0.853
1863	51	231.765	105.784	0.627	1.469	1.565	1.512
1864	51	231.765	106.784	0.57	1.339	1.141	1.352
1865	51	231.765	107.784	0.515	1.224	1.069	1.217
1866	51	231.765	108.784	0.48	1.183	1.095	1.188
1867	51	231.765	109.784	0.391	0.949	0.872	0.953
1868	51	231.765	110.784	0.393	0.935	0.954	0.94
1869	51	231.765	111.784	0.585	1.331	1.362	1.343
1870	51	231.765	112.784	0.468	1.133	1.001	1.145
1871	51	231.765	113.784	0.422	1.015	0.961	1.025
1872	51	231.765	114.784	0.414	0.966	0.951	0.966
1873	51	231.765	115.784	0.381	0.901	0.928	0.92
1874	51	231.765	116.784	0.391	0.885	0.921	0.894
1875	51	231.765	117.784	0.457	1.061	1.112	1.075
1876	52	229.808	116.519	0.54	1.273	1.248	1.283
1877	52	229.808	117.519	0.469	1.082	0.982	1.101
1878	52	229.808	118.519	0.473	1.144	1.108	1.154
1879	51	230.314	117.843	0.311	0.708	0.648	0.716
1880	52	228.308	116.577	0.198	0.439	0.569	0.46
1881	52	228.308	117.577	0.29	0.644	0.902	0.689
1882	52	228.308	118.577	0.55	1.292	1.464	1.344
1883	52	228.308	119.577	0.477	1.193	1.069	1.213
1884	52	228.308	120.577	0.333	0.814	0.711	0.803
1885	52	228.308	121.577	0.351	0.841	0.934	0.859

1886	52	228.308	122.577	0.205	0.477	0.543	0.491
1887	52	228.308	123.577	0.26	0.592	0.827	0.627
1888	52	228.308	124.577	0.35	0.836	1.031	0.886
1889	52	228.308	125.577	0.404	0.925	1.013	0.972
1890	52	228.308	126.577	0.261	0.621	0.652	0.646
1891	52	228.308	127.577	0.422	1.038	1.214	1.076
1892	52	228.308	128.577	0.377	0.891	0.878	0.914
1893	52	228.308	129.577	0.336	0.783	0.844	0.815
1894	52	228.308	130.577	0.249	0.608	0.71	0.641
1895	52	228.308	131.577	0.054	0.112	0.287	0.147
1896	52	228.308	132.577	0.217	0.54	0.949	0.611
1897	52	228.308	133.577	0.405	0.96	1.183	1.031
1898	52	228.308	134.577	0.372	0.838	0.87	0.888
1899	52	228.308	135.577	0.361	0.818	0.894	0.854
1900	51	227.765	134.216	0.364	0.851	0.935	0.881
1901	51	227.765	135.216	0.343	0.788	0.871	0.829
1902	51	227.765	136.216	0.327	0.742	0.846	0.782
1903	51	227.765	137.216	0.467	1.104	1.22	1.137
1904	51	227.765	138.216	0.412	1.012	0.969	1.03
1905	50	230.06	139.72	0.274	0.622	0.627	0.644
1906	50	230.06	140.72	0.251	0.555	0.726	0.587
1907	50	230.06	141.72	0.303	0.684	0.895	0.734
1908	50	230.06	142.72	0.36	0.776	0.93	0.828
1909	49	231.163	143.041	0.413	0.934	1.041	0.977
1910	49	231.163	144.041	0.278	0.612	0.676	0.673
1911	49	231.163	145.041	0.168	0.335	0.509	0.382
1912	49	231.163	146.041	0.376	0.775	1.082	0.838
1913	49	231.163	147.041	0.452	0.924	1.054	0.994
1914	49	231.163	148.041	0.637	1.314	1.353	1.356
1915	49	231.163	149.041	1.19	2.424	2.283	2.432
1916	49	231.163	150.041	0.445	0.991	0.445	1.029
1917	49	231.163	151.041	0.491	1.055	1.066	1.083
1918	49	231.163	152.041	0.463	0.948	0.904	0.943
1919	49	231.163	153.041	0.702	1.439	1.45	1.433
1920	49	231.163	154.041	0.691	1.37	1.169	1.349
1921	49	231.163	155.041	0.708	1.389	1.23	1.377
1922	49	231.163	156.041	0.635	1.285	1.111	1.268
1923	49	231.163	157.041	0.559	1.105	0.972	1.086
1924	49	231.163	158.041	0.519	1.014	0.959	0.999
1925	48	232.333	158.688	0.427	0.801	0.804	0.809
1926	48	232.333	159.688	0.473	0.87	0.964	0.893
1927	48	232.333	160.688	0.562	1.073	1.137	1.099
1928	49	229.163	158.408	0.555	1.018	0.992	1.038
1929	49	229.163	159.408	0.579	1.087	1.056	1.076
1930	49	229.163	160.408	0.385	0.718	0.668	0.704
1931	49	229.163	161.408	0.609	1.077	1.202	1.088
1932	49	229.163	162.408	0.533	0.963	0.915	0.956
1933	49	229.163	163.408	0.616	1.106	1.115	1.102
1934	49	229.163	164.408	0.498	0.906	0.866	0.913
1935	49	229.163	165.408	0.866	1.579	1.626	1.596

