Final Report

Fire History in ponderosa pine and mixed-conifer forests of the Catalina Mountains

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Abstract

Eighty five fire-scarred wood sections collected within five pine and mixed-conifer stands were analyzed to determine pre-1900 fire regime characteristics in the upper elevations of the Catalina Mountains. Fire frequencies were similar at all elevations when all fire events were analyzed, with a mean fire intervals (MFI) of 4 to 6 years between occurrences. However, when only more extensive fires were included MFI varied with elevation and aspect ranging from 7years at 7,000' to 10 years at 9,000' on northeast aspects. Fire frequency appeared to decline again below 7,000', however this is most likely an artifact of small sample size. Fire seasonality analysis determined that fires typically burned between late April and mid July. Fire sizes were variable, however some fires appear to have burned through large portions of the forested zone and may have exceeded 20,000 acres in size. Fires burning more than 1,000 acres appear to have been common. A change in the spatial, seasonal, and temporal character of the reconstructed fire regime at ca. 1800 may indicate a change in fire-climate relationships in the region.

Introduction

At the request of the USDA Forest Service, a tree-ring based fire history study was initiated in the Catalina Mountains to document the character, and range of variability in fire regime within the conifer forest zone of this mountain range. Although some limited sampling had been previously conducted in the vicinity of Rose Canyon Campground and the summit of Mt. Lemmon, no systematic study of the historic role of fire had been conducted prior to this work. Fifty five new specimens were collected at four sites and analyzed in conjunction with the thirty previously collected.

While it is well known that low intensity surface fires played an important role in southwestern conifer forests prior to the turn of the century, site specific information documenting characteristics such as the frequency, extent, seasonality and variability of past fires is important in the process of developing management plans that address the ecological role of fire in a specific area. The information provided in this report is both site specific and detailed, while also presenting an overview of the role of fire in the forested areas of the Catalinas. Although sampling did not extend into the northern half of the range, nor down into the woodland types, the results can be thought of as generally applicable between 5,500' and 9,000' for south, east and west aspects.

