5-2019

Analysis and Conservation of Native Forests at Kessler Mountain Fayetteville, Arkansas

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A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Arts in Geography

by

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University of Arkansas
Bachelor of Science in Earth Sciences, 2010

May 2019
University of Arkansas

This thesis is approved for recommendation to the Graduate Council.

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Abstract

Kessler Mountain in Fayetteville Arkansas has long been recognized for its beauty and natural resources. Parts of Kessler Mountain have been homesteaded and developed in the past, but most of the mountain has remained relatively undisturbed. The planned development of over 4,000 housing units to cover Kessler Mountain stimulated controversy and consideration of other management alternatives. A twist of fate involving an economic recession, a dedicated group of outdoor recreation enthusiasts, and environmental conservationists led to the permanent protection of 384 acres in the Kessler Mountain Regional Park. To help evaluate the natural resources at Kessler Mountain, forest composition, structure, and tree age were measured at two old growth forest parcels on Kessler Mountain. Forest understory and overstory were surveyed and increment cores were collected from select overstory trees. The overstory of the post oak (*Quercus stellata*) site (Site A) was dominated by post oak and northern red oak (Quercus rubra). The understory was dominated by northern red oak and black locust (*Robnia pseudoacacia*). The oldest post oak trees at the post oak site were in the 250 to 300-year-old age class based on dendrochronological analysis of core samples. The overstory of the chinkapin oak (*Quercus muehlenbergii*) site (Site B) was dominated by sugar maple (*Acer saccharum var. saccharum)* and chinkapin oak. The understory was dominated by eastern red cedar (Juniperous virginiana) and northern red oak. The oldest chinkapin oak trees at Site B were in the 200 to 250-year-old age class. The data suggest that chinkapin oak and post oak are currently not regenerating at rates necessary to maintain long term dominance in the canopy at these particular study sites on Kessler Mountain. As more land is conserved in the region significant planning and funding need to be dedicated to proper management of these lands to maintain biodiversity and healthy forests.

Acknowledgments

Thank you to the Fayetteville Natural Heritage Association for funding the field work for this research. Thank you, Tim Rogers, for assisting me in the field and the huge help with the tree identification. Thank you Jordan Burns for the assistance with the analysis. Thank you, Theo Witsell, for the outstanding ecological assessment of Kessler Mountain. Thank you Dr. Stahle for your guidance and support. Thank you to Dr. Paillet and Dr. Cleaveland for sitting on my committee. Thanks to Dr. Dorian J. Burnette, University of Memphis, for the excellent online analytical tools he has developed for investigations of the North American Drought Atlas. Thank you, Frank Sharp, for your vision and passion. Thank you, Terri Lane for being a great partner in land conservation for perpetuity! Thanks to Jesse Edmondson, for turning me onto tree rings and for being the best big brother. Many thanks to my parents Annie and Steve Edmondson, for their unending love and support.

I would also like to thank all of the people and organizations that came together to support the permanent protection of the forests on Kessler Mountain including the city of Fayetteville and the Walton Family Foundation. The community will be able to enjoy Kessler Mountain in perpetuity thanks to your excellent foresight and generosity.

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Introduction

Kessler Mountain is a prominent landform located on the southwestern edge of Fayetteville, Arkansas. Most of Kessler Mountain is now part of the Kessler Mountain Regional Park, which is owned and maintained by the City of Fayetteville. A large and controversial residential development was planned for much of this property in the early 2000's, but a number of individuals and community organizations advocated various conservation options for the Kessler Mountain property. To help explore the natural resources on Kessler Mountain, and potentially to provide additional justification for preservation of the property, an investigation of potential old growth forests on Kessler Mountain was conducted from 2013 to 2015. This investigation included a rapid field survey of the existing forest cover and more detailed analyses of two selected parcels of potentially old post oak (*Quercus stellata*) and chinkapin oak (*Quercus muehlenbergii*) dominated stands. This thesis briefly describes the history of conservation efforts at Kessler Mountain, the methods used to test for the potential presence of remnant old growth forest parcels on the mountain and presents the results of the survey and plot-based analyses.

Kessler Mountain was settled by Europeans in 1838, first by John Rieff and later in 1866 by Phillip Kessler. Phillip Kessler purchased 13 acres on the top of Kessler Mountain, planted a vineyard and built a wine cellar. As early as 1869 Kessler sold his wine as well as hard cider and brandy at his Wine Hall on West Center Street in Fayetteville (Washington County Historical Society 1985). While a few small homesteads were established on the top and along the base of Kessler Mountain, most of the mountain remained forested and undeveloped. In a 1926 publication of "Ecological Society of America's Naturalist Guide to the Americas" which identified special features in each state that needed to be protected and preserved, Kessler

Mountain was the only area in Northwest Arkansas identified (Ecological Society of America 1926). Due to its location and high elevation reaching 565.7 m (1856 feet), Kessler Mountain is able to support both northern and southern biota making it a biologically diverse location (Douglas James 2013).

In the early 2004 approximately 364 hectares (900 acres) on Kessler Mountain were purchased by a developer. The plan was to create a large housing development on Kessler Mountain to be called “Southpass” which was to include over 4,000 housing units. As a result of the housing crisis and subsequent “Great Recession” in 2008, the Southpass property ultimately became the property of Chamber’s Bank (Mt..Kessler Greenways 2013). As the economy began to recover and development began to increase in Northwest Arkansas, local conservationists and longtime residents on and near Kessler Mountain became increasingly concerned about the fate of the undeveloped portion of the mountain. Among this group of concerned citizens, a leader and champion emerged named Frank Sharp.

Mr. Frank Sharp grew up and still resides on Kessler Mountain. He and his father also built and ran the world-famous Ozark Mountain Smokehouse located on the north side of Kessler Mountain. Frank Sharp spent his youth exploring Kessler Mountain’s rugged landscape climbing rocks and hiking. Mr. Sharp founded Mt. Kessler Greenways and began to lead the grassroots effort to conserve Kessler Mountain. His main intention was to “keep some country” as the city of Fayetteville continues to grow and develop. The Northwest Arkansas mountain biking community had been building trails and riding on Kessler Mountain since the mid 1990’s. Mr. Sharp saw this as a great opportunity to get support from a large stakeholder group that had been using and enjoying Kessler Mountain for over a decade. Mr. Sharp soon gained the support of the local mountain biking club the Ozark Off Road Cyclists (OORC). Many residents had also been hiking and bird watching on Kessler Mountain for many years and Mr. Sharp gained their support and the backing of the Fayetteville Natural Heritage Association (FNHA), an important local conservation organization.

Mr. Sharp also sought support from local business leaders, government officials, and faculty at the University of Arkansas. He contacted several University of Arkansas professors including Dr. Douglas James, Dr. Steve Beaupre and Dr. Donald Steinkraus, all of whom had visited the property and wrote letters to support the preservation of Kessler Mountain. Dr. Beaupre suggested that Mr. Sharp contact Dr. David Stahle of the University of Arkansas Tree-Ring Laboratory to determine if there were any old growth forest parcels still left on the mountain. Mr. Sharp asked Dr. Stahle to survey the old growth forests on Kessler Mountain as part of the natural resource assessment and to potentially provide yet another reason for preservation of the property.

Dr. Stahle and graduate student Alan Edmondson visited the site in April of 2013 to conduct a rapid old growth forest survey of the property. This master's thesis presents the results of the forest survey conducted in the spring and summer of 2013 and the analyses of two selected forest parcels on Kessler Mountain. Specifically, a null hypothesis stating that no trees older than 150-years old were present within the two study plots on Kessler Mountain was tested as part of this thesis research. One of the parcels contained large and apparently old chinkapin oak trees, a species that has not been widely investigated for dendrochronology (i.e., tree-ring dating). Consequently, this thesis includes an investigation of the dating quality and climate response of a ring-width chronology developed from chinkapin oak at Kessler Mountain. In addition to the tree ring studies, the rapid ecological assessment conducted at Kessler Mountain by Mr. Theo Witsell, a botanist and ecologist with the Arkansas Natural Heritage Commission, is also summarized in the discussion section (Witsell 2015). Finally, the outcome of the conservation efforts of Mr. Sharp and many other community leaders and organizations is described in the concluding section, along with other recent land conservation on Kessler Mountain and in the surrounding area.

Study Area

Kessler Mountain (Figure 1 and 2) is located on the boundary of two ecoregions with the Boston Mountains Ecoregion located to the south and east and the Springfield Plateau Ecoregion located to the north and west. The elevation of Kessler Mountain is 565.7m (1856 feet) above sea level. Kessler Mountain's main ridgeline runs from north to south. The main north-south ridgeline serves as the watershed divide between the West Fork of the White River and the Illinois River. The geology of Kessler Mountain consists of level bedded limestones, sandstones, and shales, including the Fayetteville shale, the Pitkin Limestone, and the Hale, Bloyd and Atoka Formations (Manger 2019. The complex geology weathers into several soil types promoting the biodiversity of the site. The region is classified as a humid subtropical climate. The average annual rainfall is 1,148.3 mm (45.21 inches). The average daily maximum temperature is 21.2 degrees C (70.2 degrees F). The average daily minimum temperature is 8.4 degrees C (47.2 degrees F) (Washington County Soil Survey, 1969)

The modern forest cover on Kessler Mountain appears to be mostly second growth oak-hickory with some old growth trees scattered through the woodlands. There are dense thickets of Amur bush honeysuckle *(Lonicera mackii)* below the bluff line along most the east side of the mountain which suggests much of this area had previously been cleared possibly for grazing livestock. This supposition is supported by two old cattle troughs at two different springs locations below the bluffs. However, above the bluff line there are some small areas where remnants of old growth forests have escaped logging that contain uncut stands of old growth post oak *(Quercus stellata*) and chinkapin oak (*Quercus muehlenbergii)* (Figures 2-4). These stands of ancient post oak and chinkapin oak were likely not cut because they were not fit for commercial timber. The post oaks growing on dry woodlands were likely too stunted and the chinkapin oaks with a contorted growth form were likely too poorly formed to be of commercial value. The terrain of Kessler Mountain is rugged and rocky and likely therefore most of the land was not cleared for agriculture.

