# FIRE HISTORY, POPULATION, AND CALCIUM CYCLING IN THE CURRENT RIVER WATERSHED

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Abstract: Quantitative details about past anthropogenic fire regimes and their effects have been lacking in the central hardwood region. Here, we present fire scar chronologies from 23 oak-shortleaf pine (*Quercus* spp. and *Pinus echinata* Mill.) sites in the upper Current River watershed of the Missouri Ozarks. Dendrochronological methods were used to date 2,004 fire scars from 150 shortleaf pine sections with from 100 to more than 300 rings. Fire scar chronologies were constructed from scars dating back 200 to 400 years ago. The average mean fire-free intervals (MFI) calculated for the sites by time period are: the de-populated period, 1580-1700, MFI=17.7 years; the Native American re-population period, 1701-1820, MFI=12.4 years; and the Euro-American settlement period, 1821-1940, MFI=3.7 years. Fire frequency was more variable among and within sites during the Native American period (1701-1820) than during the period of Euro-American settlement (1821-1940). The percentage of sites burned annually before 1850 is correlated ($r=0.87$, $p<0.05$) with population density at the low levels (< 0.64 people per $km^2$). The percentage of sites burned annually decreases about 20% from 1850 to 1940 and is negatively correlated ($r=-0.40$, $p<0.01$) with an increase in population density approaching 4.6 people per $km^2$. About 10 to 15% of the sites burned annually between 1700 and 1800 during a period of low (<0.4 people per $km^2$) population density.

The long-term effects of an anthropogenic fire regime on calcium availability are inferred from Ca concentrations in tree-rings. Calcium concentrations in dated heartwood increments of eastern redcedar (*Juniperus virginiana* L.) for three sites in the watershed are correlated ($r = 0.82$, $p<0.05$) over 340 years with changes in the frequency of anthropogenic fire. Trends in Al concentrations in redcedar heartwood are negatively correlated with the percent of sites burned ($r = -0.70$, $p<0.05$).

## INTRODUCTION

The nature of the past anthropogenic fire regimes of the southeastern Ozarks have long been a question for speculation. Wildland fires influence processes shaping the structure and ecology of these primarily forested natural communities which lie just east of the prairie-forest border (Chandler and others 1983, Paulsell 1957, Pyne 1984, Pyne and others 1996, Wright and Bailey 1982). Long-term records of wildland fires can facilitate our understanding of the present state of the Ozark ecosystems, their wildlife, forest composition, watersheds, and ground flora. Even in the now heavily forested Current River watershed, early travelers described an ecosystem shaped by fire with some grasslands, oak savannas, and open woodlands (Schoolcraft 1821).

In earlier papers, we have described the fire history of a post oak (*Quercus stellata* Wang.) savanna, an oak-hickory (*Carya* spp.) forest, and an eastern redcedar (*Juniperus virginiana* L.) glade (Cutter and Guyette 1994, Guyette and Cutter 1991, Guyette and McGinnes 1982). This study presents results utilizing shortleaf pine (*Pinus echinata* Mill.) remnants to document fire history in the Current River watershed (Figure 1).

The data base for this study was derived from fire scars on shortleaf pine. This species has the largest geographic distribution of any of the southern pines. Over much of this range, despite humid climates, old remnant stumps of shortleaf pine can be found. In the Missouri Ozarks, remnants of shortleaf pine are found in present day oak and oak-pine forests underlain by acid soils (Fletcher and McDermott 1957). While nearly all of the pine and oak-pine

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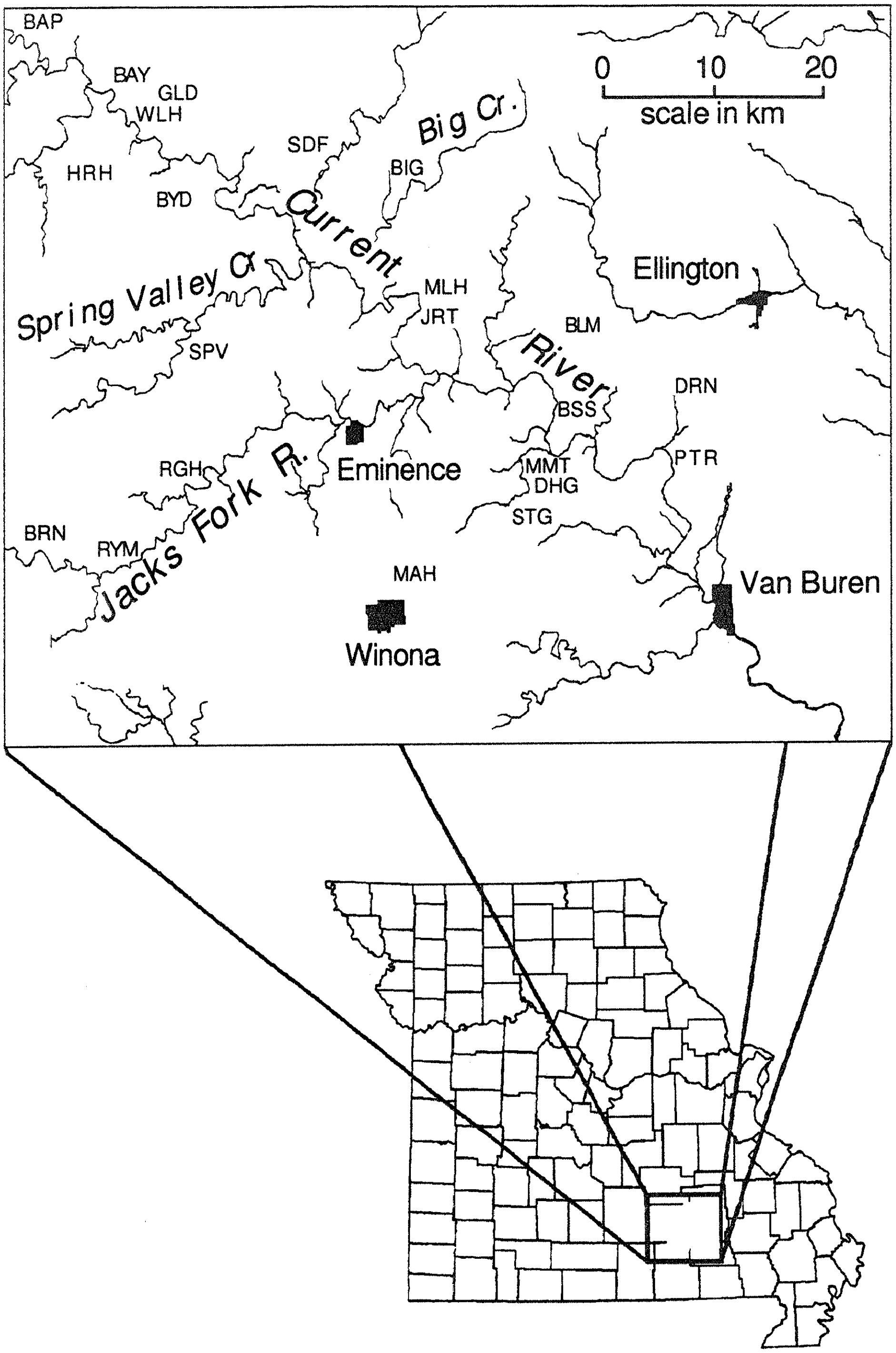


Figure 1. Locations and site codes of fire scar chronologies in the Current River watershed above Van Buren, Missouri. Site codes are identified in Table 1.

forests of this area was cut circa 1900, some old trees, natural remnants, and many old stumps remain. The fire-injured wood of shortleaf pine has been preserved by its high density, hydrophobic oleoresin content, and low moisture content.

In anthropogenic fire regimes of the humid-continental mid-west natural ignitions are rare. It is our hypothesis that gross population levels and culture are important factors influencing the frequency of wildland fire (Dey and Guyette 1996). Hypothetically, fire frequency should increase as the human population and number of potential ignitions increases. Then, as human population reaches some threshold density, fire frequency should begin to decline as humans have more to from fire. Fire suppression, intensive land use, fuel fragmentation, increased fire breaks, and cultural change all contribute to the decline in wildland fire frequency. The long-term fire histories of the Current River Watershed offer an excellent opportunity to examine these hypotheses.

Wildland fire is also a chemical reaction known to affect the chemistry of soil and plants. There is little evidence, however, of how changes in fire regimes might affect the availability of nutrients over long periods of time. Here we link changes in an anthropogenic fire regime in an Ozark watershed with long-term trends in Ca and Al concentration in dated heartwood increments of eastern redcedar. We discuss possible pathways, reactions, and implications of changes in the Ca budget of low Ca sites.