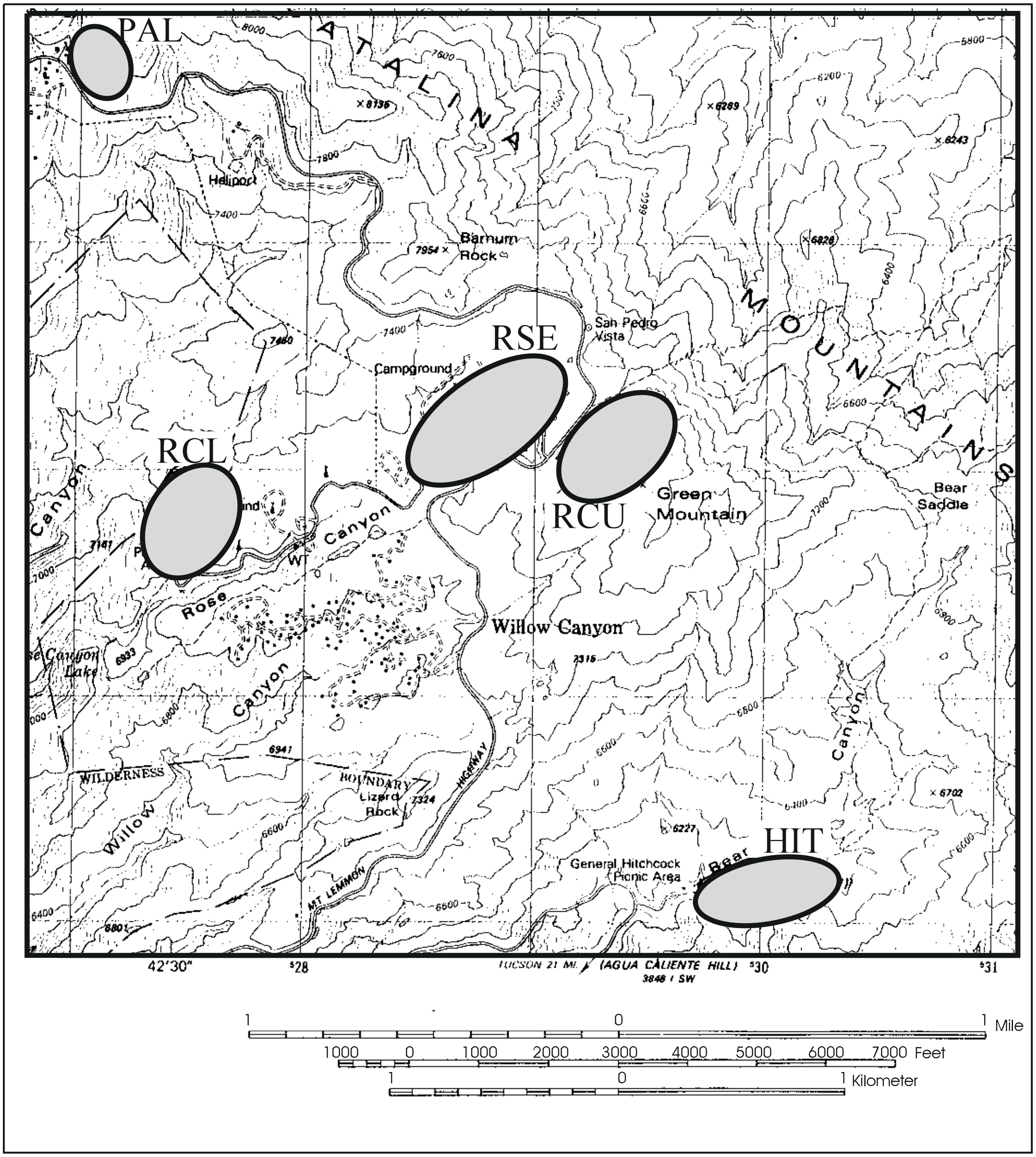

Figure 1. Map of Rose and Bear Canyon collection sites. Approximate area sampled at each sub-site is noted with a grey ellipse. Site IDs are noted in bold letters. Adapted from USGS 7.5' quadrangle map.

Collection Site Descriptions

During the 1980's, fifteen fire history samples (cross sections and partial sections from logs, snags, and stumps) were collected in the vicinity of Rose Canyon Campground and the Palisades Ranger Station. An additional fifteen were collected near the summit of Mt Lemmon, west of the ski area in 1990. For this project, two new sites were sampled in the Rose Canyon area, an additional site was sampled on Mt. Lemmon, and a new site was selected and sampled in Bear Canyon, north of the Mt. Lemmon highway. This sampling strategy was designed to provide fire history information along an elevational gradient within pine-dominated forest stands. It was also expected to provide the ability to infer past fire size in the Catalinas based on the degree of inter-site fire synchrony.

Site	# samples	Veg. Type	Elevation	Aspect	Area (ac)
HIT	7	PO/Pine/MC	6800	N	150
RCL	12	Pine	7000	flat	75
RSE	7	Pine	7200	W	75
RCU	17	Pine/MC	7400	W/NW	150
PAL	4	Pine	7600	SW	15
LEM	22	MC	9000	S/SW	100
LPK	16	MC	9000	E/NE	50

Table 1. Site names and attributes. Vegetation types sampled were PO/Pine-MC (pine-oak/ Pine-mixed-conifer), Pine (dominated by ponderosa pine), Pine/MC (ponderosa pine/mixed-conifer), and MC (mixed-conifer). Values in the Area column indicate the approximate area in acres from which samples were collected at a given site. Site elevations are given in feet.

Bear Canyon

This site (HIT) is located north (up-stream) of the Hitchcock Campground at approximately 6800' elevation (Fig 1). Seven samples were collected here along north-facing slopes on the south side of Bear Canyon. Current overstory vegetation includes mixed conifers (*Pinus arizonica, Pinus leiophylla, Pinus discolor, Pseudotsuga menziesii, Juniperus deppeana*, and *Pinus strobiformis*), oaks (including *Quercus arizonica, Q. hypoleucoides, Q. Emorii*), Arizona chaparral (*Arctostaphylos spp*.), and various riparian species (*Plantanus wrightii, Salix spp, Prunus virens*, and *Fraxinus velutina*). Species mix was highly variable and associated with aspect and distance from the drainage. Stands were quite dense, many with an understory of oaks. Slopes were steep and soils thin on south-facing slopes, while moderately deep along canyon bottoms and on north aspects.

