

Tree Ring Analysis of Eastern Red Cedar
Reveals Fire History of Fults Hill Prairie Nature Preserve,
and its Relationship to Climate and Loss of Prairie Vegetation



Ancient eastern red cedar (*Juniperus virginiana*) on the cliff escarpment above Kidd Lake Marsh and the American Bottoms at Fults Hill Prairie Nature Preserve.

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SUMMARY

We used tree ring analysis of eastern red cedar to develop a chronology of historic fire at Fults Hill Prairie Nature Preserve, and to understand its relationship to historic climate and loss of prairie habitat measured on aerial photos. Hill prairies have been declining in area in Illinois since the 1960s, and loss of prairie vegetation at Fults Hill Prairie is significantly impacting the biodiversity of an important National Natural Landmark. Hill prairie vegetation traditionally has been thought to be maintained by its xeric habitat. However, documented decline in hill prairies has been used to suggest that burning is also needed to help maintain this vegetation. Our research provides important data supporting this contention. Based on a loss rate of about 10 % of original area per decade since 1950, linear regression projected total loss of hill prairie vegetation before the year 2040, while non-linear regression projected loss of 80 % of the prairie area by that time. Our data revealed a chronology of fire extending into the 1800s, with about five fires per decade until the 1960s, when prairie vegetation began to rapidly decrease in area. These fires also were more frequent during drought years, indicating that drought-driven fire may have been important in maintaining hill prairies. We also found that cedars cut from loess prairie for management originated in the 1960s, providing more evidence for woody invasion at that time. Many older cedar trees that we studied from other habitats originated in the 1800s and may belong to natural communities associated with cliff habitat. When such cedars are removed for management, it should be done judiciously. The oldest trees, including many that were not available for study, may be of presettlement origin and valuable indicators of past fire, climate, and vegetation history. Additional work is needed to identify these trees.

ACKNOWLEDGMENTS

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INTRODUCTION

Deterioration of grassland plant communities is a critical long-term trend in Illinois (Robertson & Schwartz 1994). For example, loss of Mississippi and Illinois River hill prairies has been documented from aerial photographs (McClain 1983, McClain & Anderson 1990, Robertson et al. 1995). At Fults Hill Prairie Nature Preserve, Monroe Co., Illinois, Robertson et al. (1995) found a 53.4 % loss of prairie area between 1940-1988 (Figure 1). Fults Hill Prairie is the largest protected Illinois hill prairie on the Mississippi River, and is a National Natural Landmark (McFall & Karnes 1995). Hill prairies have a distinctive xeric micro-climate and their vegetation includes plants and animals occurring at their eastern range limits (Schwegman 1973, White & Madany 1987, Schwartz et al 1997). Such species may be relictual from a former drier climate that promoted invasion of western prairie species during the Hypsithermic Interval, approximately 7,000 years BP (e.g., Smith 1961). Consequently, microclimate may be an important factor maintaining this vegetation (Evers 1955, Kilburn and Warren 1963, Reeves et al. 1978). Moreover, fire more likely occurs during climatic drought extremes (Stambaugh & Guyette 2006, Jones & Bowles 2012), and therefore interacts with climate. Understanding the cause of loss of prairie habitat at this site, and linking it with management is critical for maintaining its natural diversity.

Chronology of fire associated with fire-dependent vegetation can be determined through analysis of fire scars revealed through tree ring analysis (Wolf 2004, Stambaugh & Guyette 2006, McClain et al. 2010, Jones & Bowles 2012). In this study, we develop a fire scar chronology from eastern red cedar (*Juniperus virginiana* L.) at Fults Hill Prairie, and link it

with past climate, change in vegetation, and site fire history. Red cedar is considered an invasive species in prairie vegetation at Fults, where it is thought to colonize from cliff habitat during periods of fire exclusion. Management removal of trees from the prairie and adjacent habitat made their stumps available for collection of cross sections for this study.

STUDY OBJECTIVES

The goal of this study was to use ages and fire scars of red cedar to develop a chronology of its invasion of hill prairie vegetation, and a fire history for Fults Hill Prairie in relation to climate and loss of prairie area. A secondary goal was to use this information to inform management recommendations and decisions. The results would help understand whether cedars were present at Fults and in what habitats during the late 1800s and early 1900s, and the historic relationship between drought and fire affecting Fults, and would thus provide a better understanding of long term management needs. Although this represents a single study site, it may have applications for other Mississippi River and Illinois River hill prairies that are undergoing loss of prairie area..

Specific research questions pertaining to Fults are 1) what is the rate of loss of prairie vegetation, 2) what are the ages of red cedars and dates of fire scars collected from Fults Hill Prairie 3) can cedar ages be used to determine a chronology of their invasion of hill prairie vegetation, 4) can red cedar growth and fire chronology be correlated with historic climatic fluctuations?

STUDY SPECIES

Eastern red cedar is a characteristic tree of the rocky bluff line of the Mississippi River, and from this habitat invades adjacent hill prairie vegetation with fire exclusion. Cedar trees may live for from 200 to 350 years (Elias 1980). This tree species has thin bark that may record a long chronology of fire (Guyette & McGuinness 1982). It is also rot resistant, and dead trees may persist for decades or more, allowing development of extended growth and fire chronologies (Guyette et al. 1980). It is also sensitive to weather, developing frost rings that allow cross-dating of older specimens. This information can provide historic records of climatic variation, as well as ages of fire scars (Edmondson 2010, Guyette et al.1980). Specimens of this species on the cliff escarpment at Fults Hill Prairie may provide such records of past fire events as well as past climatic events that could have influenced historic vegetation at this site.