The four objectives of the research presented here are: (1) to document fire history in a highly dissected forested region of the southeastern Ozarks, (2) develop the use of shortleaf pine remnants for documenting pre-European fire history, (3) test hypotheses that relate human population and culture to fire frequency, and (4) compare the regional fire history with Ca and Al concentrations in eastern redcedar.

## MATERIALS AND METHODS

### Site Selection

The watersheds of the Current and Jacks Fork Rivers are primarily forested (> 80%) and at the eastern edge of a large prairie and savanna mosaic (Figure 1). Shortleaf pine and other species were clearcut from the area between 1880 and 1920 (Cunningham and Hauser 1989). The Current River watershed (above Van Buren), where the sample sites are located, covers about 4316 $km^2$ and is dissected by steep ridges and numerous streams. The surface rocks and outcrops, which were abundant at most sampling sites, were composed of chert, sandstone, rhyolite, and dolomite. The average slope of the sample sites was 18° and ranged from 10° to 32°. Elevations in the study area range from about 140 to 414 m above sea level.

The climate of the study area is humid and continental. Precipitation ranges from 60 to 152 cm and averages 115 cm per year. Spring is the wettest season, followed by fall, summer, and winter. During the fall, winter, and spring of most years, dry warm weather during only a few days may be sufficient to dry ground fuels and permit the spread of ground fires. Severe fires during the growing season are rare but do occur during very hot and dry summers. Natural ignition is rare during most years, despite an abundance of thunderstorms (50-70 thunderstorm days per year) (Baldwin 1973).

Little is know about litter accumulation in oak-pine woods of the Ozarks. Litter accumulation is an important aspect of the fuel matrix in the surface fires of the Ozarks. The decay constant (i.e., the time is takes the litter mass to reach a dynamic equilibrium with site and climate) has important implications for the interaction between fire intervals and fuel accumulation. Scowcroft (1965) quantified litter accumulation in an oak forest of the southeast Ozarks and found that annually burned plots had about a third as much litter as did unburned control plots; plots burned once every 5 years had about 76% of the litter accumulation of the control plots. These rates of accumulation indicate a decay constant of from 6 to more than 12 years. Thus, fire return intervals less than the decay constant tend to reduce fire intensity and spread. Decay rates of litter also effect the among of nutrients, such as calcium, held in the litter layer. The decay constant is an important concept relating fire frequency to intensity, historic fire spread, nutrient pools, and management goals.

Pine stumps and natural remnants were collected from 23 oak-shortleaf pine sites in the upper (above Van Buren, Missouri) Current River watershed. Site names, site codes, the number of trees per site, and the number of scars per site are given in Table 1. Sites were not chosen at random. Sites were located by hiking steep southwest facing slopes scattered throughout the watershed and by consulting with local foresters, wildlife biologists, and land managers. Many areas yielded no remnant pine material. Less than half of the south and west-facing hillsides visited has or had a shortleaf pine component. Collections were made whenever a dendrochronological fire record (fire scars on pine stumps) was present. Dendrochronological requirements bias the sample to more pyrogenic sites with less fuel moisture for greater periods during the fire season. This may bias the sample sites toward higher fire frequencies on south and west facing slopes where shortleaf pine is most abundant and where stumps are better preserved by a lower moisture content. Thus, these site do not represent MFI for the whole landscape.

Table 1. Site names, map code, calendar years, number trees, and number of dated fire scars for fire and chemistry sites

| Fire sites | | | | |
|---|---|---|---|---|
| Site name and location | Code | Period | Trees | Scars |
| Barn Hollow Natural Area | BRN | 1904-1643 | 5 | 45 |
| Rymers Ranch, NPS | RYM | 1921-1780 | 2 | 26 |
| Manhans, Rocky Cr. S.F. | MAH | 1907-1585 | 9 | 121 |
| Mill Creek | MCR | 1869-1631 | 2 | 63 |
| Paint Rock State Forest | PTR | 1907-1668 | 3 | 64 |
| Stegall Mountain, Peck Ranch | STG | 1941-1636 | 7 | 89 |
| Denning Hollow Glade, | DHG | 1993-1641 | 9 | 102 |
| Mill Mountain, Rocky Cr. S.F. | MMT | 1993-1715 | 11 | 142 |
| Rough Hollow, NPS | RGH | 1921-1558 | 7 | 44 |
| Spring Valley, Alley Sp. S.F. | SPV | 1804-1598 | 1 | 13 |
| Jerktail Mountain, | JRT | 1941-1686 | 15 | 196 |
| Blue Spr., Carr Cr.S.F | BSS | 1993-1626 | 16 | 227 |
| Deer Run S. F. | DRN | 1904-1558 | 13 | 159 |
| Bloom Creek S. F. | BLM | 1914-1773 | 7 | 47 |
| Mill Hollow, Pioneer Forest | MLH | 1993-1656 | 20 | 273 |
| Big Creek, Mark Twain N.F. | BIG | 1950-1608 | 9 | 95 |
| Shannondale S. F. | SDF | 1928-1686 | 5 | 56 |
| Boyds Cr., MO. S. F. | BYD | 1920-1685 | 4 | 34 |
| Hartshorn S. F. | HRH | 1914-1558 | 9 | 101 |
| Welch Spring, NPS | WLH | 1923-1740 | 3 | 21 |
| Gladden Cr., Cedar Grove S.F. | GLD | 1934-1756 | 7 | 40 |
| Bay Hollow, NPS | BAY | 1960-1715 | 2 | 20 |
| Baptist Access, NPS | BAP | 1908-1724 | 2 | 26 |

| Stem chemistry sites | | | | | | | |
|---|---|---|---|---|---|---|---|
| Site name and location | Code | Period | Soil Ca (ug/g) | | | Soil depth | Trees |
| | | | O-Hor | A-Hor | B-Hor | (cm) | |
| Jerktail Mountain | JRT | 1960-1800 | 464 | 114 | 190 | 56 | 1 |
| Williams Mountain | WLM | 1960-1700 | 1112 | 351 | 214 | 91 | 9 |
| Buttin Rock Mountain | BRM | 1960-1620 | 805 | 283 | 135 | 30 | 3 |

## Fire Scar Dating

Cross-sections of more than 150 shortleaf pine remnants were cut between ground level and 30 cm. Cross-sections were cut to maximize the number of rings and fire scars. Samples were chosen by the presence of charcoal, fire scars, and the number of rings present. Compass orientation of the cross-section, slope, and aspect were recorded for each sample. Samples were obtained from cut stumps, wind fallen stems, and standing snags. Wedges were taken from the very few live trees with visible fire scars to extend the fire chronology to the present (Arno and Sneck 1977). Trees ranged in age from 100 to over 300 years. Heartrot and sapwood weathering made determination of the life span of each trees impossible.

Fire scars were identified by callus tissue, traumatic resin canals, and cambial injury. More than 90% of the fire scars were located on the up hill side of the bole. All samples had charcoal present on the scarred exterior. Scars were dated to the first year of cambial injury. Less than 1% of the fire scars occurred during the growing season (period of cambial growth).

Two types of fire scars found on most trees were a single initial scar and subsequent smaller scars. Once the tree has been wounded the thin bark of the callus tissue offers much less thermal insulation to the living tissue. The initial scarring of the bole requires considerable heat to penetrate the bark (Hengst and Dawson 1994, Spalt and Reifsnyder 1962). Lowery (1968), studying cambial injury in shortleaf pine, showed that 15 to 20 min exposure was required to kill the cambium under 4 cm of bark when exposed to air temperatures of 532° C.

The high temperature differences within a fire indicate that initial scarring of trees can be highly variable. Evidence for this variability and the resistance of shortleaf pine to initial scarring comes from old trees and stumps without scars growing adjacent to pine remnants with multiple scars. The bark of one old shortleaf pine, which had no scar, measured 15 cm thick at ground level. Cole and others (1992) found that temperatures in prescribed fires in an oak-prairie mosaic were markedly different within and between ecotypes.

The detailed observations of annual rings and scars necessary for cross-dating require that cross-sections be surfaced to reveal the structure of the rings. Cross-sections were surfaced with a electric hand planer with a sharp carbide blade. Where rings were very narrow or indistinct the ring structure and cellular detail was revealed with sandpaper (220 to 600 grit), fine steel wool, or razor cuts.

A radius (pith to bark ring series) of the cross-section was chosen for measurement with the least amount of ring-width variability due to reaction wood, injury, or callus tissue. The measurement radius was also chosen for the maximum number of rings and high frequency ring-width variance. Often, two radii were measured when ring-width series had much non-climatic variance. Ring-widths series from each sample were measured and plotted. Plots were used for visual cross-dating (Cutter and Guyette 1994, Guyette and Cutter 1991, Stokes and Smiley 1968). Visual matching of ring-width patterns allows the weighing of important "signature years" over years with low common variability among trees. Plots also aid greatly in identifying errors in measurement and missing rings associated with injury or drought.