Rose Canyon

Three sub-sites were sampled here with 12 samples collected at Rose Canyon Lower (RCL), 7 collected in the vicinity of the campground (RSE), and 17 collected above the highway, north east of the campground on the west face of Green Mountain (Fig. 1). Additionally, the location of five previously collected samples from the vicinity of the Palisades Ranger Station (PAL) is noted. Stands at these sites were dominated by ponderosa (*Pinus ponderosa*) or Arizona pine (*Pinus arizonica*) and mixed with Douglas-fir (*Pseudotsuga menziesii*) and southwestern white pine (*Pinus strobiformis*) on the north aspect of Green Mountain. All stands currently have dense thickets of small trees throughout the understory. Soils were particularly thin and poor at the RCL sub-site and most favorable on the RCU sub-site.

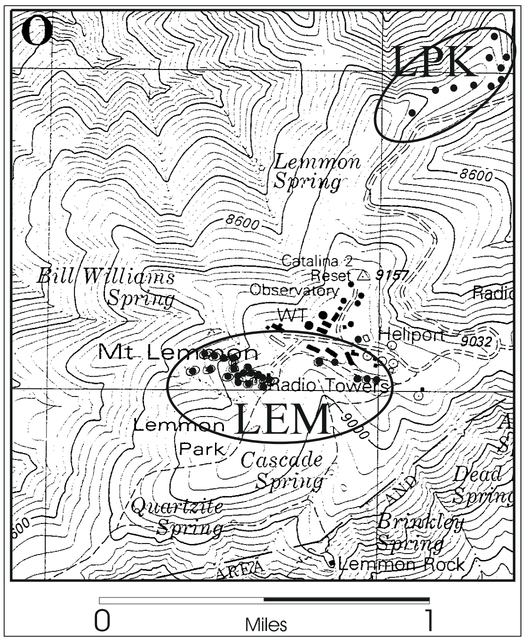

Figure 2. LEM and LPK collection areas. Adapted from USGS 7.5' Mt. Lemmon quadrangle map.

Mt. Lemmon

Two subsites were sampled : LEM, south and west of the summit of Mt. Lemmon and LPK, east of the summit at about 9,000' (Fig. 2). Both areas support mixed forest stands that include ponderosa pine in the canopy. Douglas-fir and southwestern white pine were also common. Aspen *(Populus tremuloides*)stands are scattered throughout this area and the sole stand of corkbark-fir (*Abies lasiocarpa*) in the Catalina mountains is located just south of the LPK site. The LPK site occupied north and east aspects while the LEM site included more south-facing slopes. Soils are moderately deep in both areas. 16 samples were collected at LPK and 22 at LEM.

Methods

Sample selection

Sampling strategy for field collection involved locating representative sites within areas of interest where sampling was acceptable. Sites were then surveyed for fire-scarred samples, the more promising specimens with well preserved, multiple fire scars, and thus a long record were flagged for subsequent collection. Within sites, samples were selected based on their state of preservation and the number of fire scars visible (as an indicator of the length of record preserved by a given sample). This strategy maximized the length and completeness of the reconstructed record. Samples were labeled and mapped, and notes were taken including a physical description, state of preservation, and number of fire scars visible. Complete cross sections were collected from logs and stumps while partial or "wedge" sections were removed from live trees and snags. In a few cases snags were felled for reasons of safety.