STUDY AREA

Fults Hill Prairie Nature Preserve is in the Northern Section of the Ozark Natural Division of Illinois, which represents the eastern edge of the Ozark uplift. (Schwegman 1973). The preserve's main feature is sheer bluffs raising 330 ft above the Mississippi River bottoms. Relief and boundaries are illustrated in Appendix I. A deep loess deposit caps the bluffs and provides habitat for hill prairie vegetation (Evers 1955). A limestone bedrock escarpment underlies the loess, providing cliff, thin-soiled glade, and talus slope habitats. These habitats support several Illinois endangered and threatened plant and animal species adapted to this habitat. Fults was recognized by the Illinois Natural Areas Inventory and is registered as a National Natural Landmark.

According to Evers (1955) Fults north prairie occupied about 12 acres, extending 0.6 mile along the upper southwest-facing slope of the bluff-ridge (Figure 1). On the northwest part of the bluff-ridge, long prairie spurs descended from the ridge-top to a small rock outcrop with a vertical face 2 to 3 feet high, below which was a forest covered talus slope that formed the lower third of the bluff. On the southeast part there was a high limestone cliff, and above it prairie covered both spurs and coves. As indicated, Robertson et al. (1995) documented a 53.4 % loss of prairie area at Fults by 1988. Fults has been managed by the Illinois Department of Natural Resources by prescribed burning since the early 1970s.

Burn data were unavailable for the 1970-90 period. After 1990, burn data provided by the DNR indicate that burns have been applied at an average rate of 1.2 fires/decade for each burn unit.

ANTHROPOGENIC CHANGES

The first Monroe County European settlement, St. Philippe, was established in 1723 a few miles south of Fults Hill Prairie on the Mississippi River (http://en.wikipedia.org/wiki/Monroe_County,_Illinois). Monroe County was formed in 1816 out of Randolph and St. Clair Counties. In 1829 Fults was a small settlement called Braunsberg. The Monroe County population grew from a few thousand to over 10,000 by 1870. It was stable between 1870-1950, with less than 15,000 people, but more than doubled by 2010 (Figure 2). Steam locomotives using track located along the flood plain below the bluffs may have been an ignition source for historic landscape fires (McClain 2011). The transition to diesel locomotives in the 1950s may have reduced the frequency of such fires.

METHODS

FIELD COLLECTING

Cedar cross sections were collected from 1) stumps cut after management to remove cedar from prairie and adjacent wooded areas, or from cedars scheduled for management removal. 2) dead cedars on the escarpment cliffs, and 3) live and dead trees in talus below the escarpment. We extracted tree cross sections with a 30-inch bar chain saw from 70 dead and 8 living trees. Collection sites (Appendix II) included the original Fults Hill Prairie north area studied by Evers (1955) and Robertson et al. (1995) as well as hill prairie and escarpment habitats adjacent to the south, which were added to the preserve by more recent DNR land acquisition. Each collection site was documented with a GPS location, photograph, and collection site notes. Most sections were taken within 12 inches of the tree base unless the base was rotten or if it was inaccessible due to terrain.

LABORATORY AND DATA ANALYSIS METHODS

What is the rate of loss of area of prairie vegetation?

Robertson et al. (1995) used digitized aerial photos to calculate loss of prairie area at Fults in four time periods between 1940-1988. To calculate further loss, we digitized the area of prairie at Fults Hill Prairie from the 1940 and 2007 aerial photos using ARC/INFO software. The proportional loss of prairie between 1940-2007 was then combined with proportional loss data from Robertson et al. (1995). We used linear and non-linear regression (negative exponential) analysis to model the rate of loss of prairie based on the relationship between year and proportional loss of prairie, and to project the year at which all prairie area would be lost. These projections are based on the original north unit.

What are the ages of red cedars and dates of fire scars collected from Fults Hill Prairie?

All samples were sanded with progressively finer grades of sandpaper (1500 minimum grit) to reveal annual rings and fire scars. Following Stambaugh and Guyette (2006), a radius of each cross section with the least variability due to fire scarring was used for measurement, and plots of ring-width series were used for visual cross-dating of signature years and for locating missing or false rings. False rings and frost rings also contribute to signature years in red cedar (Edmondson 2010). We recorded seven frost years in single cross sections, but a 1955 frost year appeared in six different cross sections. Once dating was completed, series accuracy was verified on the COFECHA program (Grisino-Meyer 2001) and combined into a master stand chronology represented by a standardized ring-width index using the ARSTAN program (<http://www.ldeo.columbia.edu/res/fac/trl/public/publicSoftware.html>). These chronologies represent combined data from the north and south units.

Can red cedar ages be used to determine a chronology of their invasion of hill prairie vegetation?

Ages of red cedars were determined for specimens collected from escarpment (N = 7), glade (N = 5), woodland (N = 4), and loess prairie (N = 3) habitats. The mean values were compared using a one-way Analysis of Variance (ANOVA). As with chronologies, these dates are based on combined data from the north and south units.