A computer program, COFECHA (Holmes and others 1986), was used to assist in ensuring the accuracy of both relative and absolute dating of the samples by correlation analysis. Mean between-tree correlation in ring width was 0.51. A floating chronology (undated in absolute time) was established from the samples with the highest common ring-width variance at a site. Absolute dating of the pine remnants was accomplished by cross-dating with a ring-width chronology based on live shortleaf pine growing in Shannon County, Missouri (on record at the International Tree-ring Data Bank, Boulder, Colorado) within the study area and a previously published dated shortleaf pine ring-width series (DeWitt and Ames 1978).

Fire frequency was calculated by site and individual tree locations. Not all trees are scarred in a fire because of the great variation in fuels and bark thickness. Thus, several trees at a site are combined to give a better estimate of fire frequency at a site. On the average it takes about four trees to get a record of most of the fires at a site. This is consistent with Paulsell's (1957) finding that about 25% of the trees at a site were scarred in fires.

Fire intervals for individual trees were also compiled. These fire intervals are not affected by the size of the site considered, or the patchiness of burning in low intensity ground fires within a site. Though these types of data underestimate the actual fire frequency at a site, they are of value as a good estimator of fire frequency and intensity at point locations. Shortleaf pines are good recorders of fires. This is only true, however, for trees which already have scarfaces. Fires of greater intensity or duration are necessary to cause the initial cambial injury through the thick bark (Cole and others 1992, Gill 1973). This scarring pattern (an initial scar followed by multiple scars) biases the recording of fires by individual trees. To avoid this bias in estimating fire frequency at point locations only the period of record after the first scar was used in calculating fire frequency for individual sites.

### Population Data

Shannon County population data were taken from census data and population estimates in Stevens (1991) and Rafferty (1982) dating back to 1820. Historic Native American population density was estimated from Banks (1978), Stevens (1991), and Gilbert (1996). Shannon County data were used to estimate the change in population density through time in the watershed. Linear interpolation was used to estimate annual population from decadal census data.

Proxy population data were used to relate spatial population differences in the Current River Watershed to differences in fire frequency. These proxy data include the distribution of proto-historic projectile points (Price and Price 1986, Price and others 1983), the distribution of archeological sites (Lynott 1989), and the present day distribution of towns in the Current River watershed.

### Dendrochemical Analysis

Eastern redcedar is an excellent species for dendrochemical analysis of growth increments because the effects of radial translocation of elements within the heartwood are minimal owing to the wood's low moisture content and anatomy (Cutter and Guyette 1993; Guyette and others 1989, 1991). The soils and exposures of the micro-sites on which these trees grow make them particularly sensitive to changes in the availability of mineral elements (Guyette 1994).

Heartwood Al, Ca, soil extractable Ca, and soil pH were measured for 13 eastern redcedar trees and tree sites. These sites are all in the Current River Watershed and overlap, but are not all on fire history sites. Soil sampling and dendrochemical analyses, as well as chronology construction, are described in previous papers (Guyette and others 1989, 1991, 1992a, 1992b; Guyette and McGinnes 1987; Guyette and Cutter 1995).

## RESULTS AND DISCUSSION

### Fire Frequency Among Study Sites

Fire frequency was documented at 23 sites in the Current River Watershed (Table 2). The mean fire-free interval (MFI) was determined for three time periods: 1580-1700, 1701-1820, and 1821-1940. These periods coincide with a de-populated era with few Native Americans, an era of re-population by Native Americans, and Euro-American settlement of the region. In general, the average MFI decreased with time: 1580-1700, 17.7 years; 1701-1820, 12.4 years; and 1821-1940, 3.7 years. Fire frequency was more variable (Table 3) among and within sites during the period of Native American re-population (1701-1820). The range of MFI's is larger for the earlier periods (2.7 to 30 years or more, Table 2) than for the period of Euro-American settlement (1.8 to 8 years). Standard deviations among sites also increase through time. Together this indicates a transition from a spatially variable Native American fire regime to a less variable fire regime after Euro-American settlement. No significant differences were found in the fire frequency of sites on rhyolite versus dolomitic limestone. Effective fire suppression by agencies such as the Missouri Department of Conservation began after 1940 and reduced the percent of sites burned annually from about 21% in 1940 to less than 1% in the 1990's. Chronologies of the percentages of all the trees and sites that were fire scarred in the Current River watershed are illustrated in Figure 2. Some of the years with many scarred sites and trees in the 1600's and 1700's are given.

Table 2. Mean fire free intervals by site and historic period

| Site name | Code | 1821-1940 | | 1701-1820 | | 1581-1700 | |
|---|---|---|---|---|---|---|---|
| | | mean | range | mean | range | mean | range |
| Barn Hollow Natural Area | BRN | 3.8 | (1-9) | 10.0 | (2-36) | . | . |
| Rymers Ranch, NPS | RYM | 5.1 | (1-17) | . | . | . | . |
| Manhans, Rocky Cr. S.F. | MAH | 4.1 | (1-8) | 2.8 | (1-12) | 9.7 | (1-19) |
| Mill Creek | MCR | 3.8 | (1-11) | 3.9 | (1-9) | 7.8 | (1-19) |
| Paint Rock S. F. | PTR | 2.6 | (1-9) | 9.2 | (1-36) | . | . |
| Stegall Mountain, Peck Ranch | STG | 5.0 | (1-10) | 5.0 | (2-12) | 5.9 | (2-11) |
| Denning Hollow Glade | DHG | 2.4 | (1-7) | 7.1 | (1-24) | 30.0 | (6-35) |
| Mill Mountain, Rocky Cr. S.F. | MMT | 2.0 | (1-6) | 8.8 | (1-48) | . | . |
| Rough Hollow, NPS | RGH | 4.2 | (1-8) | 13.3 | (2-57) | 30.0 | (10-73) |
| Spring Valley, Alley Sp. S.F. | SPV | . | . | 13.0 | (8-20) | 20.6 | (11-46 |
| Jerktail Mountain | JRT | 1.9 | (1-4) | 10.9 | (3-21) | . | . |
| Blue Spr., Carr Cr.S.F | BSS | 1.8 | (1-7) | 4.3 | (1-12) | >37 | (.) |
| Deer Run S. F. | DRN | 1.8 | (1-7) | 2.7 | (1-8) | 12.0 | (1-60) |
| Bloom Creek S. F. | BLM | 3.5 | (1-25) | 12.0 | (1-25) | . | . |
| Mill Hollow, Pioneer Forest | MLH | 1.7 | (1-3) | 5.5 | (1-19) | . | . |
| Big Creek | BIG | 2.6 | (1-9) | 6.3 | (1-34) | 18.6 | (8-15) |
| Shannondale S. F. | SDF | 3.5 | (1-13) | 13.3 | (1-21) | . | . |
| Boyds Cr., MO. S. F. | BYD | 4.8 | (1-21) | 20.0 | (2-30) | . | . |
| Hartshorn S. F. | HRH | 2.2 | (1-6) | 5.7 | (1-15) | 7.1 | (1-17) |
| Welch Spring | WLH | 7.4 | (1-33) | 16.2 | (1-55) | . | . |
| Gladden Cr., Cedar Grove S.F. | GLD | 3.7 | (1-20) | >45.0 | (.) | . | . |
| Bay Hollow, NPS | BAY | 8.0 | (1-20) | >50.0 | (.) | . | . |
| Baptist Access, NPS | BAP | 6.3 | (1-15) | 8.8 | (1-47) | . | . |

*Note: Open intervals at the beginning of 3 chronologies with <4 trees during the period are given an interval equal to half of the open-ended time series. Other evidence at these sites, such as live old trees without scars, indicates these sites were not burned often.