Methods

Alan Edmondson and David Stahle surveyed the oak-hickory dominated forests of Kessler Mountain in 2013 to assess the property and identify potential old growth forest study sites. Approximately 142 hectares (350 acres) of forest on Kessler Mountain were visually surveyed to determine the presence or absence of ancient trees within the existing forest matrix. This survey included the still forested ridgeline and the east and west facing slopes of the mountain. The external characteristics of oak and hickory trees provide valuable clues regarding their age (Stahle and Chaney 1994; Stahle 1990; Pederson 2010). Ancient oak trees in particular can be recognized by external attributes such as a modest canopy with only a few twisted limbs, crown die-back with dead limbs or broken tops, old branch scars, smooth patchy bark, longitudinally twisted stems, heart rot and a sometimes pronounced lean (Stahle and Chaney 1994). These external features were used to identify ancient individual trees as well as larger parcels of old growth forest during this survey. They were also used to classify the existing forest cover on Kessler Mountain into one of three broad categories: pristine uncut old growth (canopy dominated by trees over 180-years old), degraded old growth (i.e., trees over 180-years old are still present in a selectively logged forest), and second growth (no trees older than 180-years old).

Two remnant old growth sites were selected and permanent study plots were installed for detailed description of tree species composition, stand structure, and age. Site A is an east-southeast facing slope and is a woodland habitat dominated by post oak and northern red oak (*Quercus rubra*; Figure 3). Site B is a forest habitat along a limestone outcropping dominated by chinkapin oak and sugar maple (*Acer saccharum var. saccharum)* and several species of hickory (*Carya*; Figure 4). Chinkapin oak are most frequently found on alkaline soils (Sander 1990), including the limestone outcroppings and bluffs on Kessler Mountain. The tree species composition of the understory was also sampled at each location to document the recruitment potential at each site. This method of forest surveying follows classic methods previously used by Lorimer (1980) and Frelich (1994).

A 50 m x 50 m (0.25 hectare) permanent study plot was installed at the post oak woodland (Site A) and was subdivided into 25 grid squares (Figure 6). Each grid square was 10 x 10 m. Every tree that was 10 cm or greater diameter at breast height (1.4 m) was considered an overstory tree. Every overstory tree was flagged, an ID number was assigned, diameter of the tree at breast height was measured and species were recorded in each grid square. At each four-corner intersection of the grid squares a 5 m fixed radius plot was used to sample the understory. All trees within the 5 m radius that were less than 10 cm diameter and at least breast height were considered understory trees. There was a total of 16 fixed radius plots in Site A. All overstory post oak were then cored using a 5 mm diameter Swedish Increment borer. Increment cores were taken at breast height (1.4 m) on the northwest side of the tree to maximize the potential registration of frost damaged rings which are helpful for the exact dating of the tree-ring series.

A 20 m x 100 m (0.20 hectare) grid system was set up on the chinkapin oak escarpment (Site B) because of the shape of the narrow limestone escarpment on which the chinkapin oak are located (Figure 7). Each grid square was 10 x 10m. Every tree 10 cm or larger diameter at breast height was considered an overstory tree. Every overstory tree was flagged, and ID number was assigned, diameter of the tree at breast height was measured and species was recorded for each grid square. The understory was sampled using fixed radius plots of 5 m at every four-corner intersection. All trees within the 5 m radius that were less than 10 cm diameter and at least breast height were considered understory trees. The understory trees were then put into two size classes greater than or less than 5 cm. The species and abundance in each radius sample were recorded. Every overstory chinkapin oak in the plot was cored at breast height on the northwest side of the tree. In order to increase the sample size for age, diameter distribution, and potential climate data, every chinkapin oak within 10 m of the perimeter of the grid was also cored using the above method. The chinkapin oak cored outside of the grid were not included in forest species composition data.

The increment cores were air dried, glued to core mounts and sanded using increasingly finer grained sand paper to obtain a well-polished surface that can be analyzed with a microscope. Cores were ring counted to approximate tree age. Skeleton plots were constructed, cross dated, and a master tree-ring dating chronology was developed (Stokes and Smiley 1996) The annual rings of a subsample of the oldest chinkapin oak were measured using a sliding-stage micrometer to 0.001mm precision. The numerical ring width data were uploaded into COFECHA to check for crossdating accuracy (Holmes 1983; Grissino-Mayer 2001). The computer program ARSTAN (Cook and Krusic 2005) was used to develop the numerical tree-ring chronology for chinkapin oak at Kessler Mountain. Statistics computed with ARSTAN were used to describe the level of correlation among the dated ring width series of chinkapin oak. The derived chronology was then correlated with monthly Palmer Drought Severity Indices (Palmer 85) available on a gridded basis over the continent from the North American Drought Atlas (NADA; Cook et al. 2007; Dorian J. Burnette, personal communication, 2019).

Results

The rapid qualitative survey of Kessler Mountain indicates that the existing forests on the ridgeline and steep upper slopes can largely be classified as second growth oak-hickory with individual trees over 180-years old still present on a scattered basis within the fabric of mostly younger trees (what can be referred to as "degraded old growth" or "second growth with remnant pre-settlement cull trees"). The forests on the lower slopes of Kessler Mountain, in many places below the prominent bluff, appear to have been heavily impacted by past human activity. Many of these lower slope forests were previously cleared, contain few if any trees over 180-years old, and have been heavily impacted by invasive plant species. The forest below the bluffs on the east side of Kessler Mountain are heavily invaded with Amur bush honeysuckle. There are several areas where Amur bush honeysuckle is the only plant growing in the understory. There are also a few dense patches of tree of heaven *(Ailanthus altissima)* along the main ridgeline just off Trent trail.

A few small areas of relatively pristine old growth forest were also found at Kessler Mountain. A dwarf post oak dominated shale barrens with very old trees is present on the ridge and a core taken from a post oak only 15 cm in diameter at breast height (DBH) at this location was over 250 years old (located near 36.031490° N -94.217127° W). Another post-oak dominated stand with many old trees was found on a dry, east-facing site. And a stand of large and old chinkapin oak was located on a west-facing limestone outcrop. Core samples from living trees and a cross section cut from a dead log indicated that many trees in the post oak and chinkapin oak sites were quite old, 18 trees were found to have a minimum age of 180 or older. There were 6 post oak trees over 180 years old with the oldest minimum tree age of 286 years old. There were 12 chinkapin oak trees over 180 years old with the oldest minimum tree age of

229 years old. Permanent study plots were installed at the post oak and chinkapin oak sites for quantitative analysis of stand age, composition, and structure. The results for the old growth post oak and chinkapin oak sites are presented separately below.

a. Site A, the Post Oak Stand

A total of 125 overstory trees were surveyed on the 0.25-hectare post oak woodland at Site A (36.023696° N -94.215298° W). The overstory at Site A is dominated by post oak with a total of 72 trees, or 57% of the overstory trees sampled (Figure 8a). Northern red oak is a co-dominant canopy species at Site A, with 31% of the overstory. It should be noted that this was identified as northern red oak during field work, and not black oak which is known to look almost identical, but uncertainty remains on this identification. The next two most abundant species are white oak (*Quercus alba*) at 6% and blackjack oak (*Quercus marilandica*) at 4 % of the overstory trees. One eastern red cedar (*Juniperus virginiana*) and one sugar maple were also counted (less than 1% each; Figure 8a).

The understory of Site A is dominated by northern red oak at 50% of the relative frequency (Figure 8b). The next two most abundant species are post oak and eastern red cedar, each representing 8% of the understory. Winged elm *(Ulmus alata*) is third most abundant at 7 %. Blackjack oak, downy service berry (*Amelanchier arborea*), and white oak each represented 6% (Figure 8b). Although black locust (*Robinia pseudoacacia*) was not represented by high numbers in the understory (< 5 %) it should be noted that a significant portion of the understory is black locust but have not yet reached breast height.

The diameter distribution for the Site A indicates that the highest frequency of post oak stems are in the 21 to 25 cm DBH class (19 trees; Figure 9a). But the overall frequency distribution for post oak stem sizes largely declines with increasing diameters, which would be typical in relatively undisturbed post oak dominated woodlands (e.g., Bragg et al. 2012). The diameter distribution for the northern red oaks indicates that the highest frequency stem size is 10 to 15 cm DBH with 20 trees recorded (Figure 9b). The next highest frequency is 16 to 20 cm with 13 trees followed by 26 to 30 cm with 3 trees. The three largest diameter ranges had a total of 5 trees with 2 measured in the 31 to 35 cm range 1 measured in the 36 to 40 cm range and two measured in the 41 to 45 cm range. It is interesting to note that there were no red oak were recorded in the 21 to 25 cm range, the range with the highest number of post oak diameters (Figure 9a-b).

The age distribution for the post oak site shows the highest frequency in the 51 to 100-year age class and the 101 to 150-year age class with 16 trees in each cohort. The next highest frequency is the 151 to 200 year age class with 9 trees followed by 201 to 250 and 251 to 300 year age classes with one tree in each cohort. No trees were dated in the 0 to 50-year age class (Figure 10). These age data demonstrate that there are indeed old-growth pre-settlement post oak present at Site A. One of the oldest looking post oaks was cored and dated with an inner ring year of 1724. However, pith was not reached on this tree and the core was taken at breast height, so the estimated age of this tree is over 300 years old. Many other post oaks that appeared to be old were hollow so their true age could not be determined. The age data nonetheless indicate that the oldest post oaks at Site A are in the 200 to 300-year age class.