Can red cedar growth and fire chronology be correlated with historic climatic fluctuations?

We developed a master stand tree-ring growth chronology from 1821 to 2012. This chronology included multiple fire scars from the 1800s that were not used because they could not be precisely dated at this time. We analyzed fire chronology using scars with precise dates beginning in 1875. These fire events recorded from tree collections were assembled into a chronological sequence and expressed as fires/decade. To assess growth responses to climatic factors, the stand ring-width index was correlated with 1901-2009 rainfall and temperatures in years t and $t-1$ for fall, winter, spring, and summer months. Data were obtained from the Illinois State Climatologist Office for Anna, IL from the Illinois State Water Survey website (<http://www.isws.illinois.edu/data/climatedb/>). We also compared fire scar chronology to the instrument-based Palmer Drought Severity Index (PDSI) values from Grid 103 for southeast Missouri (Cook and others 2004). These represent average summer (June, July, August) values.

We used the average fire return interval (i.e., number of years between successive fires) and the number of fires per decade to explain fire history. Decadal fires were also calculated as a running 10-year cumulative number of fires for statistical treatments. We used three time periods (1875-1920 vs 1921-1960 vs 1961-2010) as temporal categorical variables for analysis. We chose these periods because they reflect important periods of changing attitudes toward fire and fire protection (beginning in the 1920s), and the rapid increase in population coupled with loss of steam trains and the greatest decline in prairie cover at Fults (beginning in the 1960s). To evaluate climatic effects, we developed three climatic variables based on the five-year running average PDSI, representing drought (< -0.05), moderate ($-0.05 - +0.05$), and moist (> 0.05) conditions. One way ANOVA was used to test whether fire return interval and the running ten-year cumulative number of fires differed significantly over the time periods and climatic categories. Data were ln-transformed to achieve normality.

RESULTS

Although there was no loss of prairie area at Fults between 1940 and 1950, it had been reduced to 46.6 % of its original area by 1988 (Robertson et al. 1995). By 2007, 35.2 % of the original area remained (Figure 3). Linear regression modeled a significant ($r^2 = 0.9796$) loss rate of about 10 % of original area per decade, and a projected total loss of the prairie before the year 2040. This projection may vary between about 2020 and 2070 based on 95 % confidence intervals (Figure 3). Non-linear regression also had a high correlation ($r^2 = 0.9787$); it projected loss of about 80 % of total prairie area before 2040, loss of 90 % by the end of this century, and total loss of prairie area by about 2200 (Figure 3).

Thirteen red cedar collections containing 50 fire scars representing 37 fire years were precisely dated between 1875 and 2012 (Figure 4). These fires were recorded from prairie, glade, escarpment (cliff and talus) and woodland habitat with partial tree cover. Fires recorded in 1888, 1913, 1925, 1945, and 1958 were recorded by trees in all habitats. Red cedars sampled in loess prairie established in about 1950, and were significantly younger than cedars established in other habitats, which established before 1900 (Figure 5). This included six trees cut for management from escarpment, glade and loess woodland habitat.

The red cedar growth chronology was significantly positively correlated with summer rainfall ($r = 0.327$, $P = 0.0012$) and with the Palmer Drought Severity Index ($r = 0.4545$, $P < 0.0001$). Palmer drought severity had moderate cycles of about 5 years and more extreme deviations at 10-15 year cycles (Figure 6). The running ten-year cumulative number of fires was significantly correlated with the PDSI ($r = -0.2325$, $P = 0.0193$), and had peaks in the first decade of the 1900s, the 1930s and the 1950s (Figure 6). These peaks corresponded to direct measures of fires per decade, which ranged from 1-5, and were greater before 1960 (Figure 7).

When compared among time and drought categories, fire return intervals were significantly greater after 1960, with greater than 5-year average return intervals (Figure 8). Fire return intervals also were significantly lower during drought years, with less than 2-year average return intervals (Figure 8). The running cumulative number of fires per decade was inversely proportional to fire return interval, with significantly fewer fire occurrence during the 1921-1960 time period and more occurrences during drought years and (Figure 9).

DISCUSSION

Our data indicate that the trend in loss of prairie area at Fults Hill Prairie identified by Robertson et al. (1995) has continued, and that loss of 80-100 % of the prairie area may occur before the year 2040. Such loss has been thought to be related to fire exclusion (Robertson et al. 1995), but a direct connection between fire history and loss of prairie area has been lacking. Our data provide this information, and indicate that fires occurring at a rate of at least five fires per decade may have maintained hill prairie vegetation from the late 1800s through the mid 1900s. This was followed by a shift to less than two fires per decade after 1960, which may have allowed the large decline in prairie area that then took place (Figure 1). The average date of establishment of red cedars (about 1960) in loess hill prairie also supports the loss of prairie occurring at that time. Although our data suggest that five fires/decade may have been necessary for maintaining hill prairie vegetation at Fults, the actual rate of fire occurrence may have been higher but not recorded by cedars. For example, a 1953 drought driven landscape fire that moved from Kidd Lake Marsh up the talus slope and through the hill prairie vegetation onto the uplands (McClain 2011) was not recorded by cedars on the talus slope. Nevertheless, a similar rate of about five fires per decade was found for shortleaf pine habitat in southern Illinois during early settlement (Jones & Bowles 2012). Although the frequency of management fires between 1970-1990 is unavailable, management units received burns at a rate of only 1.2 fires per decade after 1990, which may have further contributed to loss of prairie.