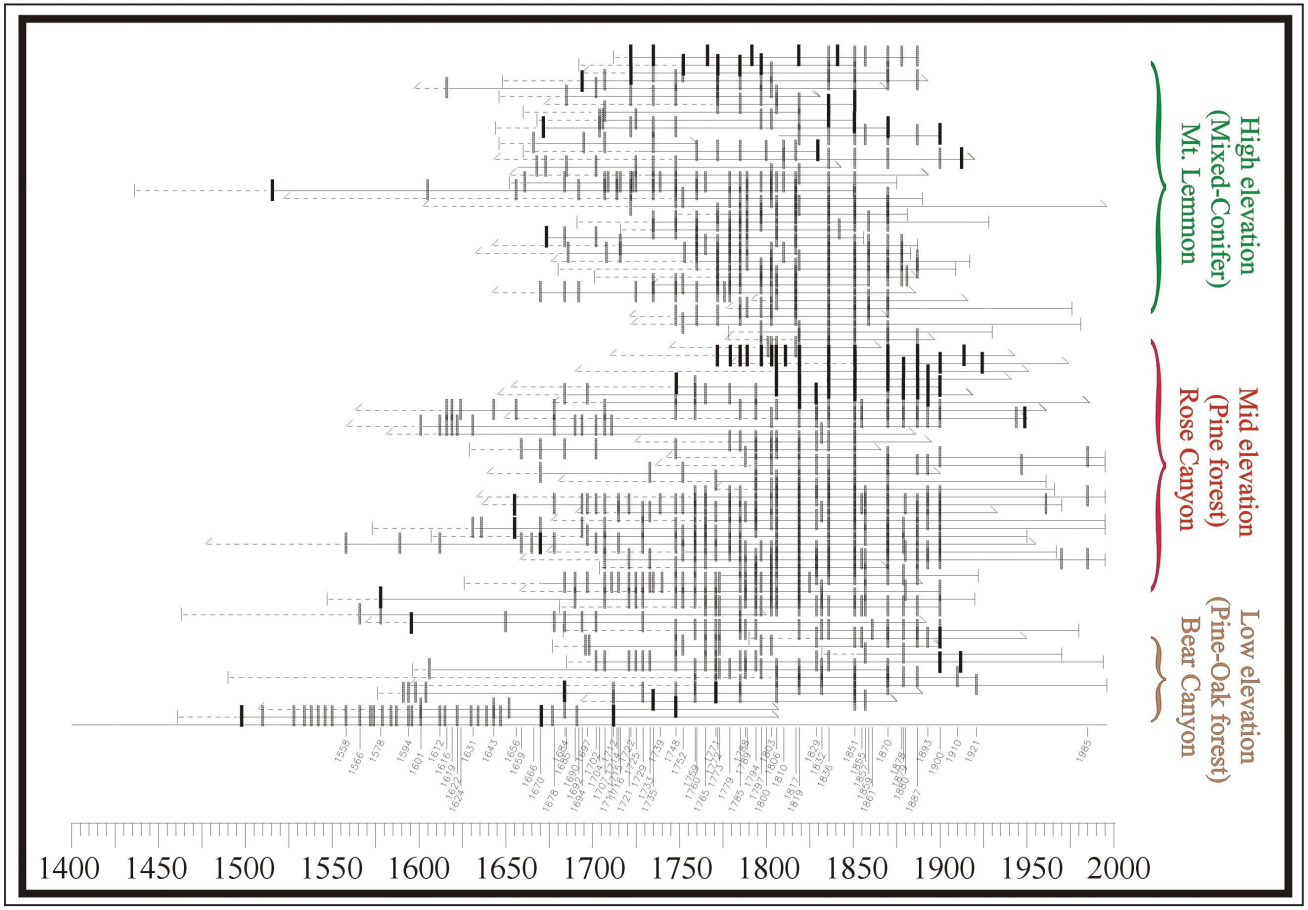

Figure 3. Fire history chart for the Catalina Mountains. Horizontal lines represent individual tree records while vertical bars represent fire events recorded by that tree. Vertical alignment of the bars indicates the spatial extent of fires. Note the change of fire frequency and spatial extent that occurred about 1800. Also, note the sharp decline of fire after 1900 as grazing followed by fire suppression impacts the fire regime.

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Sample preparation, and analysis

Samples were sectioned with a band saw and surfaced with belt sanders to a high polish allowing clear viewing of annual rings and cell structure with a binocular microscope. Samples were then dated with all annual rings assigned to the calendar year of formation using the dendrochronological technique of crossdating or pattern matching (Glock 1933, Douglass 1941, Stokes and Smiley 1968, Baillie 1982, Fritts and Swetnam 1989). This allowed precise determination of the years of fire injuries and reliable cross comparison of fire dates among samples and between sites. This information was then compiled into a database and analyzed with Fire2, a software program developed by H.D. Grissino-Mayer (1995). For more detailed descriptions of fire history methodology and analytical procedures see Dieterich and Swetnam 1984, Baisan 1990, and Swetnam and Baisan in 1996.