The diameter distribution at Site A indicates that post oak is presently the canopy dominant species (Figure 8a. Post oak is also present in the understory (Figure 7b) suggesting that post oak should continue to maintain a presence in the canopy of Site A in the future. However, post oak only represents some 8% of the understory compared to 50% for northern red oak documented in the understory (Figure 7). This understory composition along with the large number of small red oak stem diameters relative to larger trees (Figure 8b) and the high density of very small black locust observed in understory suggests that the post oak woodland may eventually transition into a red oak dominated stand. The absence of overstory post oak in the youngest age category (0 to 50 years old) suggests that this gradual process of post oak replacement may be underway at Site A (Figure 10).

b. Site B, the Chinkapin Oak Stand

A total of 122 trees were surveyed on the 0.20-hectare chinkapin escarpment at Site B (36.040815° N -94.219147° W). The overstory at Site B is dominated by sugar maple with a total of 81 trees, or 66% of the overstory trees (Figure 11a). Chinkapin oak is only 17% of the overstory with just 21 trees. The next most abundant species is eastern red cedar at 6% of the relative frequency. There were a number of different hickory species at the site but shagbark hickory (*Carya ovata*) were the most common (three trees or 2% of the relative frequency). There were also two pignut hickory (*Carya glabra*), two post oak, one black hickory *(Carya texana*), one gum bumelia (*Sideroxylon lanuginosum*), one mockernut hickory (*Carya alba*), one red hickory (*Carya ovalis*), one northern red oak and a sugar berry (*Celtis laevigata*; Figure 11a).

The understory of Site B is dominated by eastern red cedar and northern red oak at 32 and 28% of the individual stems, respectively (Figure 11b). The next two most abundant are carolina buckthorn (*Frangula caroliniana*) at 19% and sugar maple at 14% of the understory. There were also three mockernut hickory, three shagbark hickory and three sugar berry each representing 2% of the understory (Figure 11b).

The diameter distribution for Site B shows the highest frequency of chinkapin oak in the 31 to 40 cm DBH class (Figure 12a). No chinkapin oak were recorded in the smallest size category 1(0 to 20 cm DBH; Figure 12a). The diameter distributions sugar maple are nearly the opposite of chinkapin oak (Figure 12b). The highest frequency of sugar maple is in the 10 to 20 cm DBH class (50 maple trees recorded). No sugar maple were recorded in the two largest size classes (Figure 12b).

The age distribution for chinkapin oak indicates the highest frequency of stems in the 151 to 200-year age class (25 chinkapin oak trees recorded; Figure 13). The next highest frequency is the 101 to 150-year age class with 16 trees. The oldest age class 200 to 250 years has two chinkapin oak trees. No young chinkapin oak in the 0 to 50-year age class were identified at Site B (Figure 13).

The diameter distribution at Site B indicates chinkapin oak and sugar maple are co-dominant in the canopy. The age data for Site B demonstrate that some of the canopy dominant chinkapin oak exceed 200 years in age. However, eastern red cedar and northern red oak dominate the understory, together representing 62% of the understory stems. Sugar maple is also present in considerable numbers in the understory (14 %), but only one chinkapin oak was counted in the understory survey. The extremely low number of chinkapin oak in the understory suggests that it is not regenerating at a rate needed to maintain dominance in the future. Figure 5 shows young sugar maple with leaves and eastern red cedar in the understory and a large old chinkapin oak in the overstory.

c. Dendrochronological Analysis of Chinkapin Oak at Kessler Mountain

A selection of 12 old trees from the chinkapin oak site were dendrochronologically dated and the annual rings were measured to produce a numerical chronology of chinkapin oak growth for the past 223-years (1790-2012). Chinkapin oak has not been widely used for the development of tree-ring chronologies, but the tree ring data from Site B indicates that the time series of tree growth from the individual trees are highly correlated. The average correlation among the sample trees included in the chronology (RBAR; computed with the ARSTAN program) is 0.494. This strong "crossdating" among the selected chinkapin oak at Kessler Mountain is illustrated in Figure 14 and suggests a strong influence of inter-annual climate variability. In fact, the derived mean index chronology registers most of the major drought and wet years seen in other tree-ring chronologies developed for Arkansas and Oklahoma (e.g., the dry years of 1828, 1855, 1874, 1886, 1911, 1925, 1936, 1953, 1977, 1988, 2001, 2009, 2012, and the wet years of 1836, 1869, 1904, 1920, and 1975: Figure 14).

The simple mean ring width chronology and the detrended and standardized mean ring width index chronologies are both illustrated in Figure 15. The mean ring width chronology documents a growth release during the 1850s and 1860s (Figure 15, top), which might reflect a natural disturbance or possibly a human impact on the stand during the early years of settlement. The mean index chronology is very well correlated with the PDSI for the month of May over northwest Arkansas for the entire period in common to both records (i.e., 1895-2005; Figure 16). Only significant correlations are mapped in Figure 16 ($p < 0.05$) and the strongest correlations (above $r = 0.50$) extend from northcentral Texas across Oklahoma and western Arkansas and into the Midwest (Figure 16). These results indicate that chinkapin oak at Kessler Mountain is exceptionally well correlated with soil moisture at the end of the spring season. These results are also similar to the PDSI signal recorded by other tree species in the central United States (e.g., Stahle and Cleaveland 1988; Cleaveland and Stahle 1996), indicating that chinkapin oak has considerable potential for paleoclimate reconstruction.

Discussion

The age data proves there are pre-settlement trees 180 years and older surviving on Kessler Mountain. The composition data from the two study sites indicate that post oak at Site A and especially chinkapin oak at Site B appear to currently be struggling to regenerate and recruit into the canopy. The near absence of chinkapin oak recorded in the understory compared with the high number of northern red oak, eastern red cedar and sugar maple in the understory indicate very poor chinkapin oak regeneration at Site B. The low number of post oak recorded in the understory compared to the high numbers of red oak and black locust suggests poor post oak regeneration at Site A as well. While there is much uncertainty as to the cause of this poor oak recruitment based on the limited data available, there are a few potential candidates that could be affecting oak regeneration at these sites. Natural forest succession could be occurring at these sites. There could be some type of long-term dynamics occuring in the composition of these stands. Human activity could also be impacting these sites. Invasive plant species are likely having a negative effect on the woodlands and forest on some parts of Kessler Mountain. There are invasive plant species all over the mountain as documented by Witsell (2015). Some areas are more impacted than others with the highest concentration of invasive plant species in areas which were previously disturbed. There are areas below the bluffs on the east side of Kessler Mountain that are heavily invaded with Amur bush honeysuckle shading out the entire understory. Herbivory could be influencing the oak regeneration. Deer have been known to have significant impacts on forest regeneration (Askins 2014). The absence of fire could also be having a negative effect on the woodlands and forests on Kessler Mountain as indicated by the lack of post oak and chinkapin oak regeneration observed in the understory. This shift in forest composition from more fire tolerant, shade intolerant species to more fire intolerant, shade tolerant species has been known to occur in fire adapted habitats where fire has been suppressed, Nowacki and Abrams (2008) use the term "mesophication" and describe the process as follows:

> By altering environmental conditions, shade-tolerant species deter fire through (a) dense shading that promotes moist, cool microclimates and (b) the production of fuels that are not conducive to burning (flaccid, moisture-holding leaf drop; moist, rapidly decaying woody debris). This phenomenon is reinforced and amplified by feedback loops, whereby conditions continually improve for shade-tolerant mesophytic species and further deteriorate for shade-intolerant, fire-adapted species.

Witsell (2015) refers to the "densification" (i.e., an increase in stem density) and mesophication of the forests and woodlands on Kessler Mountain in his ecological assessment. Witsell references a master's thesis by Miller (1972) in which Miller reconstructed a map of historical vegetation in Northwest Arkansas by using historical vegetation data from the General Land Office (GLO) surveys conducted in the early 1830's. The Miller map indicates that the area on Kessler Mountain may have been dominated by oak barrens (which Witsell notes is now referred to as savanna) and upland forest. Witsell (2015) notes that according to the tree density reported on GLO records, the upland forests of Kessler Mountain were more open and closer to what ecologists now call woodland with an open canopy and dense herbaceous plant cover on the ground surface. Witsell also cites the presence of prairie plant species that are still surviving in the understory in a few places where the canopy is still open. To return to these historic more open canopy conditions, Witsell (2015) recommends implementing prescribed fire management as well as controlling the hardwood midstory using herbicide injection and mechanical treatment. Witsell (2015) also recommends removing the woody invasive plant species and treating the cut stump with herbicide to prevent re-sprouting.

The ecological assessment of Kessler Mountain by Witsell (2015) documented 11 different habitat types. Five of the habitats were identified as ecologically significant which were defined as an area relatively intact or high-quality natural communities or habitat that contributes significantly to the overall biodiversity of the site. The ecologically significant habitat types identified on Kessler Mountain are Shale Barrens, Bluffs, Old Growth Post Oak Woodland, Riparian Habitat, Seep and Springs (Witsell, 2015). There were 544 plant species documented by Witsell (2015) indicating that Kessler Mountain is a biologically diverse site with high ecological integrity. Nine plant and animal species of state conservation concern were also documented with at least two species, Missouri Ground Cherry and Church's Wild Rye, being of global concern. The documentation of old growth post oak and chinkapin oak forests adds independent support to Witsell's conclusions regarding the ecological integrity of Kessler Mountain. There are other examples of natural areas that have been discovered to have old growth forests that are regularly used to study the forest history, health and climate. One such example is Wachusett Mountain, Massachusetts. Wachusett Mountain is a popular recreational area outside of Boston. Orwig (2001) documented one of the largest old-growth forests in southern New England hiding in plain sight. These stunted, gnarled and damaged trees likely escaped logging because they were not ideal for lumber and are living to be over 300 years old. Areas like Kessler Mountain, Arkansas and Wachusett Mountain, Massachusetts where parcels of intact old growth forests have survived relatively undisturbed close to urban centers present many opportunities for research and exploration of historic forest conditions, forest dynamics and climate at locations that are easily accessible for long term studies.

Conclusions

This thesis found evidence for the presence of pre-settlement old trees and small old growth parcels on Kessler Mountain. This information on forest conditions was used by advocates in the effort to preserve Kessler Mountain as a regional park and natural area. The entire mountain is not old growth forest, but a number of presettlement age trees are scattered throughout the second growth forests and make the site ideal for the restoration of a mature to old growth oak-hickory forest in the coming decades. A main challenge will be to manage invasive species and attempt to bring occasional fire back into the woodlands. This thesis project also documented the strong climate signal present in the old growth chinkapin oak. The development of additional chinkapin oak chronologies could be valuable for future paleoclimate studies throughout the range of this interesting species.