Xeric habitat of hill prairies may contribute directly to their persistence by slowing rates of woody succession (Evers 1955). However, dry conditions also contribute to greater flammability of vegetation, including invading trees and shrubs, which would be enhanced in hill prairies during drought years. Indeed, our data indicate that burning is more likely to occur during drought years. This suggests that an ecological effect of xeric habitat on maintaining hill prairie vegetation may operate indirectly through a drought-driven fire process. If the most xeric habitat at Fults retards woody invasion and loss of prairie to a greater degree than adjacent less xeric habitats, the rate of loss of prairie might eventually decrease, leaving small fragments that would persist for a greater time period than projected. Our non-linear regression would support this hypothesis. However, the ongoing fragmentation of habitat would probably hinder fire movement among prairie openings, while an increasing edge to interior ratio would further accelerate loss of prairie area (Robertson et al. 1995). Also, smaller hill prairie fragments that might persist on more xeric habitat would be vulnerable to shade from adjacent tree crowns, which would reduce grass cover and prairie species richness, and shift vegetation structure, as well as animal habitat structure, away from original conditions.

Post settlement fire suppression associated with increased settlement in the mid-late 1800s has been suggested as a cause of decreased fires recorded by oaks in southeast Wisconsin (Wolf 2004) and south central Illinois (McClain et al. 2010). Although our current data include only the late 1800s, they suggest that fire suppression did not take place at Fults following a rapid population increase that reached a plateau in 1870. Likewise, Jones & Bowles (2012) did not record a decline in fire during early settlement on xeric bluffs at Pine Hills, also in southwestern Illinois. The xeric habitats in these study areas may have promoted greater flammability and greater likelihood of fire, even with increasing settlement, and their remote locations may have attracted less focus on fire suppression.

Our data have multiple management implications. If the current rate of loss continues, decisive management actions may be needed to prevent the total loss of prairie area at Fults. Our data indicate that more frequent burning will be needed to recover and maintain hill prairie vegetation at Fults. We suggest that at least biennial burning may be needed to maintain this vegetation, as it does in mesic prairie vegetation (Bowles & Jones 2013). More frequent fire coupled with removal of woody vegetation may be needed to recover former prairie area. Our data also indicate that red cedar occurring on escarpment, glade and talus habitat originated in the 1800s, and they may belong to natural communities that burned less frequently or with less intensity than hill prairie vegetation. When such trees are removed for management, it should be done judiciously. The oldest trees, including many that were not available for study, may be of presettlement origin and could provide linkages with past fire, climate, and vegetation history. Additional work is needed to identify these trees. If our results represent ongoing rates of prairie loss and reduced fire frequency for other Illinois hill prairies, similar management would be needed for these sites as well.

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Figure 1. Distribution of loess hill prairie at Fults Hill Prairie Nature Preserve in 1940 (left image) and in 2007 (right image). White outline on 2007 image indicates continuous prairie cover in 1940. See Figure 3 for proportional loss between 1940 and 2007.