S.F. indicates State Forest; N.F., National Forest; NPS, National Park Service

Table 3. Site, fire, and chronology means by historic period and bedrock substrate. Years of record is the sum of the dated rings on all samples. The MFI's of the early periods (1581-1700,1701-1820) are not significantly ($p<0.05$) different from each other but are significantly ($p<0.01$) different than the later period (1821-1940). Different super scripts denote significant differences in MFI's. Rhyolite sites were not significantly different from dolomite sites.

| Period | 1581-1700 | 1701-1820 | 1821-1940 |
|---|---|---|---|
| Number of sites | 11 | 21 | 22 |
| Number of trees | | | |
| (maximum) | 47 | 143 | 148 |
| (minimum) | 4 | 47 | 21 |
| Years of record | 2,254 | 11,167 | 12,616 |
| MFI all sites | 17.7[b] | 12.4[b] | 3.7[a] |
| standard deviation | 10.1 | 11.9 | 2.1 |
| coefficient of variation | 0.57 | 0.96 | 0.57 |
| MFI of rhyolite sites | 18.0 | 7.9 | 2.8 |
| # of sites | 2 | 4 | 4 |
| standard deviation | 17 | 2.5 | 1.4 |
| MFI of dolomite sites | 19.3 | 4.3 | 2.4 |
| # of sites | 4 | 5 | 5 |
| standard deviation | 12.4 | 5.9 | 0.5 |

Scar Intervals on Individual Trees

The distribution of fire-free intervals from single trees (100 to 300 years in age) approximates a skewed normal curve (Figure 3). The most frequent fire intervals at point locations (single-tree site) changed from 4 years between 1580 and 1820 to 2 years between 1821 and 1940. Fifty percent of the fire intervals were below 5.8 years before 1820, while after 1820, 50% were below 4.8 years. This may indicate that fuel-constrained fire intensity limits the scarring frequency of individual trees, since mean fire interval (compiled from many trees) for the associated sites decreased by about 9 years. It is also evident from Figure 2 that the percent of trees scarred annually does not increase as much as the percentage of sites scarred annually. This is an indication that lower amounts of fuels owing to frequent burning are reducing the scarring of individual trees. Fires were more frequent after Euro-American settlement in the 1 to 11 year class and less frequent in the 12 to 50 year class. Figure 3 illustrates the difference (early minus late period) between the percentages of fire intervals on individual trees before and after 1820.

Fire Frequency From Sentinel Pines

A method for estimating the number of fires and changes in fire frequency in a small watershed is the use of "sentinel pines." These are individual shortleaf pines which have a special landscape position relative to fire dynamics. Sentinel pines grow in lose gravel with very little local ground fuel. Despite the lack of ground fuel they have large multiple scars on the uphill side. They grow on the upper slopes of both cherty-dolomite and rhyolite substrate. Long slopes of 15 to 33 degrees with 60 to 240 m of relief typically lie below sentinel pine sites. This landscape position makes these trees good recorders for most of the fires which burn in a small watershed. Pre-heating, turbulence on the lee (uphill side) of the trunk, slope-fire generated winds, and flame length at the top of the

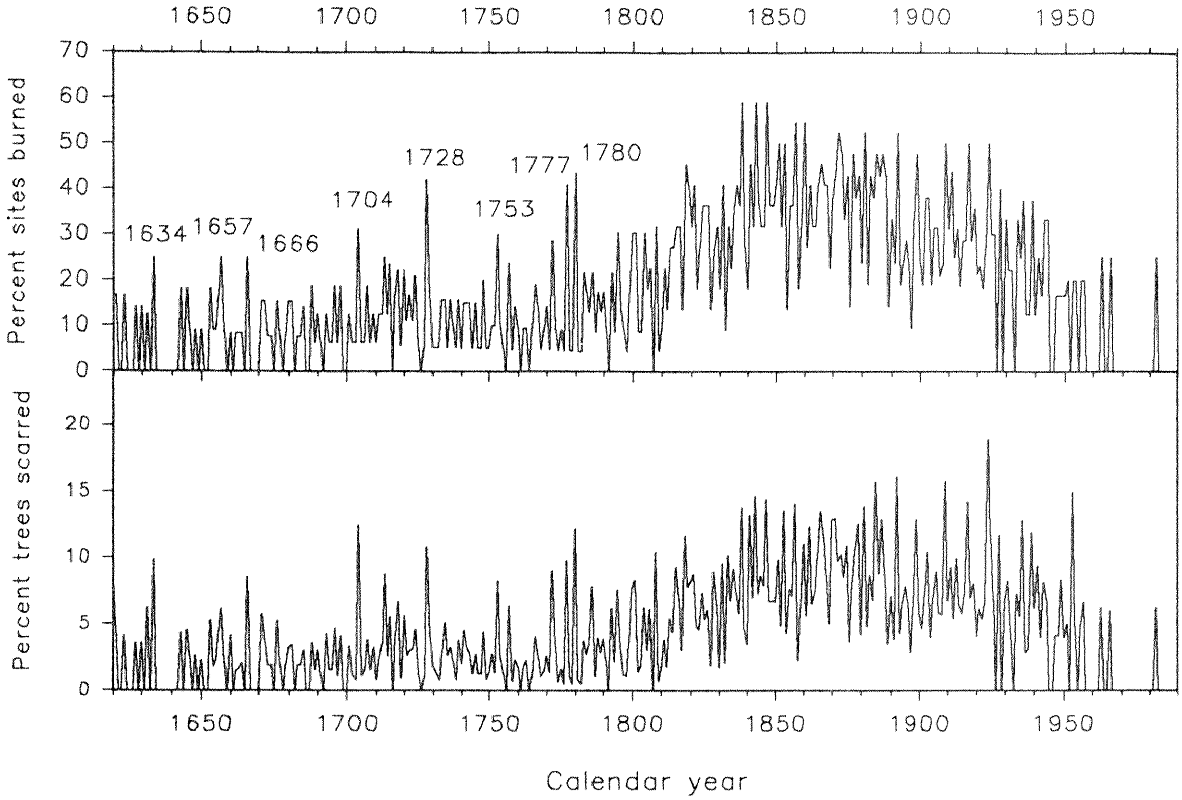


Figure 2. The percentage of trees and sites with fire scars in the Current River watershed. Calendar dates of the years with high percentages of fire scars in the 1600's and 1700's are given.

slope make initial scarring of this thick barked species likely in these locations. These trees are also particularly sensitive to scarring by later fires because of their slow growth and slow healing of wounds. Slow growth, high oleoresin content, high xylem density, and a dry micro-climate, contribute to the preservation of these pine remnants. Because of their landscape position, sentinel pines are excellent recorders of the occurrence of fire in small watersheds. Table 4 gives some basic data on a number of sentinel pines in the Current River Watershed. The mean fire free interval for this group of sentinel pines is 7.0 years for the period (1709-1877). Note that this fire interval, derived from only the 12 trees in Table 4, yields a MFI of 7.0 years that is very close to the average MFI (8.0 years) for the two periods with over 150 trees (1701-1820, 1821-1920; Table 3).

Population

The fire history of the Current River watershed reveals some widespread tenets about this anthropogenic fire regime. Changes in fire frequency coincide with changes in human populations and culture (Figure 4). Human population is the most important factor affecting fire ignition in much of the central hardwoods region of eastern North America where lightning fires play a minor role in ignitions (Schroeder and Buck 1970).

Old-stock Euro-Americans from the southeastern U.S., mainly Tennessee, began settling in the area circa 1820 (Gerlach 1986). Later, circa 1860, Scotch-Irish immigrated into the area. Fire frequency and the percent of sites burned increased with population density in the Current River Watershed during the 1810-1850 period. Fire frequency is positively correlated ($r = 0.87$, $p < 0.05$) with population at the low population densities (< 0.64 people per km$^2$) of this period. The average percent of sites burned in a year increased from 20% in 1810 to 39% in 1850.