1936	48	229.458	165.375	0.505	0.922	0.662	0.908
1937	48	229.458	166.375	0.777	1.395	1.429	1.398
1938	48	229.458	167.375	1.024	1.89	1.714	1.88
1939	48	229.458	168.375	0.623	1.106	0.715	1.076
1940	48	229.458	169.375	0.515	0.913	0.854	0.89
1941	48	229.458	170.375	0.494	0.857	0.907	0.867
1942	48	229.458	171.375	0.495	0.856	0.934	0.886
1943	48	229.458	172.375	0.44	0.803	0.864	0.824
1944	48	229.458	173.375	0.671	1.13	1.22	1.154
1945	48	229.458	174.375	0.64	1.08	1.037	1.104
1946	48	229.458	175.375	0.571	0.945	0.913	0.96
1947	48	229.458	176.375	0.535	0.902	0.94	0.93
1948	48	229.458	177.375	0.519	0.83	0.86	0.837
1949	48	229.458	178.375	0.608	0.978	1.038	0.977
1950	48	229.458	179.375	0.591	0.937	0.973	0.97
1951	48	229.458	180.375	0.481	0.797	0.833	0.826
1952	48	229.458	181.375	0.464	0.741	0.839	0.774
1953	48	229.458	182.375	0.456	0.75	0.876	0.79
1954	48	229.458	183.375	0.576	0.929	1.04	0.961
1955	48	229.458	184.375	0.535	0.834	0.873	0.862
1956	48	229.458	185.375	0.517	0.841	0.923	0.873
1957	48	229.458	186.375	0.905	1.438	1.533	1.487
1958	48	229.458	187.375	0.911	1.52	1.323	1.524
1959	48	229.458	188.375	0.991	1.641	1.416	1.633
1960	48	229.458	189.375	0.646	1.074	0.749	1.01
1961	48	229.458	190.375	0.702	1.195	1.137	1.146
1962	48	229.458	191.375	0.457	0.77	0.686	0.75
1963	48	229.458	192.375	0.473	0.78	0.873	0.777
1964	48	229.458	193.375	0.495	0.789	0.88	0.796
1965	48	229.458	194.375	0.453	0.697	0.81	0.733
1966	48	229.458	195.375	0.404	0.623	0.786	0.683
1967	48	229.458	196.375	0.433	0.664	0.848	0.725
1968	48	229.458	197.375	0.593	0.938	1.087	0.981
1969	48	229.458	198.375	0.709	1.088	1.132	1.13
1970	48	229.458	199.375	0.62	0.939	0.9	0.958
1971	48	229.458	200.375	0.736	1.122	1.151	1.14
1972	48	229.458	201.375	0.652	1.007	0.951	1.012
1973	48	229.458	202.375	0.689	1.022	1.033	1.043
1974	48	229.458	203.375	0.712	1.106	1.108	1.131
1975	48	229.458	204.375	0.804	1.221	1.173	1.231
1976	48	229.458	205.375	0.891	1.372	1.27	1.369
1977	48	229.458	206.375	0.62	0.927	0.766	0.92
1978	48	229.458	207.375	0.66	0.974	1.004	0.977
1979	48	229.458	208.375	0.656	0.952	0.974	0.97
1980	48	229.458	209.375	0.659	0.984	1.001	0.994
1981	47	229.426	209.915	0.714	1.046	1.061	1.064
1982	47	229.426	210.915	0.772	1.144	1.135	1.166
1983	47	229.426	211.915	0.697	1.025	0.977	1.049
1984	47	229.426	212.915	0.672	1.004	0.996	1.021
1985	47	229.426	213.915	0.808	1.19	1.199	1.213

1986	47	229.426	214.915	0.768	1.157	1.082	1.173
1987	47	229.426	215.915	0.667	1.002	0.941	1.016
1988	47	229.426	216.915	0.577	0.868	0.88	0.892
1989	47	229.426	217.915	0.748	1.104	1.172	1.134
1990	47	229.426	218.915	0.525	0.767	0.709	0.768
1991	47	229.426	219.915	0.696	1.042	1.144	1.056
1992	47	229.426	220.915	0.876	1.298	1.281	1.309
1993	47	229.426	221.915	0.695	1.008	0.874	1.005
1994	47	229.426	222.915	0.579	0.882	0.888	0.895
1995	46	229.63	223.978	0.659	0.995	1.05	1.013
1996	46	229.63	224.978	0.374	0.522	0.541	0.552
1997	26	207.462	200.231	0.576	0.916	1.136	0.961
1998	26	207.462	201.231	0.585	0.857	0.917	0.906
1999	26	207.462	202.231	0.802	1.148	1.233	1.2
2000	26	207.462	203.231	0.723	1.074	1.022	1.108
2001	24	205.083	201.5	0.605	0.82	0.81	0.859
2002	24	205.083	202.5	0.658	0.932	1.018	0.966
2003	24	205.083	203.5	0.554	0.773	0.793	0.785
2004	24	205.083	204.5	0.602	0.862	0.963	0.881
2005	14	208.143	208.143	0.387	0.762	0.83	0.787