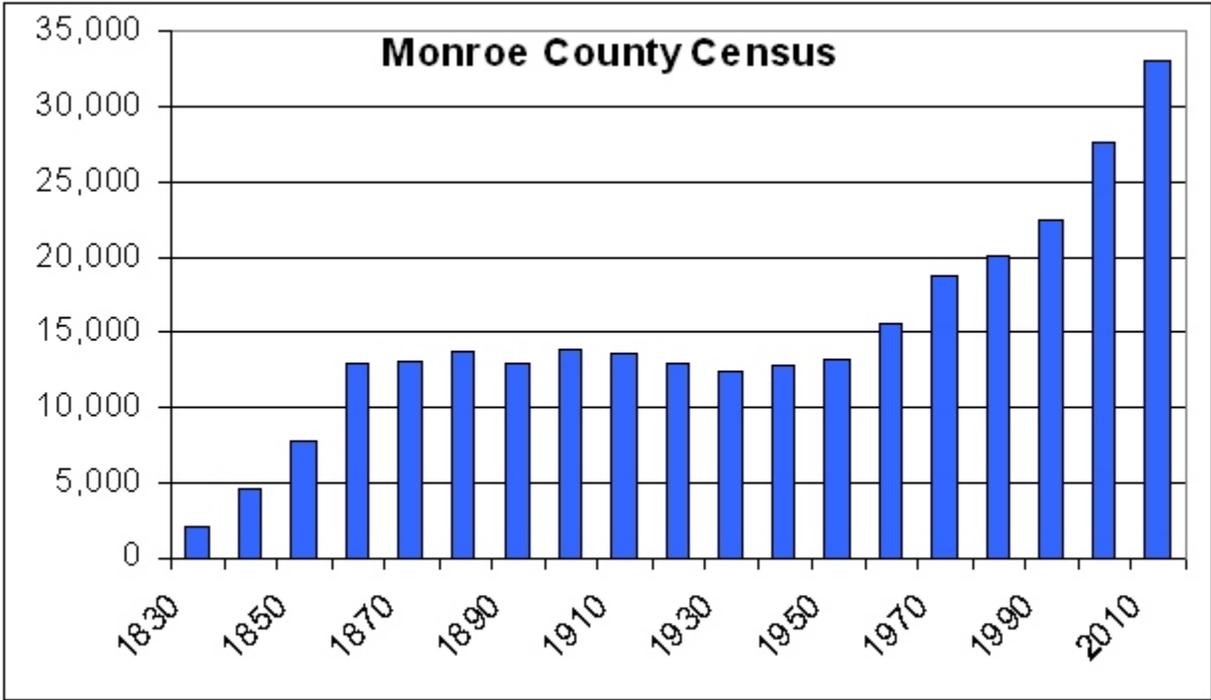


Figure 2. Temporal change in population of Monroe Co., IL Source: http://en.wikipedia.org/wiki/Monroe_County,_Illinois

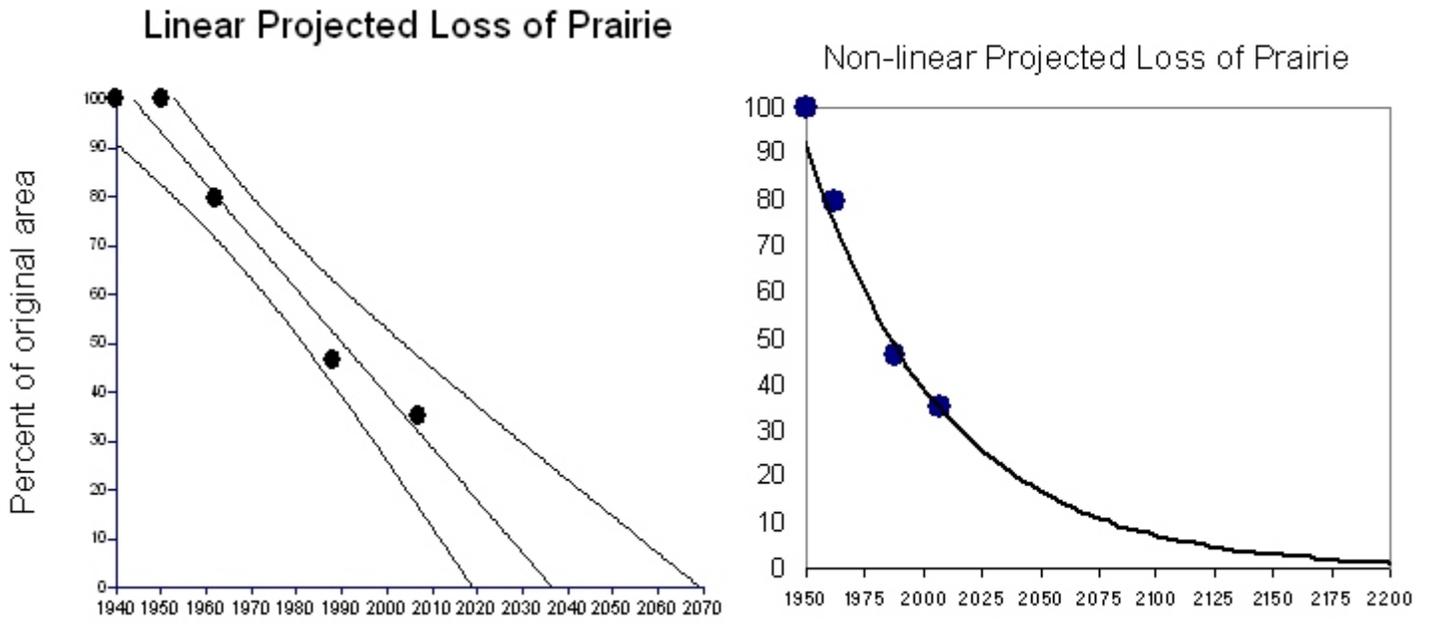


Figure 3. Projected loss of prairie area at Fults Hill Prairie. Linear regression ($r^2 = 0.9796$, $P = 0.0021$) and 95% confidence intervals. Non-linear projection ($r^2 = 0.9787$).