Results and Discussion

The reconstructed fire history shows a consistent pattern of frequent, low-intensity fires dominated the entire range of conifer forest sites sampled (Figure 3). Fires occurred somewhere within at least one of the sites every 1- 4 years. More extensive fires, that is fires that scarred at least 25% of the sampled trees, occurred every 7 years on the average, with a range of 4 to 12 years. Some fire events involved all sites, suggesting that extensive fires that burned large portions of the range occurred up to six times a century.

Fire Intervals

a. Any tree scarred

SITE / ELEVATION (feet)	Aspect	Mean Fire Interval (yrs)	Range (yrs)	WMPI (yrs)
Bear Canyon HIT (6,200')	N	9.9	2-23	9.3
Rose Canyon RCL (7,000')	flat	5.5	1-15	5.2
Rose Canyon RSE (7,200')	SW	6.1	2-15	5.8
Rose Canyon RCU (7,400')	W	6.4	1-15	6.1
Mt. Lemmon LEM (9,000')	S/SW	5.0	1-15	4.5
Mt. Lemmon LPK (9,000')	E/NE	6.1	1-11	5.7
Any tree, all sites	--	3	1-10	2.6

b. ≥25% trees scarred

SITE / ELEVATION	Aspect	Mean Fire Interval (yrs)	Range (yrs)	WMPI (yrs)
Bear Canyon HIT (6,200')	N	14.1	6-36	13.4
Rose Canyon RCL (7,000')	flat	7.3	2-15	6.9
Rose Canyon RSE (7,200')	SW	8.3	2-27	7.6
Rose Canyon RCU(7,400')	W	7.9	3-17	7.6
Mt. Lemmon LEM (9,000')	S/SW	8.4	2-19	8.0
Mt. Lemmon LPK (9,000')	E/NE	10.4	2-24	9.8
All Sites	--	8.2	1-18	7.6

Table 2. Fire interval statistics. Mean interval or MFI, Weibull mean probability interval or WMPI, range of intervals, and site aspect are presented. The Weibull mean provides a better estimate of central tendency for skewed distributions, and is thus appropriate for characterizing fire interval distributions. The more traditional MFI is provided for comparison with other studies.

The results of fire interval analysis for the period 1700 to 1910 are presented in Table 2. With the exception of the Bear Canyon site, the results for all fire events (i.e. fire scarring any tree within a site) were quite similar regardless of elevation averaging 5 to 6 years. This was particularly surprising at the high elevation sites where mean intervals were nearly identical to those at the Rose Canyon sites several thousand feet lower in elevation. The means varied from 9 years at Bear Canyon to less than 5 on the south side of Mt. Lemmon. When only more extensive fires were analyzed (those scarring at least 25% of the trees within a site) some segregation by elevation was apparent with longer mean intervals at the higher elevation sites (Table 2b).

The results from Bear Canyon stand out as anomalous and can perhaps be explained as an artifact of limited sample size and/or poor sample preservation at this site. The oldest sample collected here documents frequent fire occurrence during the 1500s with 20 fires recorded for the century. The resulting MFI of 5 years is similar to the other sites. Either fire frequencies changed dramatically at this site or the samples collected were insufficient to reliably reconstruct the fire regime during the later centuries. We believe the latter explanation is more likely.

High fire frequencies recorded on Mt. Lemmon may be explained by several factors. South facing slopes, even at 9,000', support productive, open forest stands with a grass-dominated understory that dry out readily during the annual May-June drought. Fire spreads most readily uphill, thus the summit might be expected to gather fire from all adjacent areas in addition to the expected local ignitions from lightning. Previous fire history research in the mixed-conifer forests of the Pinaleño Mountains to the east also documented mean fire intervals in the 4 to 5 year range (Grissino-Mayer et. al. 1994).

In addition to the mean fire interval, the range of fire intervals is an important characteristic of fire regimes. At all sites, again with the exception of Bear Canyon, fire intervals ranged from 1 to 15 years for all fires and 2 to 30 years for larger fires. The larger ranges in Bear Canyon and the RSE site probably are an indication of insufficient data to adequately characterize the period analyzed. Variability of fire occurrence in time and space leads to diversity of spatial pattern in fuels, community structure and habitat. Thus fire variability and its associated attributes may determine landscape pattern. The longer intervals between fires that characterized the early 19th century at all sites are an important feature of the this reconstruction. Longer fire intervals provide a window of opportunity for the establishment of woody plants with extended juvenile stages (i.e. trees and shrubs). Longer intervals may also result in higher fire intensities due to fuel accumulation during the fire-free period.