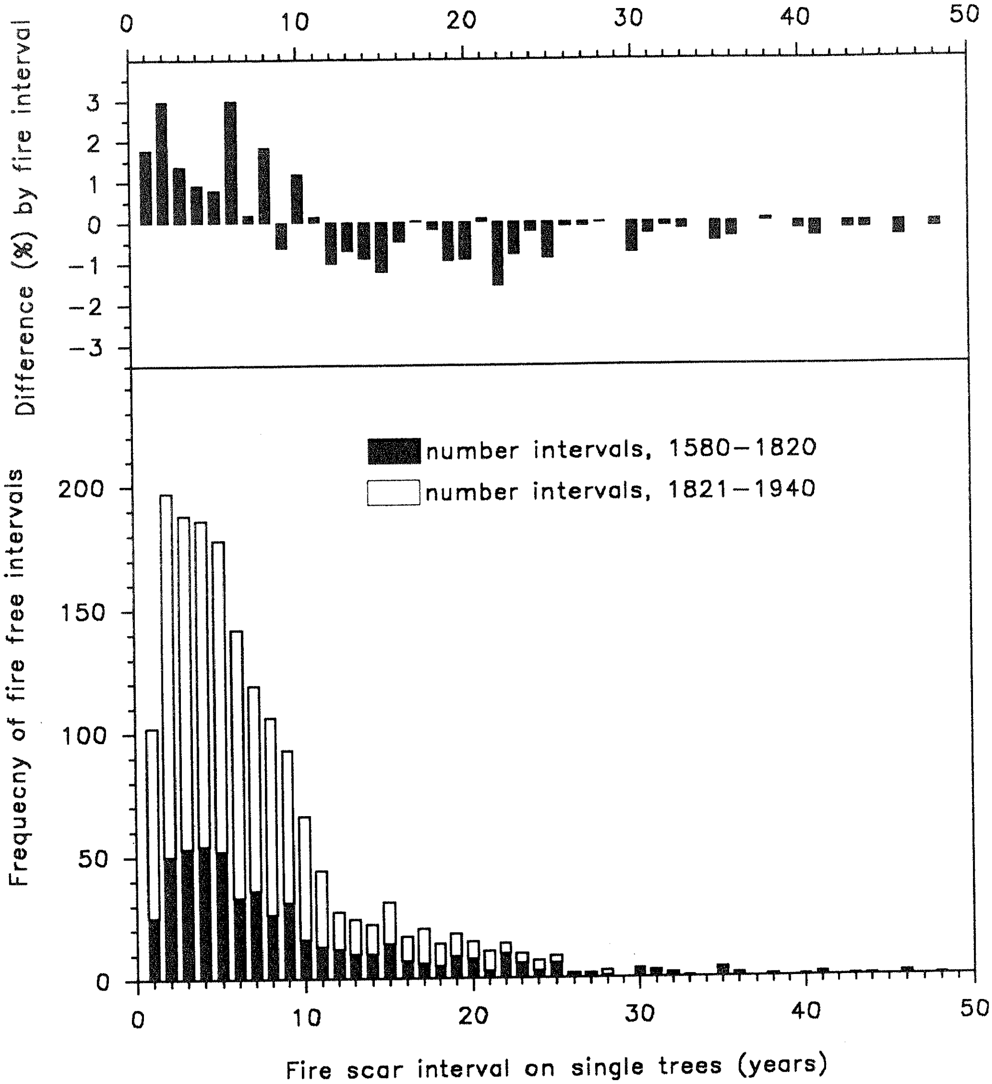


Figure 3. A frequency distribution (lower graph) of the number of fire free intervals (years between scars) on individual trees. The difference of distributions (upper graph) is the difference between there normalized distributions (1580-1820 %MFI's minus 1821-1940 %MFI's). Note the general shift in the difference of the distributions to shorter intervals (<10 years).

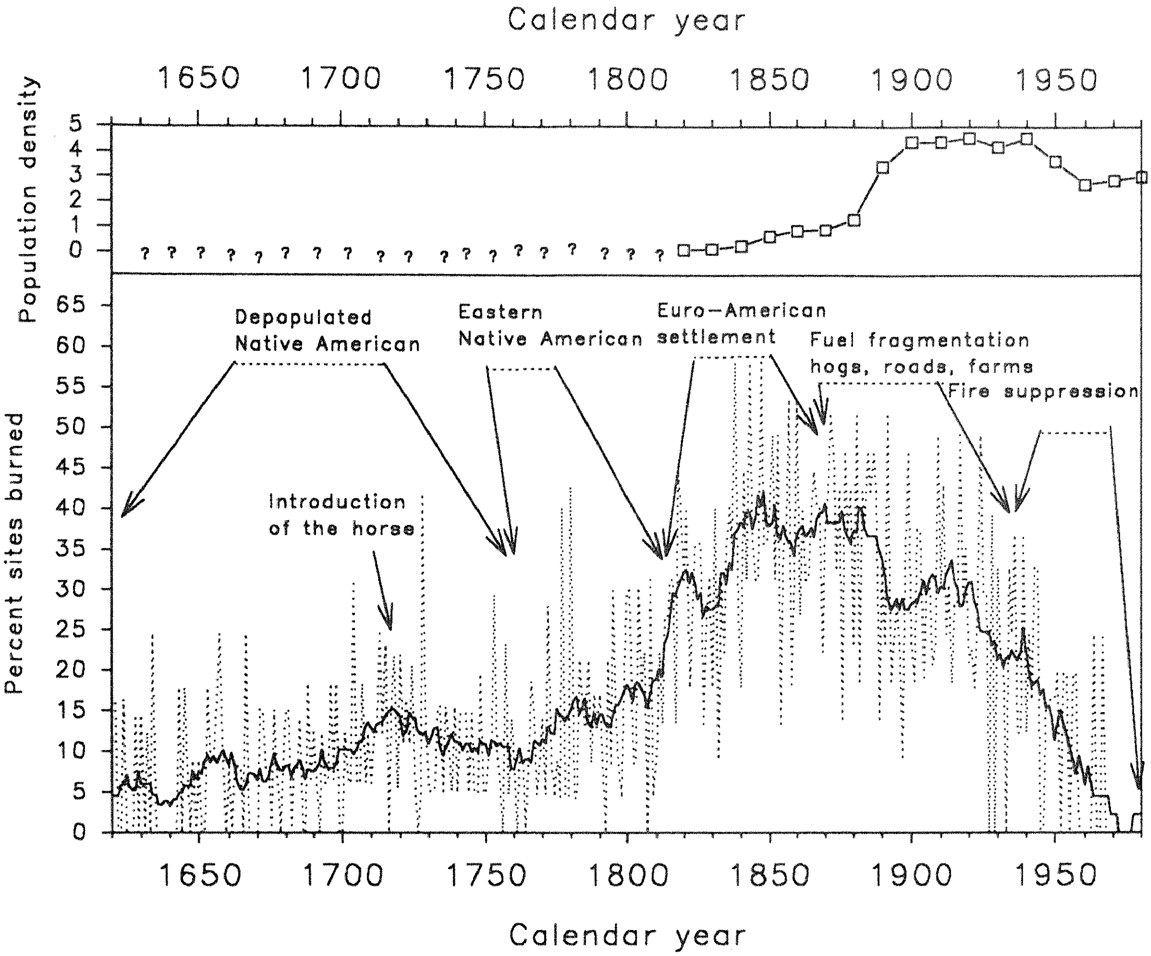


Figure 4. Historic changes in human populations (people per km²) and culture compared to the percentage of sites burned. The dotted line is the sites burned annually (%) while the solid line is an 11 year moving average of the sites burned.

Table 4. Comparison of fire scars on sentinel shortleaf pines from different sites in the Current River Watershed. Sentinel pines are shortleaf pine which occupy sites high on the landscape, with steep slopes, with long distances to the bottom of slopes, and low quantities of local ground fuels. Records are from one tree per site.

| Site | # Scars | Period | Recurrence interval (yrs) |
|---|---|---|---|
| Mill Creek (Middle Current River) | 43 | 1631-1871 | 5.6 |
| Deer Run (Deer Run S. F.) | 20 | 1711-1847 | 6.8 |
| Paint Rock (Paint Rock S. F.) | 25 | 1675-1899 | 9.0 |
| Mahans Creek (Jacks Fork, Rocky Creek S. F.) | 34 | 1748-1870 | 3.6 |
| Stegall Mountain (Peck Ranch, NPS) | 8 | 1645-1695 | 6.3 |
| Mill Hollow (Pioneer Forest) | 26 | 1719-1897 | 6.8 |
| Blue Spring (Carrs Creek S. F.) | 27 | 1747-1887 | 5.2 |
| Mill Mountain (Rocky Creek S. F., NPS) | 25 | 1702-1831 | 5.2 |
| Denning Hollow Glade (Rocky Creek S.F.) | 18 | 1715-1898 | 9.7 |
| Jerktail Mountain (Pioneer Forest) | 29 | 1708-1911 | 7.0 |
| Nordic Hollow (Peck Ranch) | 17 | 1720-1856 | 8.0 |
| Huckleberry Hollow (Cardareva S. F.) | 23 | 1659-1911 | 11 |

At higher population densities (>0.64 people per km$^2$), fire frequency and the percent of sites burned stops increasing with population and begins to decrease. This decrease in the percent of sites burned coincided with increasing population density between 1850 and 1940. A peak in population density (about 4.6 people per km$^2$) was reached in the 1920's. Causal factors for this decline in fire frequency may relate to grazing, fuel trampling by hogs, open range for live stock, roads, some fire suppression, vegetation change, and land clearing.

Population in the Current River watershed has varied greatly over the last thousand years. People of Mississippian Culture populated the rich fertile bottom lands of the Current and Jacks Fork River about 1000 A.D (Lynott 1989, Price and others 1983). These agricultural communities may have supported a relatively large population. Burning for land clearing, defense, game and vegetation management, probably made this a period of high fire frequency. By 1350 these people and their culture left the Current River Watershed.

The end of the Mississippian phase marked the beginning of a long and major de-population of the watershed. De-population caused by disease, warfare, and migration occurred throughout much of North America (DeVivo 1991) and is often linked with changes in fire history (Guyette and Dey 1995, Dey and Guyette 1996). This de-populated era is documented by a decline in the Mississippian substage during which there is only sparse evidence of proto-historic aboriginal people (Price and others 1976). The chronicle of Desoto's exploration in Arkansas mentions that "the only people to the north are those who carry their houses on their backs." During historic times, the Osage traveled from the west to hunt in the Current River watershed (Banks 1978) and the Quapaw lived to the southeast in Arkansas (Chapman 1964, O'Brien 1996).