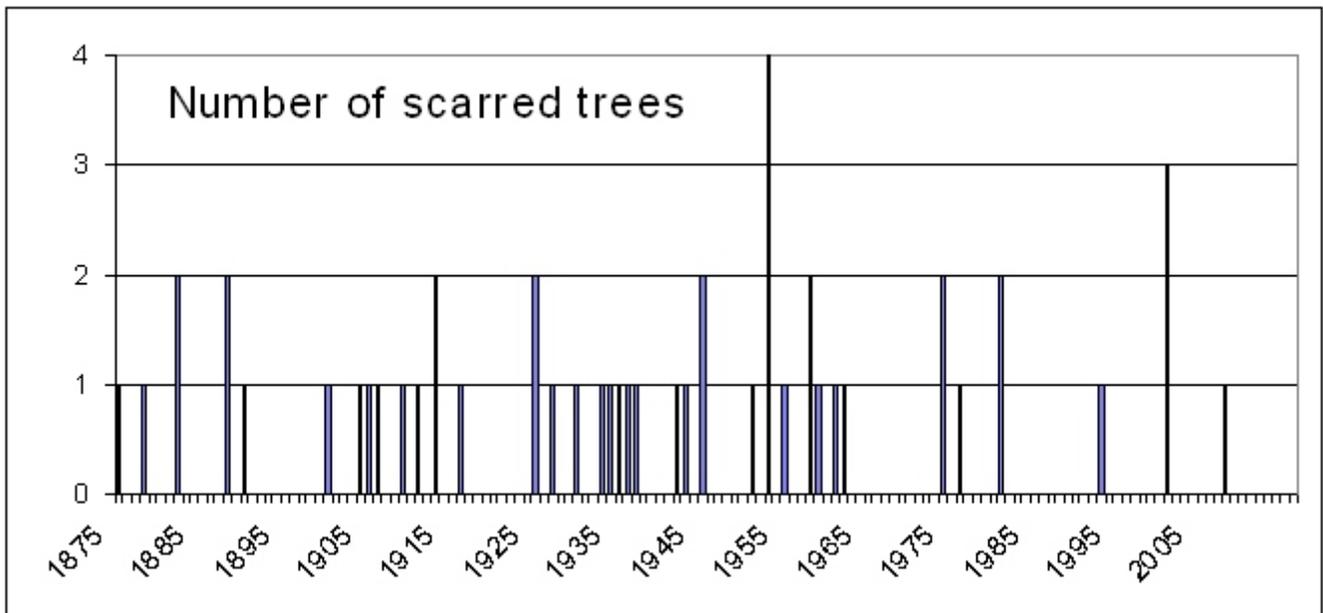


Figure 4. Fire chronology and number of scars recorded by red cedar.

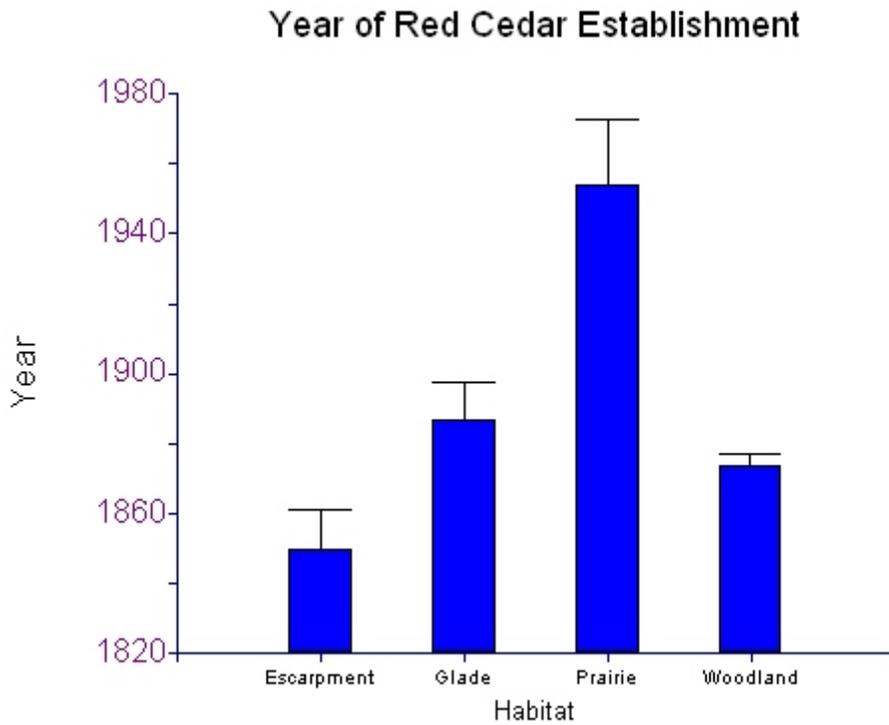


Figure 5. Average year of establishment of red cedars in different habitats at Fult's Hill Prairie ANOVA ($F = 10.32$ $P = 0.000354$). Escarpment includes cliff and talus. Woodland represents prairie and glade vegetation with partial tree cover.

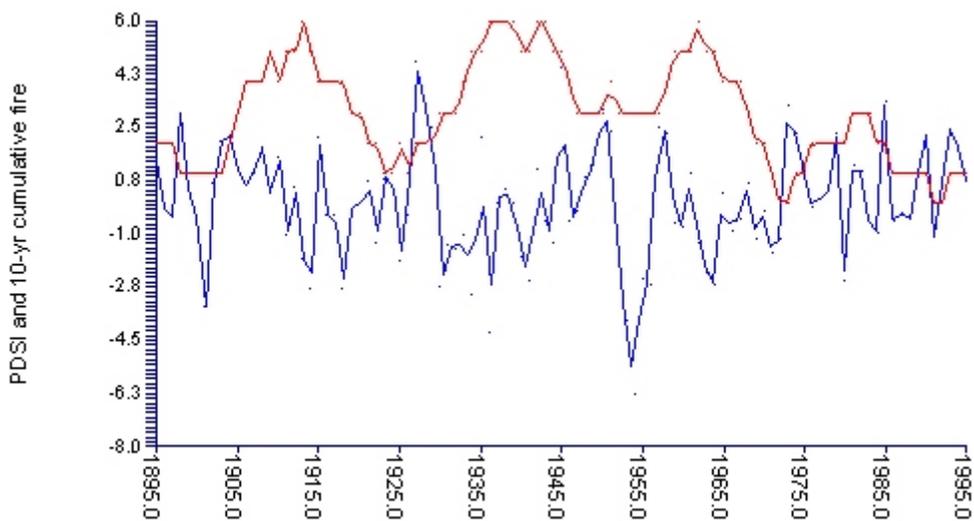


Figure 6. Palmer Drought Severity Index (blue) and running 10-year cumulative number of fires (red). Correlation: $r = -0.2325$, $P = 0.0193$.