The city of Fayetteville was encouraged by an overwhelming show of public support to preserve the forests on Kessler Mountain as part of a community park, due in no small part to the passion and dedication of Mr. Frank Sharp. Prior to the potential acquisition of the Southpass property, the city of Fayetteville already owned 81 hectares (200) acres of abandoned farms and fields at the base of Kessler Mountain which was donated by Chamber's Bank to the city to be used as the site of a future city park. In February 2013, the city of Fayetteville with matching funds from The Walton Family Foundation purchased an additional 152.2 hectares (376 acres) on Kessler Mountain for 3 million dollars from Chamber's Bank. The Fayetteville Natural Heritage Association pledged $300,000 to the city of Fayetteville to help offset expenses, pay for educational signage, and for the ecological assessment of Kessler Mountain conducted by Theo Witsell in 2013. The Walton Family Foundation's matching funds came with the requirement that the city of Fayetteville ensure the permanent protection of Kessler Mountain with a conservation easement. The city of Fayetteville worked with the regional land conservation organization, the Northwest Arkansas Land Trust, to place a permanent conservation easement on the property in 2015.

Local mountain bike organizations have developed biking trails on Kessler Mountain since the mid 1990's, and when the City of Fayetteville purchased the property from Chamber's Bank the property already had approximately 11.3 km (7 miles) of trail. Progressive Trail Design, a locally based trail building company, was hired by the City to improve the existing trail system to be more sustainable and to design additional trails to be built on Kessler Mountain. Progressive Trail Design and the city of Fayetteville worked together with several local stakeholder groups including mountain bikers, trail runners, hikers, birding enthusiasts, and conservationists to design and route trails in a way that all user groups would find agreeable, while also taking care to avoid sensitive ecological areas on Kessler Mountain identified by Witsell (2015) and this survey of old growth forest remnants.

The existing trail system was improved to meet sustainable standards and approximately 6.5 km (4 miles) of additional trails have been built as of 2019. The city of Fayetteville has also completed construction on "phase 1" of the city park at the base of Kessler Mountain. Additional construction is planned for more sports infrastructure and an amphitheater for outdoor performances. The Kessler Mountain Regional Park now boasts several baseball and soccer fields, parking, paved walking trails, restrooms, and concessions, in addition to the 155 hectares (384 acres) of permanently conserved woodlands and forest with over 16.1 km (10 miles) of multiuse natural surface trails. Kessler Mountain has become an important regional destination for outdoor sports and the simple enjoyment of nature.

The permanent protection of the city of Fayetteville's Kessler Mountain property is truly a success story and great example of grass roots community-based land conservation. Thanks to the vision of Frank Sharp, the foresight of the city of Fayetteville, support from the Fayetteville Natural Heritage Association, and the generosity of the Walton Family Foundation a large tract of Kessler Mountain will be conserved in perpetuity. There are more opportunities for conservation on and near Kessler Mountain and some are already being pursued. The Northwest Arkansas Land Trust has protected an additional 81 hectares (200 acres) on Kessler Mountain. Local outdoor recreation organizations including the Ozark Off Road Cyclists, the Northwest Arkansas Trailblazers, and private landowners are taking steps to ensure that other adjacent portions of Kessler Mountain remain undeveloped for the benefit of the community. In total over 324 hectares (800 acres) on Kessler Mountain have been saved from development with over 243 hectares (600 acres) permanently protected through conservation easements. The natural landscape is one of the main factors that makes Northwest Arkansas such a desirable place to live and the strong community support for the conservation of Kessler Mountain is evidence that this is widely appreciated.

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Appendix

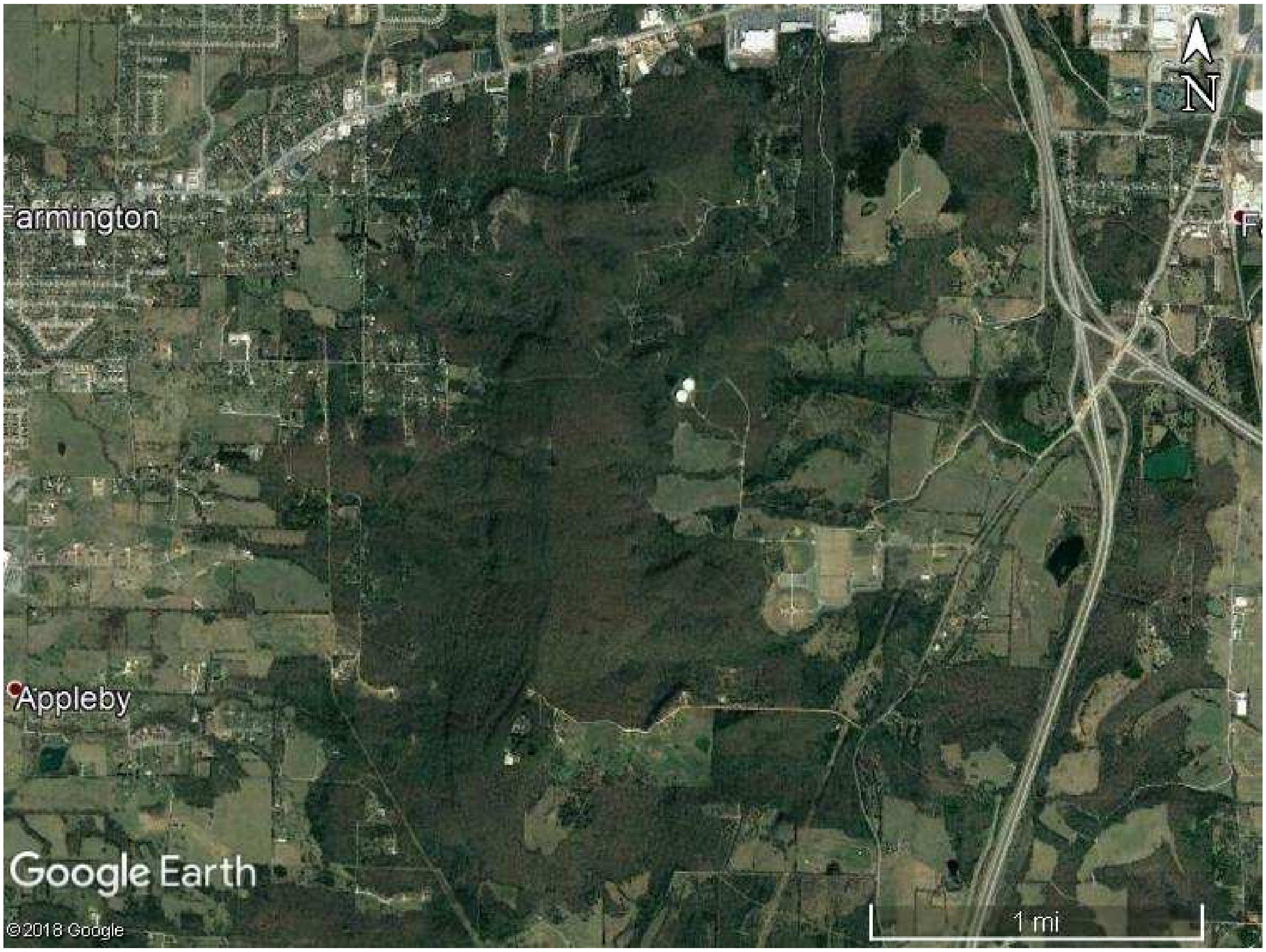


Figure 1. This visual satellite image from Google Earth illustrates the extensive forest cover still present at Kessler Mountain in Fayetteville, Arkansas (image date: 2018).

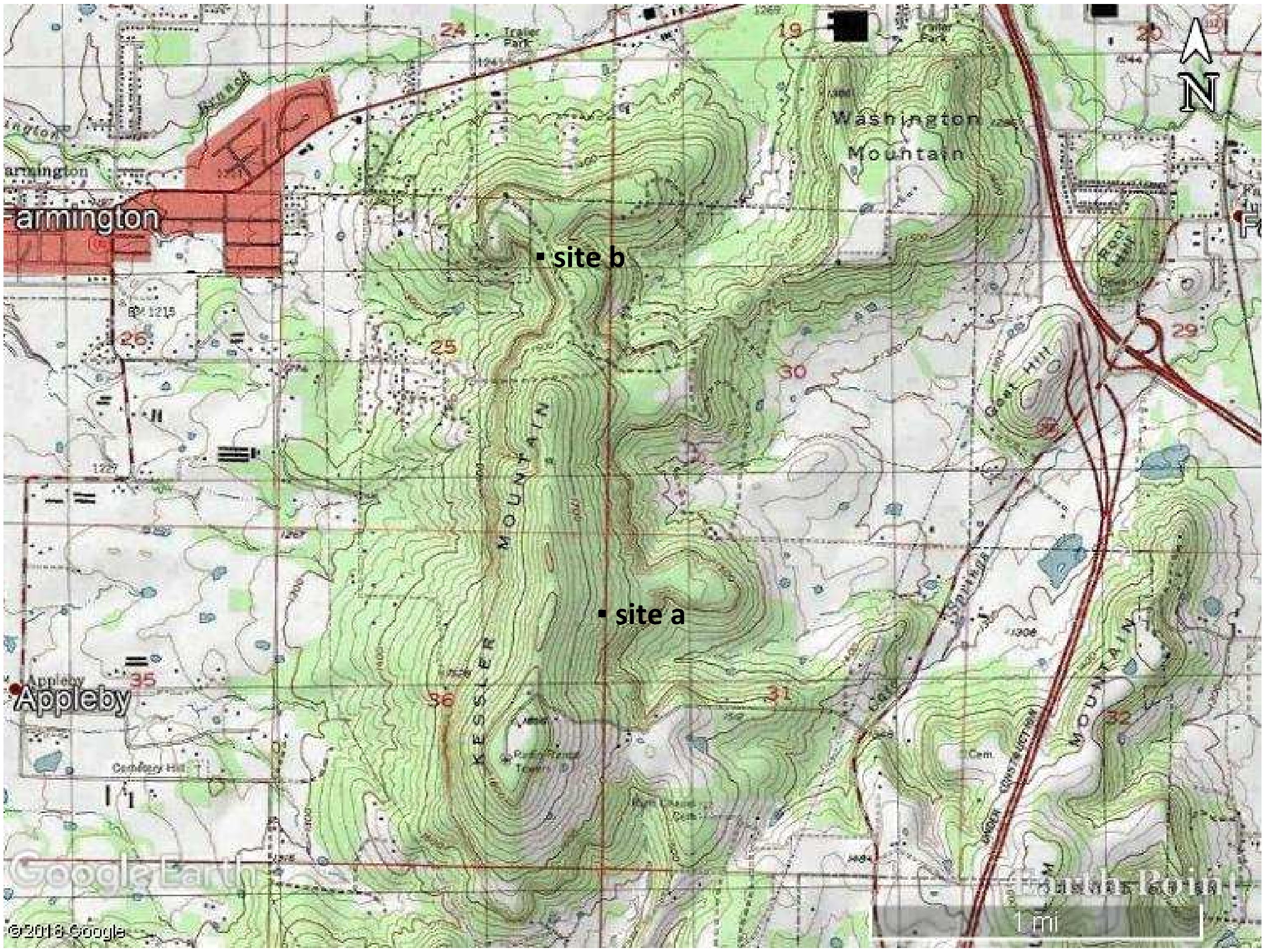


Figure 2. This Google Earth/ Earthpoint topographic map of Kessler Mountain identifies the locations of the post oak site (Site A) and the chinkapin oak site (Site B).