One remarkable aspect of the early fire record during the de-populated era is that a small human population can maintain a fire regime where about 10 to 15% of the sites are burned annually. Although there are no population estimates of Native Americans in the Current River Watershed before 1820, the 1820's the population density was probably less than 0.10 persons per $km^2$ and much less before the eastern migration of Euro-Americans and Native Americans. In 1820 about 30% of the sites were burning annually. Thus, some very small population (< 0.05 people per $km^2$), whether transient or resident, maintained a fire regime where 10 to 15% of the study sites burned annually. This ratio of population to burning is even more remarkable considering the highly dissected terrain of the Current River Watershed which does not favor for the rapid spread of fire.

Native Americans began migrating back into the Current River watershed in the late 1700's as they were pushed from their eastern lands by Euro-Americans. A general increase in the percentage of sites burned annually in the watershed occurred from 1760 (9%) to 1820 (30%) coincident with the migration of the Cherokee (Gilbert 1996), Delaware, and Shawnee from Eastern North America (Stevens 1991). The Delaware had a history of wildland fire use before arriving in Missouri (Whitney 1994). A 5% increase in the percent of sites burned that occurred circa 1720 is coincident with the acquisition of the horse by the Osage (Waldman 1985).

Artifacts such as willow leaf projectile points, found predominately in the lower reaches of the Current River, indicate some limited use of the area until the late 1700's (Price and others 1986) and a connection to an Armorel cultural phase in northern Arkansas. Although the fire frequency during the earlier part of the de-populated period is generally lower than during later periods it is still much greater than might be expected from lightning ignitions (Schroeder and Buck 1970). Seasonal hunting trips in the Current River watershed by peoples from downstream reaches of the river system may have been an ignition source. The mean fire free intervals for each of the 23 sites during two periods (1701-1820, 1821-1940) is positively correlated (1701-1820, $r = 0.54$; 1821-1940, $r = 0.58$) with the upstream distance of the sites. Less frequent fires in the upper parts of the watershed suggest that these areas were less frequented by humans. Many archeological and historic Native American sites are located in the larger and more fertile bottom lands in the downstream reaches of the Current River (Stevens 1991). Quapaw lived south east of the watershed (Chapman 1964). Also, the Mississippian cultural phase persisted in the southeast Ozark border area until as late as 1700 (Price and others 1976). Even today the lower reaches of the Current River have larger towns than the upper sections. The mean fire free intervals among time periods (1701-1820 and 1821-1940) are significantly correlated (0.54, $p = 0.01$) indicating some continuity in fire frequency through time. Perhaps fertile soils attract more game, hunters, gatherers, and agriculturalist or are correlated with landscape level fire dynamics. All factors that persist to some extent through time. Alternatively, landform gradients within the watershed, such as topographic roughness, may effect the spread and frequency of fire.

## Calcium Cycling and Fire Frequency

Parallel trends in the fire frequency of the Current River watershed and heartwood Ca concentrations from three low Ca sites in the watershed were found in the 340 years of common record (Figure 5). The Ca chronology of dated redcedar heartwood increments is highly correlated (Table 5) with the 20 year grouped means of the percent of sites scarred ($r = 0.81$, $p<0.05$) and trees scarred ($r = 0.77$, $p<0.05$). In contrast, aluminum concentrations in heartwood redcedar were negatively correlated (Figure 6) with both the percent of sites scarred ($r = -0.65$, $p<0.05$) and trees scarred ($r = -0.70$, $p<0.05$). Calcium and Al concentrations, however, were not significantly correlated ($r = -0.36$, $p=0.19$) in dated heartwood growth increments.

Table 5. Correlation coefficients among concentrations of elements in eastern redcedar heartwood and estimates of the frequency and extent of fire in the Current River watershed

| Elements | Sites burned (%) | Trees scarred (%) |
|---|---|---|
| Ca (ug/g) | 0.81* | 0.77* |
| Al (ug/g) | -0.65* | -0.70* |
| Ca/Al | 0.75* | 0.79* |

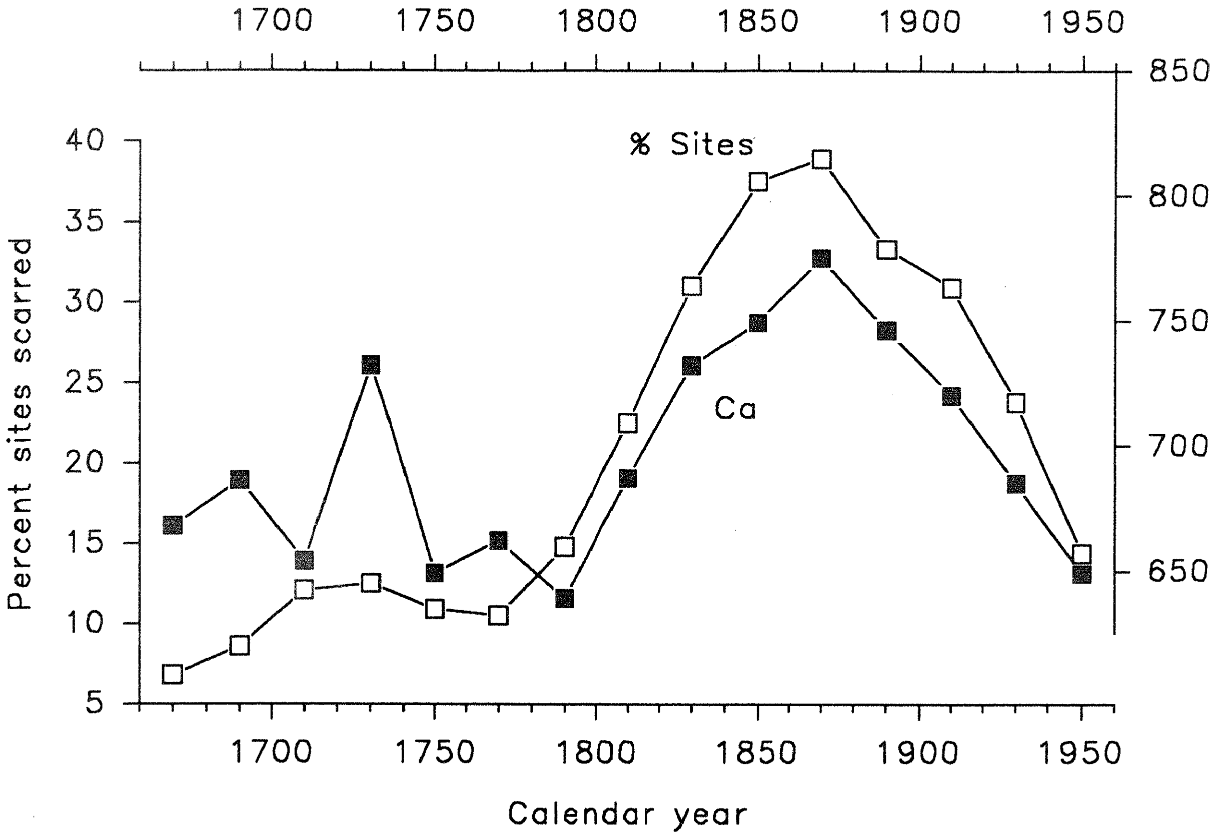


Figure 5. A Ca chronology derived from heartwood increments of 13 redcedar trees compared with the percentage of sites scarred. Annual percentages of sites scarred are grouped and averaged by 20 year periods.

The long-term effects of changes in the frequency of low intensity fires on the Ca availability of soils are not known. The three sites from which Ca chronologies of eastern redcedar were derived have low levels (Table 1) of exchangeable soil Ca (Guyette and others 1992a). Soils from dolomite and limestone sites have from 5 to 8 times the available Ca. These sites, with shallow soils over rhyolite, are an excellent place to examine the long-term effects of changes in fire frequency on Ca cycling because where Ca is scarce its availability is likely to be a factor influencing its concentration in growth increments. Calcium deficiency has been linked to water relations and drought in a number of studies (Lazaroff and Pitman 1966, Tibbitts 1979, Vigouroux and others 1989). Control of Ca uptake in plants via the transpiration stream can result in Ca deficiency. Some redcedar growing at these sites show signs of drought-induced Ca deficiency, such as apical dieback and low sapwood Ca concentrations (Guyette 1994).