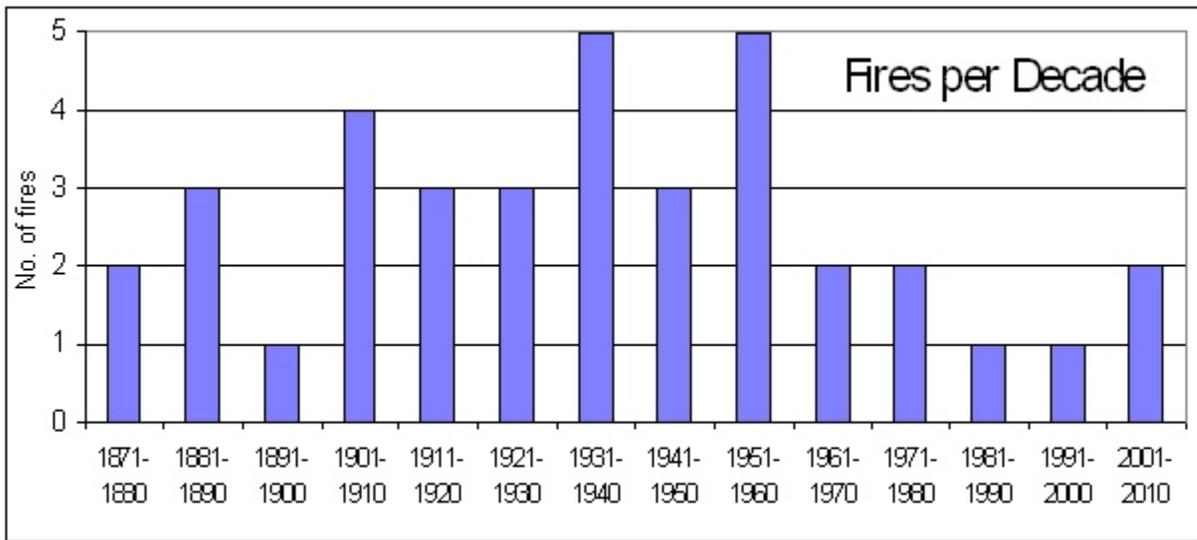


Figure 7. Fire occurrences per decade recorded in red cedar.

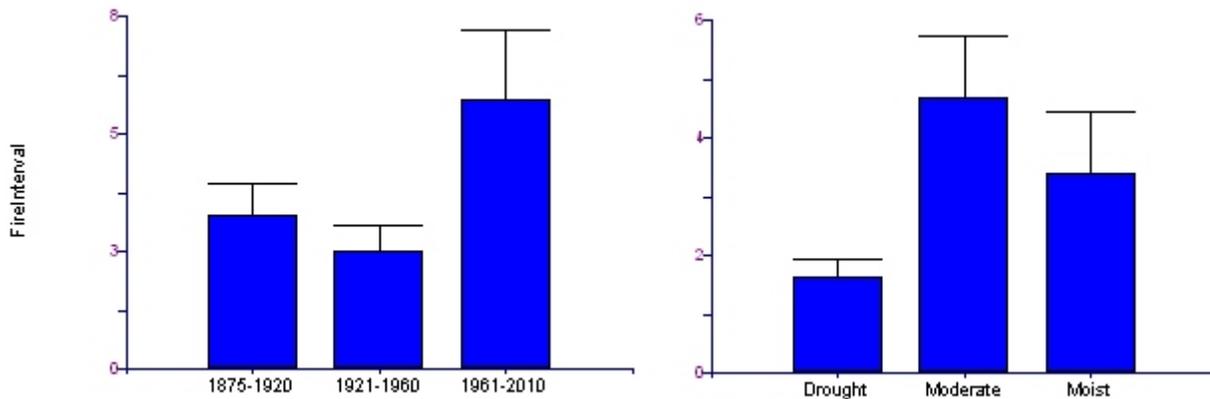


Figure 8. Average fire return intervals in relation to time period ($F = 3.12$, $P = 0.0573$) and drought severity ($F = 3.30$, $P = 0.0523$) categories.