Figure 3. Photograph by Dr. David Stahle of the author coring an old post oak at Site A on Kessler Mountain.

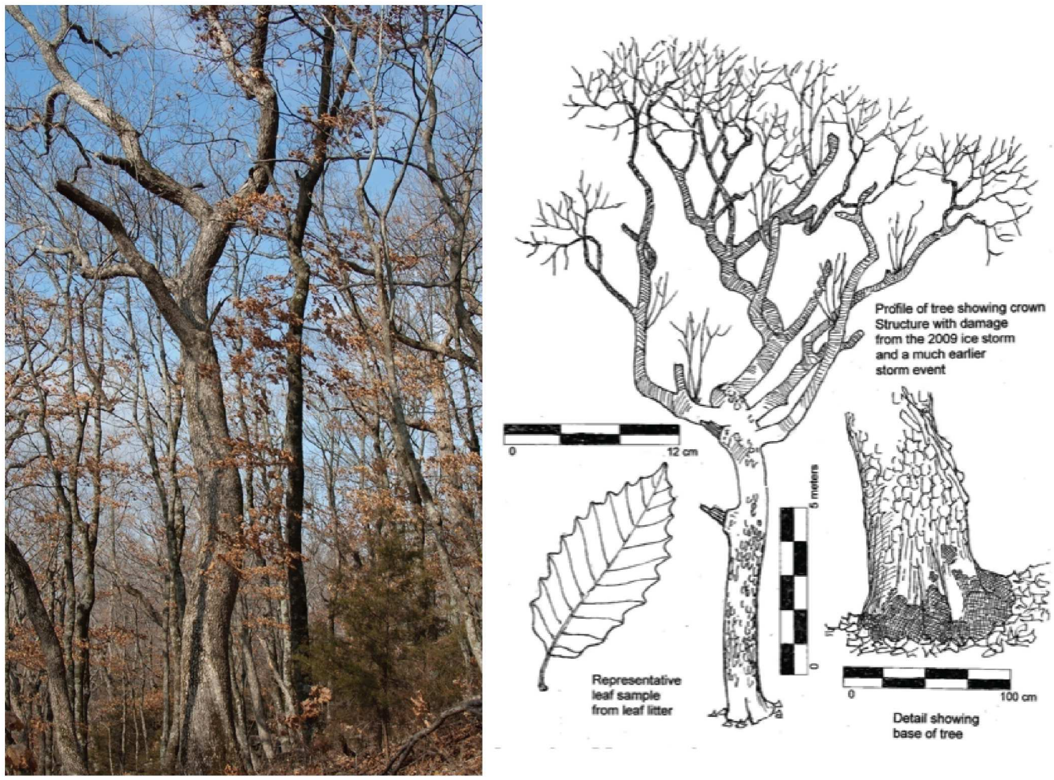


Figure 4. (left) Photograph of old chinkapin oak at Site B on Kessler Mountain. (right) Line drawings by Dr. Fred Paillet of an old growth chinkapin oak tree at Kessler Mountain illustrating canopy damage from the ice storm of 2009 and damage from an earlier storm event. A typical chinkapin oak leaf and the lower stem of an old age individual are also illustrated.

Figure 5. Photograph of young sugar maple with leaves in foreground with old chinkapin oak in background.

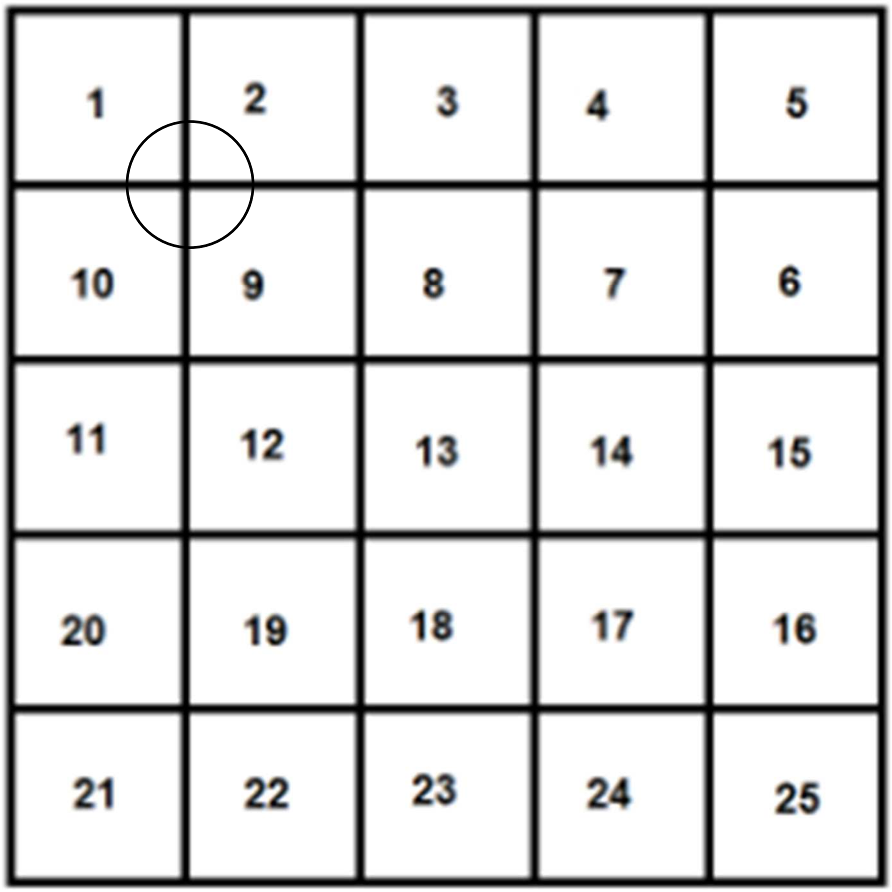


Figure 6. This graphic illustrates the 50 x 50 m grid design for overstory study at the post oak site (Site A) and the 5 m fixed radius plot for understory sampling.

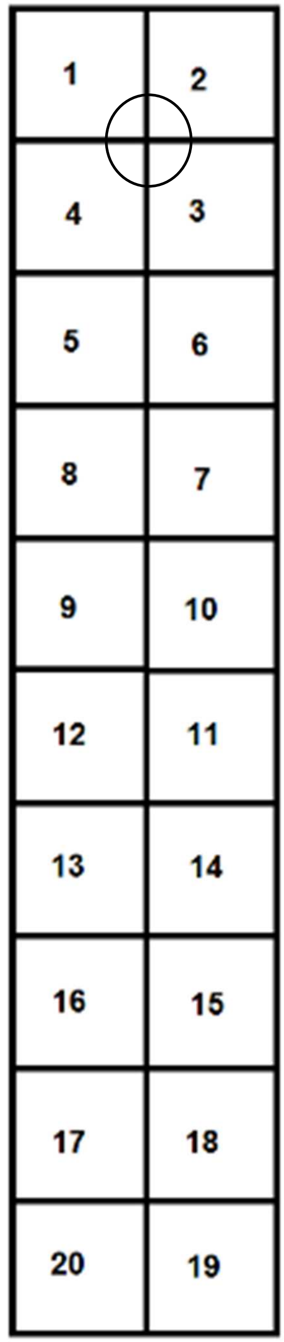
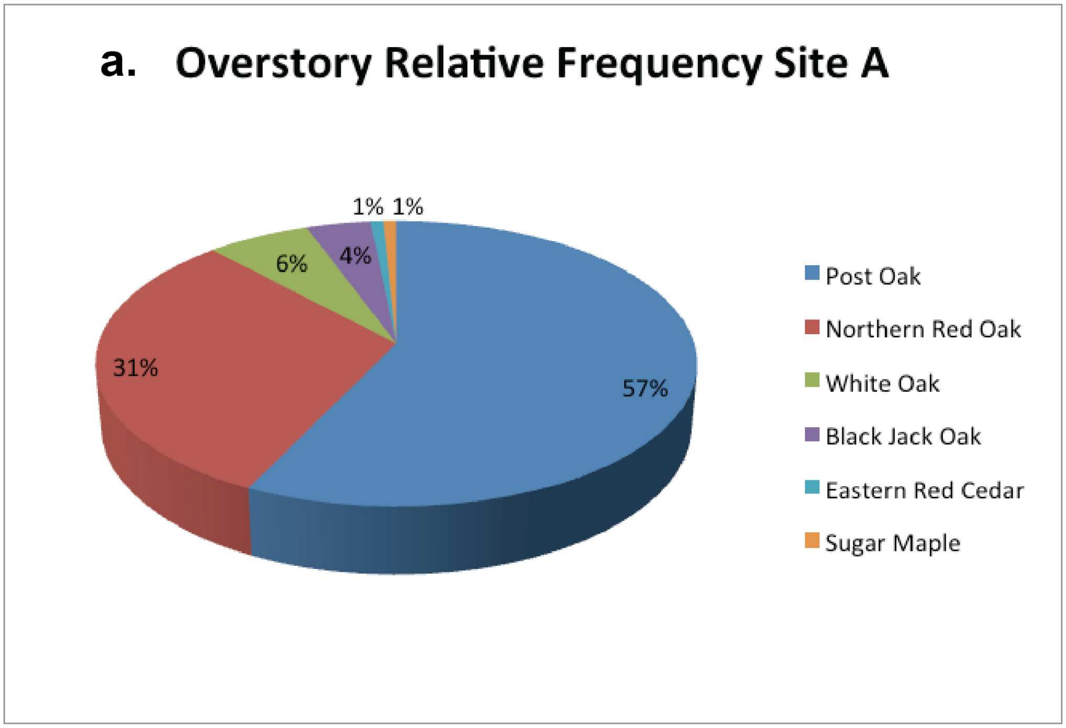


Figure 7. Same as Figure 6 for the 20 x 100 m grid design at the chinkapin oak site (Site B).