Many studies have indicated that Ca is more available to plants after fires. Decomposition of organic matter by fire is both rapid and abiotic. The rate of decomposition by fire is almost instantaneous compared to the rate of decay by biological decomposers. Calcium and other base cations in plant matter are released to ash and leached to mineral soil after fires (Alban 1977) and tend to increase the pH and the concentration of exchangeable Ca (Chandler and others 1983). DeBano and others (1977) found increases in surface soil Ca of 136 kg/ha after a prescribed burn in chaparral. Soil pH is also generally higher in chaparral soils after burning (Vogl and Schorr 1972). Gilliam (1991) found increased Ca availability and an increase in soil pH in the upper 5 cm and 10 cm of soil after a winter burn in an oligotrophic Coastal plain pine flatwoods. Calcium content of the herbaceous layer increased from 2.2 to 5.0 kg/ha. Groesch and co-workers (1991) found increases in soil pH following prescribed burns in Virginia mixed pine forests. Zinke (1991) reviewed the effects of fire on mineral cycling and concluded that Ca and soil pH increase after burns.

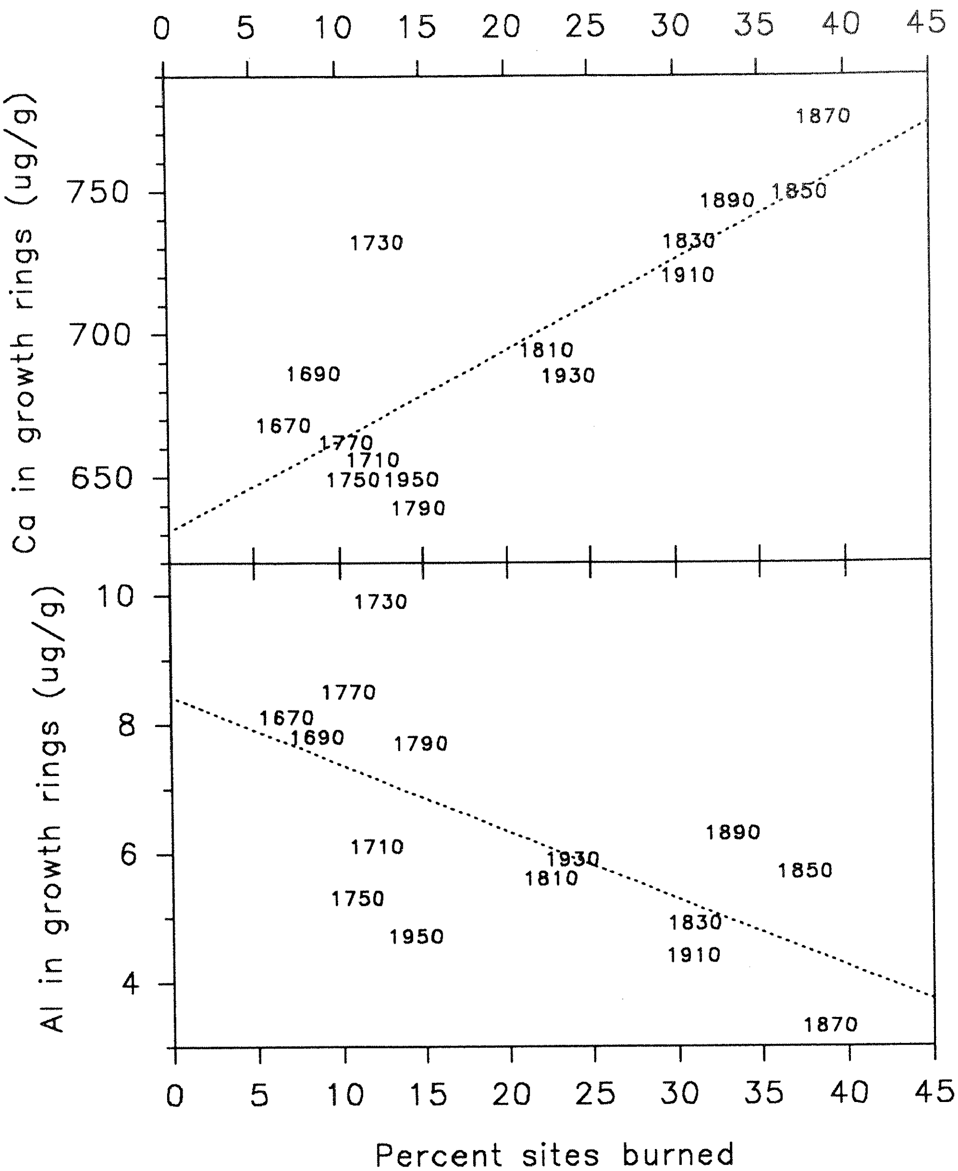


Figure 6. Scatter plots of heartwood element concentrations versus the percentages of sites burned are plotted by date of occurrence. Regression lines are shown.

Guyette and others (1992b) found only an insignificant increase (0.2 units) in a soil pH reconstruction for these sites during the period of high fire frequency (1830-1940). At these sites the acid (mean pH = 4.16) and Al- buffered soils, along with the rapid uptake of scarce soil Ca, may mitigate the effects of the increased rate of Ca cycling on soil pH.

Decreasing Ca cycling owing to reduced fire frequency, coupled with acid precipitation, may limit the availability of Ca in the future on rhyolite knobs in the Ozarks. With more Ca tied up for longer periods in vegetation, plants on these low Ca sites could be more susceptible to drought-induced Ca deficiency in future decades.

## CONCLUSIONS

Fire histories from 23 oak-shortleaf pine sites in the upper Current River watershed of the Missouri Ozarks were reconstructed using dendrochronological methods. Some 2,004 fire scars from 150 shortleaf pine sections were dated to construct fire scar chronologies dating back to 1580. Archeological historical evidence and fire chronologies indicate that the region has gone through three distinct anthropogenic fire regimes during this time. The first, the period from 1580 to 1700, is considered the de-populated period. From 1701 to 1820, Native American tribes settled in the area and used the lands on a continual basis. The final period is from 1821 to 1940 and coincides with Euro-American settlement of the region. Since ca. 1940, effective fire suppression has greatly reduced the scope and intensity of wildfire in this area.

The average mean fire free intervals (MFI) calculated for all sites by time period are: the de-populated period, 1580-1700, MFI=17.7 years; the Native American re-population period, 1701-1820, MFI=12.4 years; and the Euro-American settlement period, 1821-1940, MFI=3.7 years. Fire frequency was more variable within and among sites during the 1701-1820 period. At low population densities (< 0.64 people per $km^2$), fire frequency was correlated ($r = 0.87$, $p<0.05$) with the population and settlement of Euro-Americans. At higher population densities (>4.6 people per $km^2$) fire frequency was negatively correlated ($r=-0.40$, $p<0.01$) with population.

The long-term effects of an anthropogenic fire regime on calcium availability are inferred from Ca concentrations in tree-rings. Calcium concentrations in dated heartwood increments of eastern redcedar (*Juniperus virginiana* L.) are correlated ($r = 0.82$, $p<0.05$) over 340 years with changes in the frequency of anthropogenic fire. Trends in Al concentrations in redcedar heartwood are negatively correlated with fire frequency ($r = -0.70$, $p<0.05$)

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## LITERATURE CITED

Alban, D.H. 1977. Influence on soil properties of prescribed burning under mature red pine. USDA Forest Service Res. Pap. NC-139.

Arno, S.F. and K.M. Sneck. 1977. A method for determining fire history in coniferous forests of the Mountain West. USDA Forest Service Gen. Tech. Rep. INT-142.

Baldwin, J.L. 1973. Climates of the United States. U.S. Department of Commerce, NOAA, Envir. Data Service, Washington, DC. 113 p.

Banks, A. 1978. Indians of the Upper Current River. Alan Banks. Eminence, Missouri. 87 p.

Chapman, C.H. and E.F. Chapman. 1964. Indians and Archaeology of Missouri. University of Missouri Press. Columbia, MO. 161 p.

Chandler, C., P. Cheney, P. Thomas, L. Traband, and D. Williams. 1983. Fire in forestry. Vol. I: Forest fire behavior and effects. Wiley-Interscience. New York. 450 p.

Cole, K.L., K.F. Flick, and N.B. Pavlovic. 1992. Fire temperature monitoring during experimental burns at Indiana Dunes National Lakeshore. Nat. Areas J. 12: 177-183.

Cunningham, R.J. and C. Hauser. 1989. The decline of the Ozark Forest between 1880 and 1920. In (T.A. Waldrop, ed.) Proceedings of pine-hardwood mixtures: a symposium on the management and ecology of the type. Atlanta, GA, p. 34-37.

Cutter, B.E. and R.P. Guyette. 1993. Factors affecting species choice for dendrochemistry studies. J. Environ. Qual. 22: 611-619.

Cutter, B.E. and R.P. Guyette. 1994. Fire frequency on an oak-hickory ridgetop in Missouri. Am. Midl. Nat. 132: 393-398.