Seasonal Analysis

Important insight into seasonal timing of fires can be gained by close analysis of wound position. Seasonal position of fire wounds was compiled for all sites. For approximately 23% of the scars analyzed the season could not be reliably be determined. The remaining cases (n = 783) were classified as one of five categories: D or dormant season, EE or early earlywood, ME or mid-earlywood, LE or late earlywood, or L or latewood (Figure 4, 5). Generally, tree growth begins in April and continues through August, with latewood formation typically beginning in late June (Fritts 1976). However both site elevation (growing season length varies with elevation) and current growing conditions can cause the rate and duration of growth to vary from place to place and year to year. In most cases EE scars represent fires that occurred in late April or May; ME scars fires in late May or early June, and LE scars represent June or early July fires. Latewood scars were formed by fires occurring in July or August. Dormant season

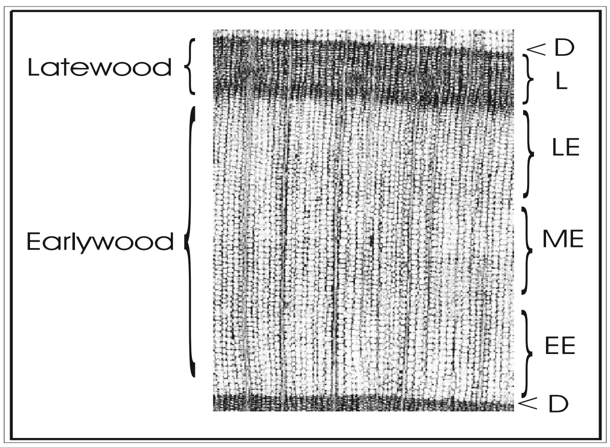

Figure 4. Conifer tree-ring with fire-scar seasonal positions noted. Earlywood is formed rapidly in the spring and early summer when growing conditions are most favorable. Latewood is formed during the summer as the growth rate slows. Trees are dormant from late fall through early spring.

Figure 5. Fire scars on a conifer wood section. The upper scar is a late earlywood or "LE" scar from a fire that probably occurred in early July. The lower one is an "EE' scar, perhaps from a May fire.

scars can represent either fires occurring in the spring or fall, however in the southwest these scars are thought to represent spring fires, as few fires occur here in the fall (Barrows 1978, Baisan and Swetnam 1990). During drought years growth and maturation rates are very slow and scars designated dormant season may represent fires occurring as late as the first part of June.

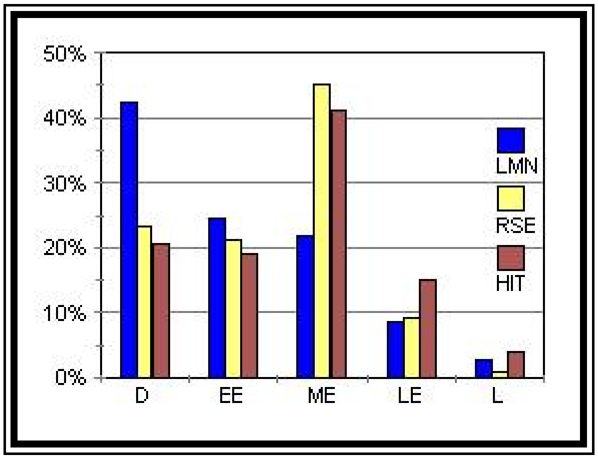

Figure 6. Seasonal position of fire scars by elevation. Note the predominance of dormant season scars at Mt. Lemmon and of mid-early scars at Rose and Bear Canyons.

High elevation sites on Mt Lemmon show a predominance of dormant season scars while the lower sites show about the same proportion of mid-earlywood scars (Figure 6). This segregation of position by elevation suggests the importance of growing season length in determining scar position. Trees at the high elevation sites begin growth later than the trees below, and thus the scars typically appear earlier in the ring. This general pattern can be compared with the distributions for particular fire events and the variability through time.