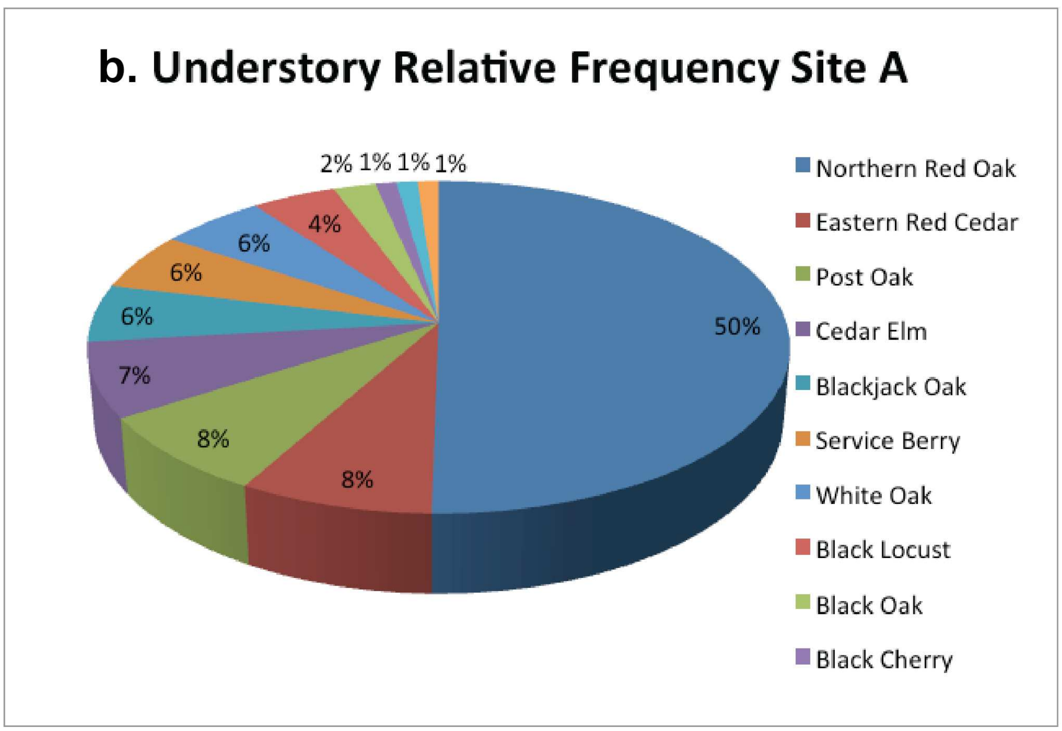


Figure 8. Pie chart showing the relative frequency (in %) of overstory (a) and understory tree species (b) at the post oak site (Site A).

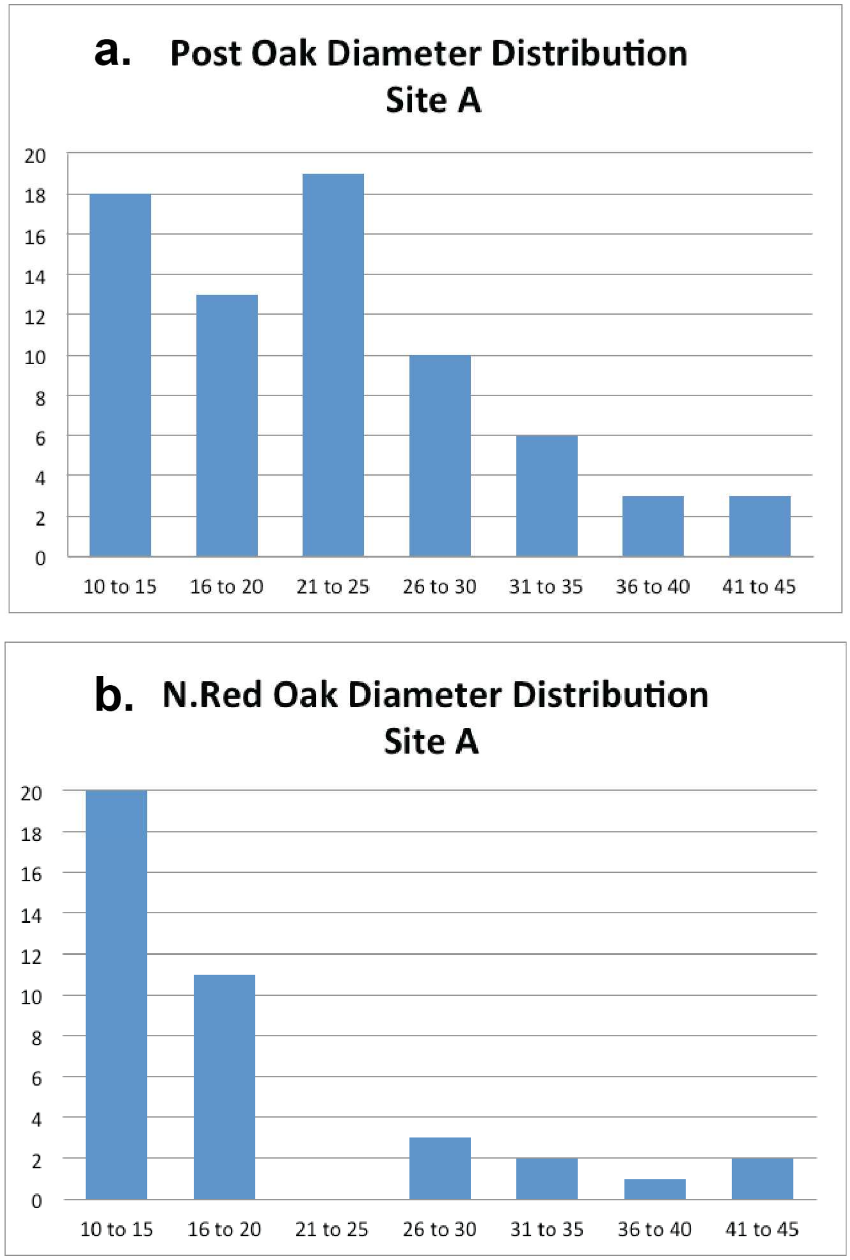


Figure 9. This bar graph illustrates the diameter distribution (DBH in cm) for the overstory post oak (a) and northern red oak (b) at Site A.

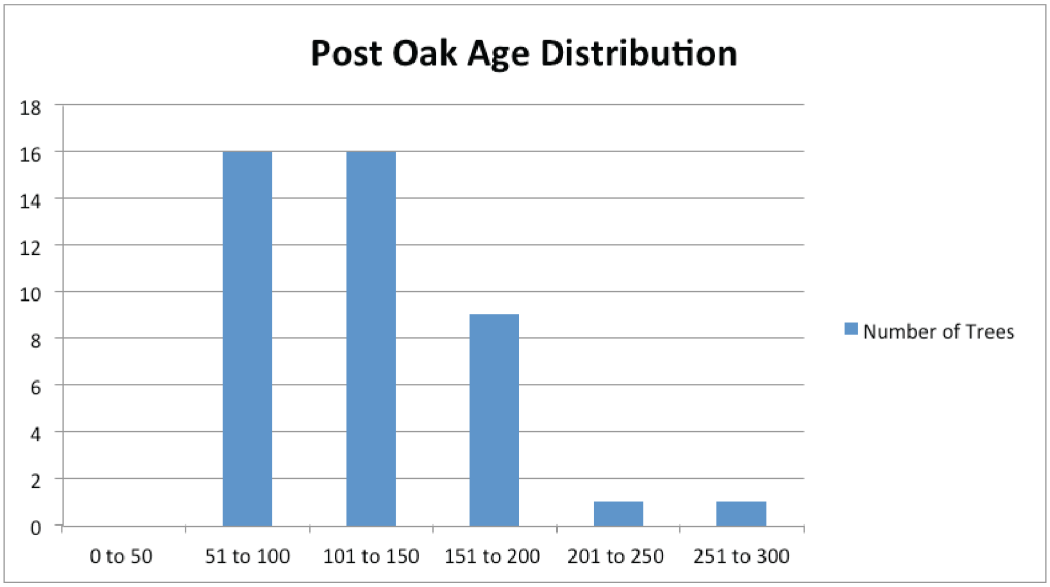


Figure 10. This bar graph illustrates age distribution of the overstory post oak at Site A.