DeBano, L.F., P.H. Dunn, and C.E. Conrad. 1977. Fire's effect on physical and chemical properties of chaparral soils. In Proceedings of the symposium on the environmental consequences of fire and fuel management in Mediterranean ecosystems. USDA Forest Service Gen. Tech. Rep. WO-3. p. 65-74.

Dey, D.C. and R.P. Guyette. 1996. Fire history near an historic travel corridor in Ontario. Ontario Forest Research Institute For. Res. Rep. 140. Sault Ste Marie, Ontario. 9 p.

Dey, D.C. and R.P. Guyette. 1996. Early fire history near Papineau Lake, Ontario. Ontario Forest Research Institute For. Res. Note 54. Sault Ste Marie, Ontario. 4 p.

DeVivo, M.S. 1991. Indian use of fire and land clearance in the Southern Appalachians. In Fire and the environment, ecological and cultural perspectives. USDA Forest Service Gen. Tech. Rep. SE-69. p. 306-310.

DeWitt, E. and M. Ames. 1978. Tree-ring chronologies of eastern North America. Chronology Series IV, Volume I. Laboratory of Tree-Ring Research, University of Arizona, Tucson, AZ. 42 p.

Fletcher, P.W. and R.E. McDermott. 1957. Influence of geologic parent material and climate on distribution of shortleaf pine in Missouri. University of Missouri Agricultural Experiment Station Res. Bull. 625. 43 p.

Gerlach, R.L. 1986. Settlement Patterns in Missouri. University of Missouri Press. Columbia, MO. 88 p.

Gill, A.M. 1974. Toward an understanding of fire-scar formation: Field observation and laboratory simulation. For. Sci. 20: 198-205.

Gilliam, F.S. 1991. The significance of fire in an oligotrophic forest ecosystem. In Fire and the environment, ecological and cultural perspectives. USDA Forest Service Gen. Tech. Rep. SE-69. p. 113-122.

Groesch, D.A., J.E. Johnson, and D.Wm. Smith. 1991. Forest soil characteristics following wildfire in the Shenandoah National Park, Virginia. In Fire and the environment, ecological and cultural perspectives. USDA Forest Service Gen. Tech. Rep. SE-69. p. 129-137.

Gilbert, J. 1996. The trail of tears across Missouri. University of Missouri Press, Columbia, MO. 122 p.

Guyette, R.P. 1994. A dendrochemical perspective on the effects of climate change in the Ozark Highlands. In (M. Beniston, ed.) Mountain environments in changing climates. Routledge Pub. Co., London. p. 259-269.

Guyette, R.P. and B.E. Cutter. 1991. Tree-ring analysis of fire history of a post oak savanna in the Missouri Ozarks. Nat. Areas J. 11: 93-99.

Guyette, R.P. and B.E. Cutter. 1994. Barium and manganese trends in tree-rings as monitors of sulfate deposition. J. Water, Air, and Soil Pollut. 73: 213-223.

Guyette, R.P. and B.E. Cutter. 1995. Water-use efficiency as monitored by dendrochemistry. In (T.E. Lewis, ed.) Tree rings as indicators of ecosystem health. CRC Press, Boca Raton, FL. p. 95-122.

Guyette, R.P. and D.C. Dey. 1995. A dendrochronlogical fire history of Opeongo Lookout in Algonquin Park, Ontario. Ontario Forest Research Institute For. Res. Rep. 134. Sault Ste. Marie, Ontario. 4 p.

Guyette, R.P. and E.A. McGinnes, Jr. 1982. Fire history of an Ozark glade in Missouri. Trans. Missouri Acad. Sci. 16:85-93.

Guyette, R.P., E.A. McGinnes, Jr., G.E. Probasco, and K.E. Evans. 1980. A climate history of Boone County, Missouri, from tree-ring analysis of eastern redcedar. Wood and Fiber 12: 17-29.

Guyette, R.P., B.E. Cutter, and G.S. Henderson. 1989. Long-term changes in molybdenum and sulfur concentrations in redcedar tree-rings. J. Environ. Qual. 18: 385-389.

Guyette, R.P., B.E. Cutter, and G.S. Henderson. 1991. Long-term correlations between mining activity and levels of lead and cadmium in tree-rings of redcedar. J. Environ. Qual. 20: 146-150.

Guyette, R.P., B.E. Cutter, and G.S. Henderson. 1992a. Inorganic concentrations in the wood of eastern redcedar grown on different sites. Wood and Fiber Sci. 24: 133-140.

Guyette, R.P., B.E. Cutter, and G.S. Henderson. 1992b. Reconstructing soil pH from manganese concentrations in tree-rings. For. Sci. 38: 727-737.

Hengst, G.E. and J.O. Dawson. 1994. Bark properties and fire resistance of selected tree species from the central hardwood region of North America. Can. J. For. Res. 24: 688-696.

Holmes, R.L., H.K. Adams, and H. Fritts. 1986. Quality control crossdating and measuring. Laboratory of Tree-Ring Research, University of Arizona, Tucson, AZ.

Lazaroff, N. and M.G. Pitman. 1966. Calcium and magnesium uptake by barley seedlings. Aust. J. Biol. Sci. 19: 880-888.

Lowery, R.F. 1968. The effect of initial stem temperature on time required to kill cambium of shortleaf pine. M.S. Thesis, University of Missouri, Columbia, MO. 52 p.

Lynott, M.J. 1989. An archeological evaluation of the Gooseneck and Owls Bend Sites: Ozark National Scenic Riverways, Southeast Missouri. U.S. Department of the Interior. National Park Service, Midwest Archeological Center.

O'Brien, M.J. 1996.The story of Missouri archaeology. University of Missouri Press. Columbia, MO. 561 p.

Paulsell, L.K. 1957. Effects of burning on Ozark hardwood timberlands. University of Missouri Agricultural Experiment Station Res. Bull. 640. 24 p.

Price, J.E. and C.R. Price. 1986. Archaeological Investigations in the Ozark National Scenic Riverways, Project No. CAR-640. Archaeological Survey of Missouri. Columbia, MO.

Price, J.E., C.R. Price, and S.E. Harris. 1976. An Assessment of the Cultural Resources of the Fourche Creek Watershed. University of Missouri, Southeast Missouri Archaeological Research Facility.

Price, J.E., C.R. Price, R. Saucier, and T. Petula. 1983. Archeological Investigations in the Ozark National Scenic Riverways, 1981-1982. Midwest Archeological Center, Lincoln, NE.

Pyne, S.J. 1982. Fire in America. Princeton University Press. Princeton, NJ. 654 p.

Pyne, S.J., P.L. Andrew, and R.D. Laven. 1996. Introduction to Wildland Fire. Wiley-Interscience, New York. 769 p.

Rafferty, M.D. 1980. The Ozarks land and life. University of Oklahoma Press, Norman, OK, 282 p.

Schoolcraft, H.R. 1821. Journal of a tour into the interior of Missouri and Arkansaw [sic]....performed in the year 1818 and 1819. Richard Phillips and Co. London.

Schroeder, M.J. and C.C. Buck. 1970. Fire weather. USDA Forest Service Agric. Handb. 360. 288 p.

Scowcroft, P.G. 1965. The effects of fire on the hardwood forests of the Missouri Ozarks. M.S. Thesis. University of Missouri, Columbia, MO. 126 p.

Spalt, K.W. and W.E. Reifsnyder. 1962. Bark characteristics and fire resistance: a literature survey. USDA Forest Service Occas. Pap. 193. Southern Forest Experiment Station, New Orleans, LA.

Stevens, D.L., Jr. 1991. A homeland and a hinterland the Current and Jacks Fork Riverways. Historic Resource Study, Ozark National Riverways, National Park Service, Van Buren, MO. 248 p.

Stokes, M.A. and T.L. Smiley. 1968. Introduction to tree-ring dating. University of Chicago Press. Chicago, IL. 78 p.

Tibbitts, T.W.X. 1979. Humidity and plants. BioScience 29 (6): 358-63.

Vigouroux, A., C. Bussi, and J.F. Berger. 1989. Importance of water consumption for calcium nutrition of trees. Ann. Sci. For. 46: 369s-371s.

Vogl, R.J. and P.K. Schorr. 1972. Fire and manzanita chaparral in the San Jacinto Mountains, California. Ecology 53: 1179-1188.

Waldman, C. 1985. Atlas of the North American Indian. Facts of File, New York. 276 p.

Whitney, G.G. 1994. From coastal wilderness to fruited plain. Cambridge University Press, New York. 451 p.

Wright, H.A. and A.W. Bailey. 1982. Fire ecology: United States and Southern Canada. Wiley-Interscience. New York. 501 p.

Zinke, P.J. 1977. Mineral cycling in fire-type ecosystems. In Proceedings of the symposium on the environmental consequences of fire and fuel management in mediterranean ecosystems. USDA Forest Service Gen. Tech. Rep.WO-3. p. 85-94.