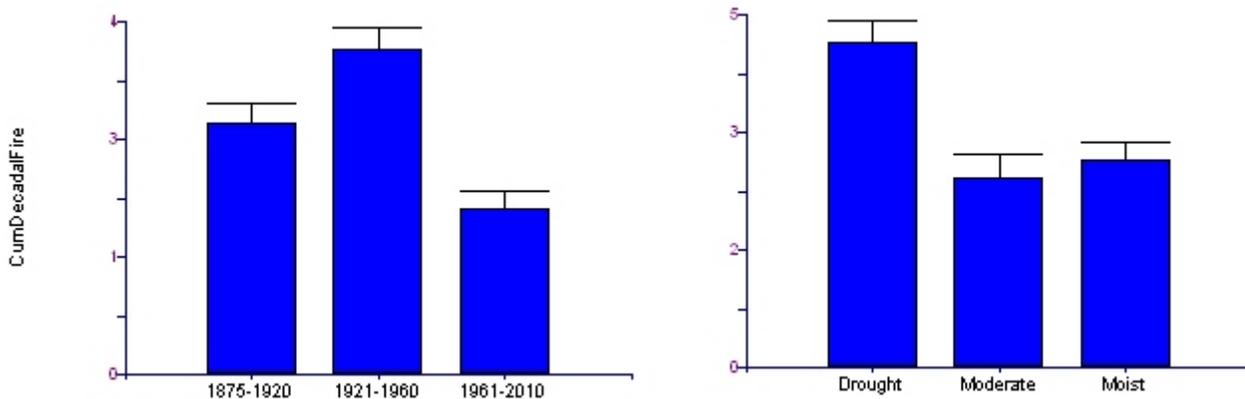
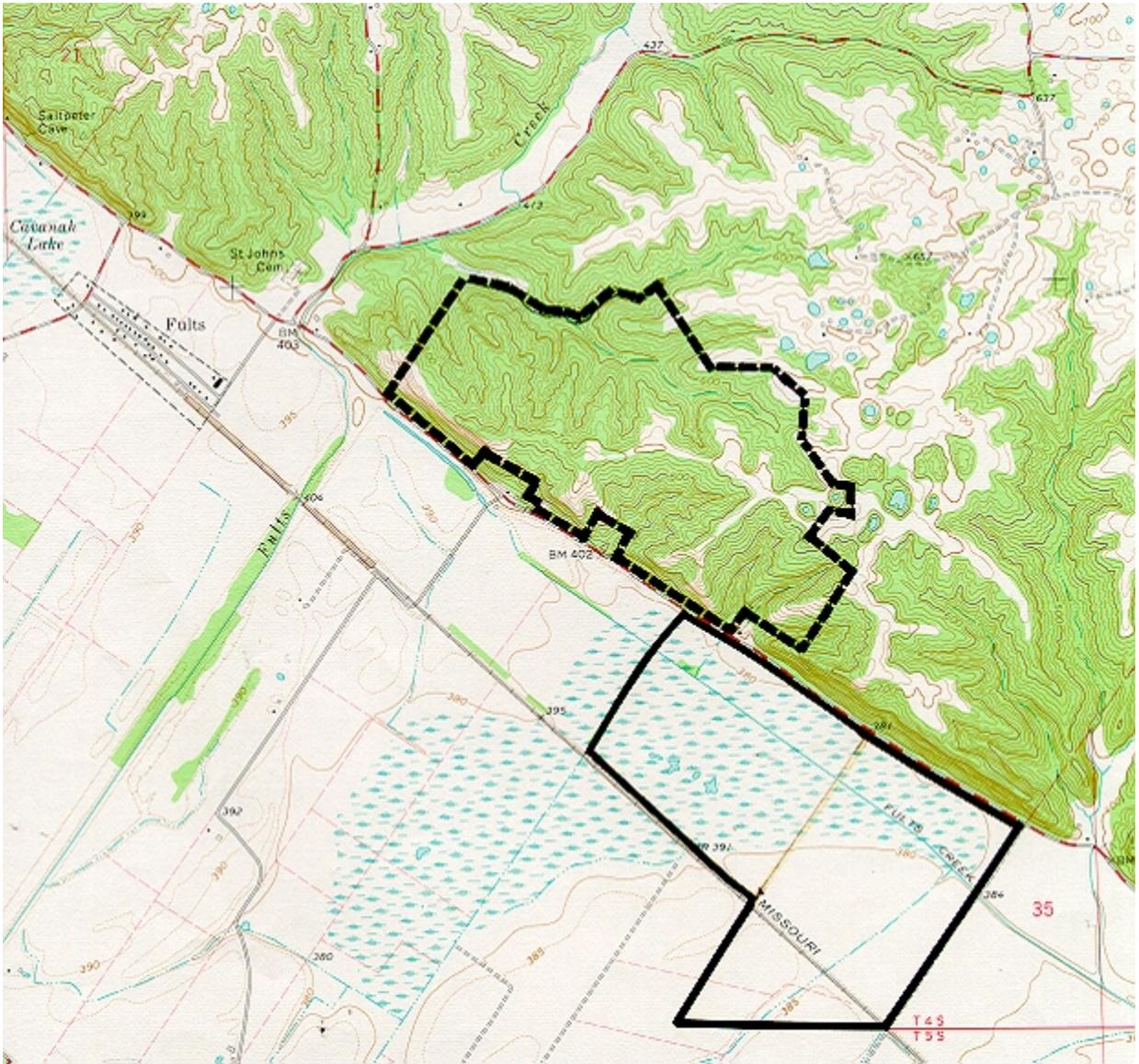


Figure 9. Average running cumulative number of fires recorded per decade in red cedar in relation to time period ($F = 19.99$, $P < 0.0001$) and drought severity ($F = 9.67$, $P = 0.0001$) categories.

Appendix I. Fults Hill Prairie Nature Preserve.



Appendix II. Red cedar GPS collection points (represented by green circles) at Fults Hill Prairie..