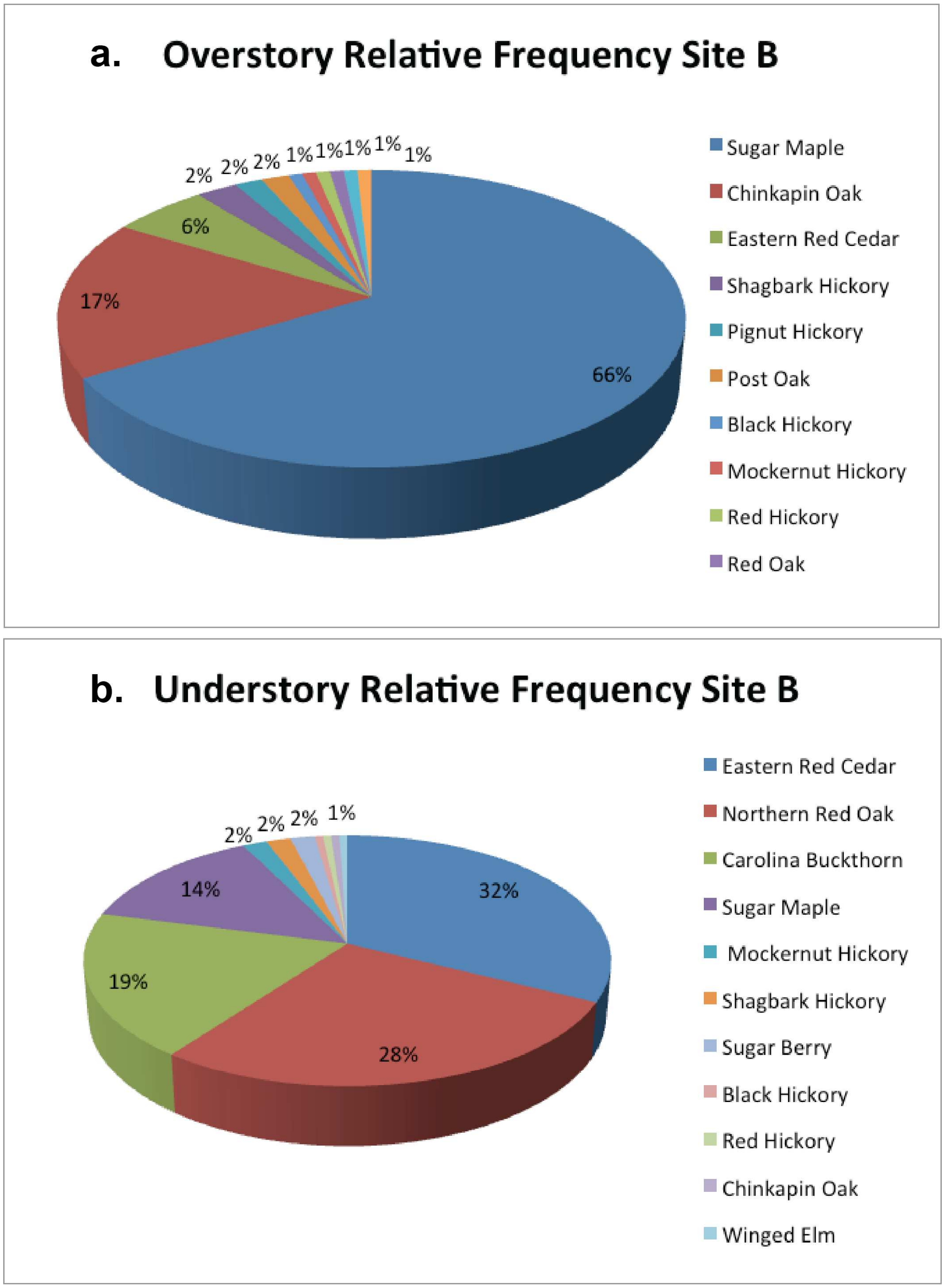
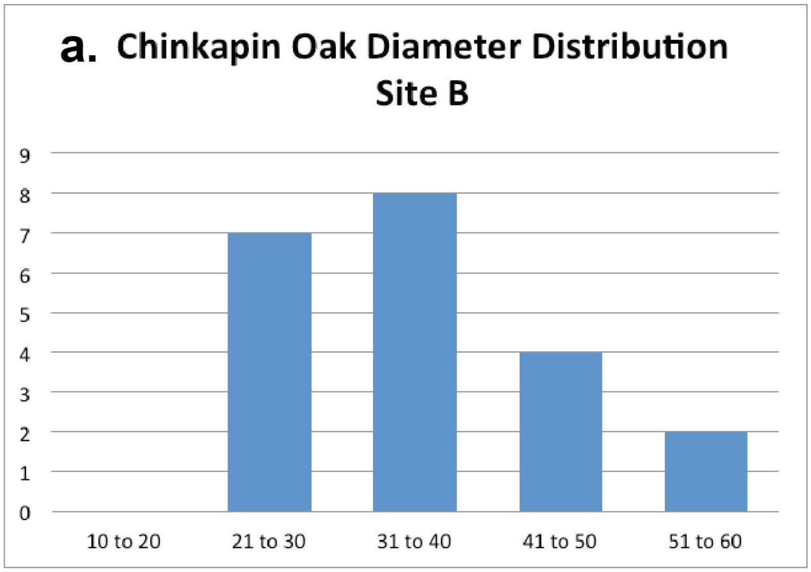


Figure 11. These pie charts present the relative frequency of overstory (a) and understory (b) tree species at the chinkapin oak site (Site B).



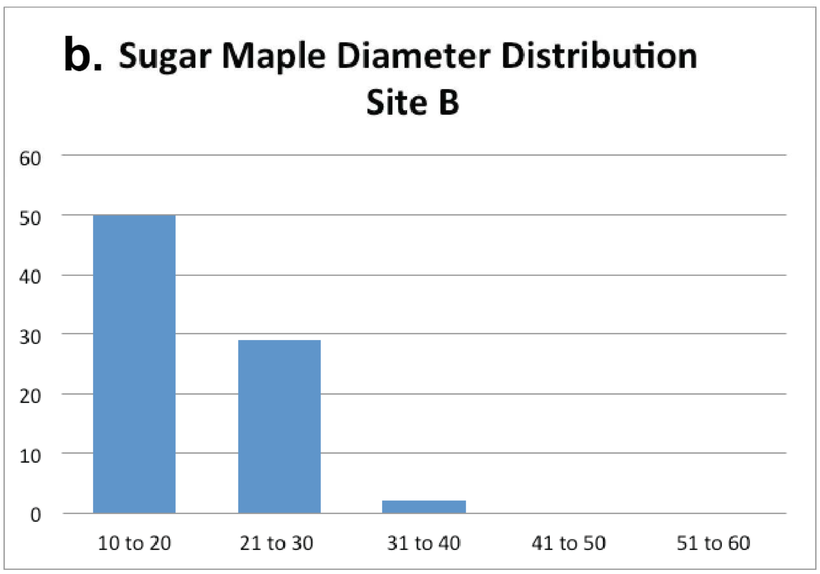


Figure 12**.** These bar graphs illustrate the diameter distribution (DBH in cm) of the overstory chinkapin oak (a) and sugar maple (b) at the chinkapin oak site (Site B).

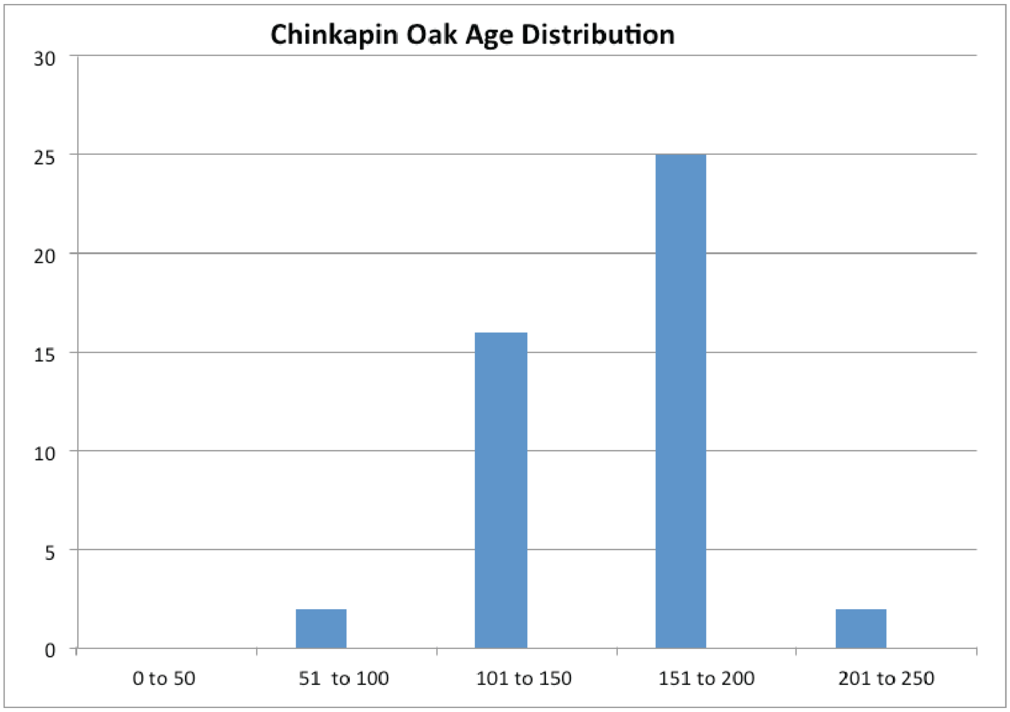


Figure 13. This bar graph illustrates the age distribution (years) of the overstory chinkapin oak at Site B.

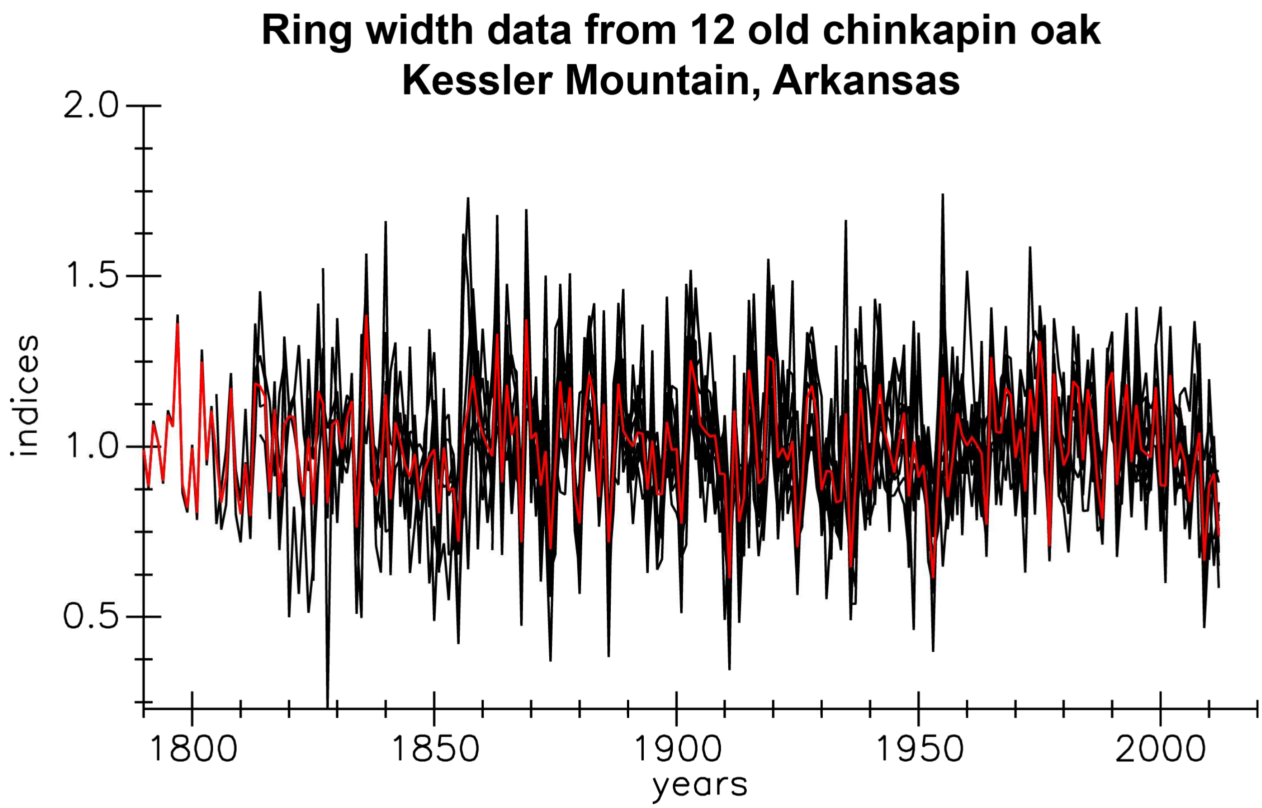


Figure 14. The detrended, standardized, and autoregressively modeled ring width indices for 12 old chinkapin oak trees from Kessler Mountain are plotted (black curves) along with the mean (red curve; output from ARSTAN, Cook and Krusic 2005). Note the strong co-variability of ring width among trees, especially during severe drought (e.g., 1855, 1874, 1886, 1911, and 1953).

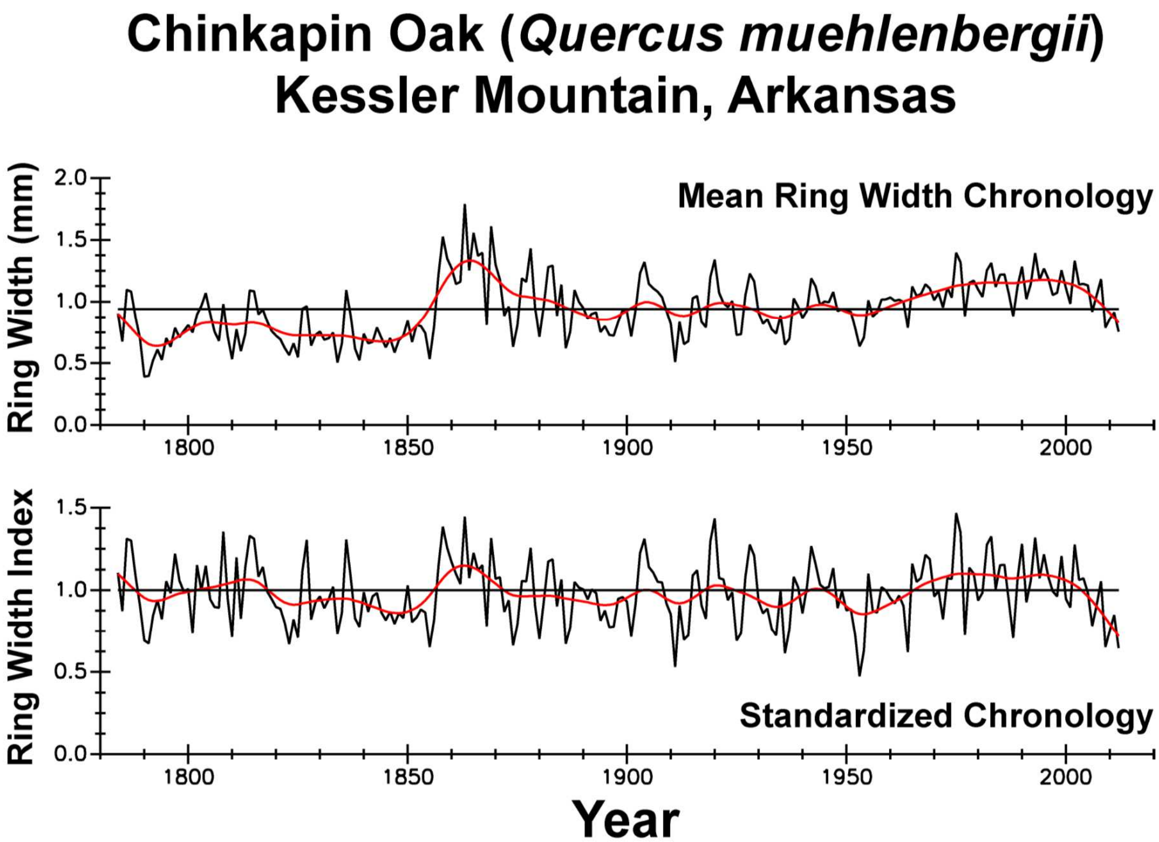


Figure 15. The dated and measured ring width data from 12 canopy dominant chinkapin oak trees were used to develop two tree-ring chronologies for Site B, the mean ring width chronology (top time series) and the detrended and standardized mean ring width index chronology (bottom series). These chronoloiges document the history of tree growth at Site B, including a growth release in the late 1850s (top series), and the impacts of severe regional droughts (e.g., 1911, 1953, 1988, bottom series; output from ARSTAN, Cook and Krusic 2005).

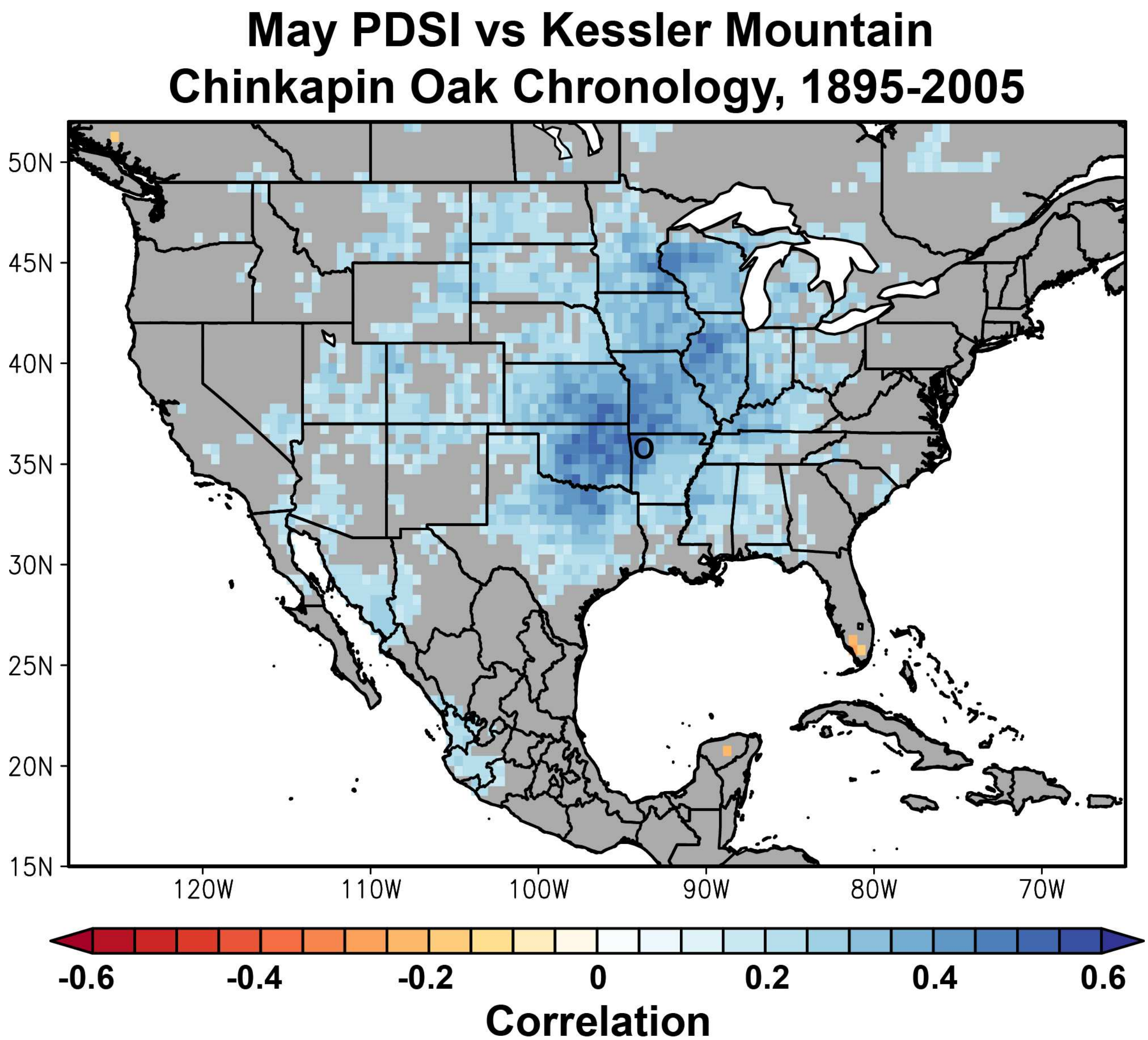


Figure 16. The Kessler Mountain chinkapin oak chronology (residual version) was correlated with instrumental May PDSI on a gridded basis over North America using the online analytical tools developed by D.J. Burnette, University of Memphis (Burnette 2019). The location of the Kessler Mountain site is indicated by the circle and significant correlations are mapped for the period 1895-2005.