Distributions for two fire years common to all sites, 1785 and 1836, suggest a general shift in conditions affecting fire occurrence and character (Figure 7, 8). The data for 1785 is typical of wide-spread fires in the 18th century. Scars for these events exhibit similar seasonal distributions regardless of elevation. This suggests that site elevation had no effect on the duration or timing of tree growth during this century. In contrast, for a typical 19th century fire in 1836, the high elevation trees show predominantly dormant scars while the lower sites had a preponderance of mid-early scars. This latter example fits the expectation that on a given date the upper elevation trees will have formed less tissue those below. The climate of the first half of the 19th century is widely documented to have been cooler and somewhat wetter than average (Fritts 1991, Luckman et. al. 1997). Such conditions may provide the explanation for the observed changes in fire regime, as cool spring temperatures might slow tree growth at the higher sites. Alternatively, the rate and timing of fire spread may have been different during these two centuries.

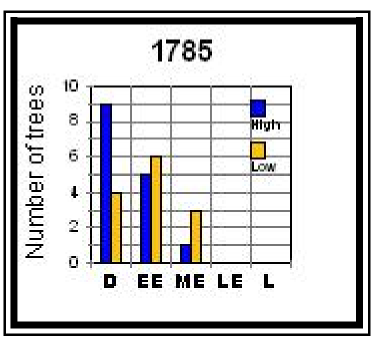

Figure 7.

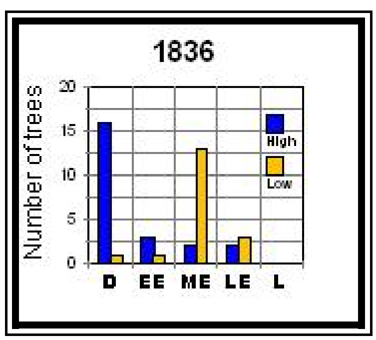

Figure 8.

Fire Extent

The extent and spatial character of past fires is visually characterized in Figure 3. Vertical alignment of black bars in the diagram on a given date give a sense of the spatial extent of fire events. While multiple ignitions over a few days or a season surely played a role in some cases, large fires (hundreds to thousands of acres) were clearly a common occurrence in the past. Local newspapers often carried accounts of fires, a few of which a cited here for example:

> "For the last month the country north, south, and east of Tucson has been in a constant blaze. The grasses on the mesas, mountains, and in the valleys, have been eaten up by the flames; during the last two days the fire has traveled over the Santa Catarina [Catalina] Mountains and is burning now miles beyond. It has climbed almost to the summit of the Santa Rita, after devouring most of the pastures below, and bids fair to continue its course until the grass of the whole country has been licked up in flames. . . " Arizona Star, June 23, 1877.

> "Fires have been raging in the mountains east and south of here [Tucson] for some time past. . . " Arizona Weekly Star, May 22, 1879.

> "The southeastern slope of the Santa Catarina and the west side of the Rincone [Rincon] mountains have been ablaze for the last four days. . . " Arizona Weekly Star, June 19, 1879.

> "The fires in the Santa Catarinas continue their destructive work." Arizona Weekly Star, June 26, 1879.

> "For the past two weeks fires have been burning on the Santa Catalina, Santa Rita, Pajarito, and Oro Blanco Mountains; during that time over 100 square miles have been burned over. . . " Tucson Daily Record, June 4, 1880.

> "Immense forest fires are still prevailing in some parts of western New Mexico and southern Arizona. . . " Arizona Daily Star, May 21, 1882.

For a discussion of historic fire accounts and land use changes in southern Arizona see Bahre. 1985, 1991. Prescribed fires often continue to burn for weeks at a time and often cover large areas if not suppressed. We believe that although fires of all sizes occurred, most of the area burned was burned in a small number of large fires hundreds to thousands of acres in size that resulted from single or multiple ignitions from lightning. This resulted in most areas burning every 4-6 years.

The data presented here suggest that the largest fires, those that burned all sampled sites, occurred every 18 to 20 years on the average. On the other hand, a fire of some size typically occurred somewhere within the area sampled every one to three years. Smaller fires were much more common in the 18th than in the 19th century and this change in fire character clearly had a significant impact on forest structure. Preliminary results from an ongoing stand age-structure study in the Rose Canyon area suggest that the current overstory is dominated by trees that established in the gaps between the early 19th century widespread fires (A. White, unpublished data).

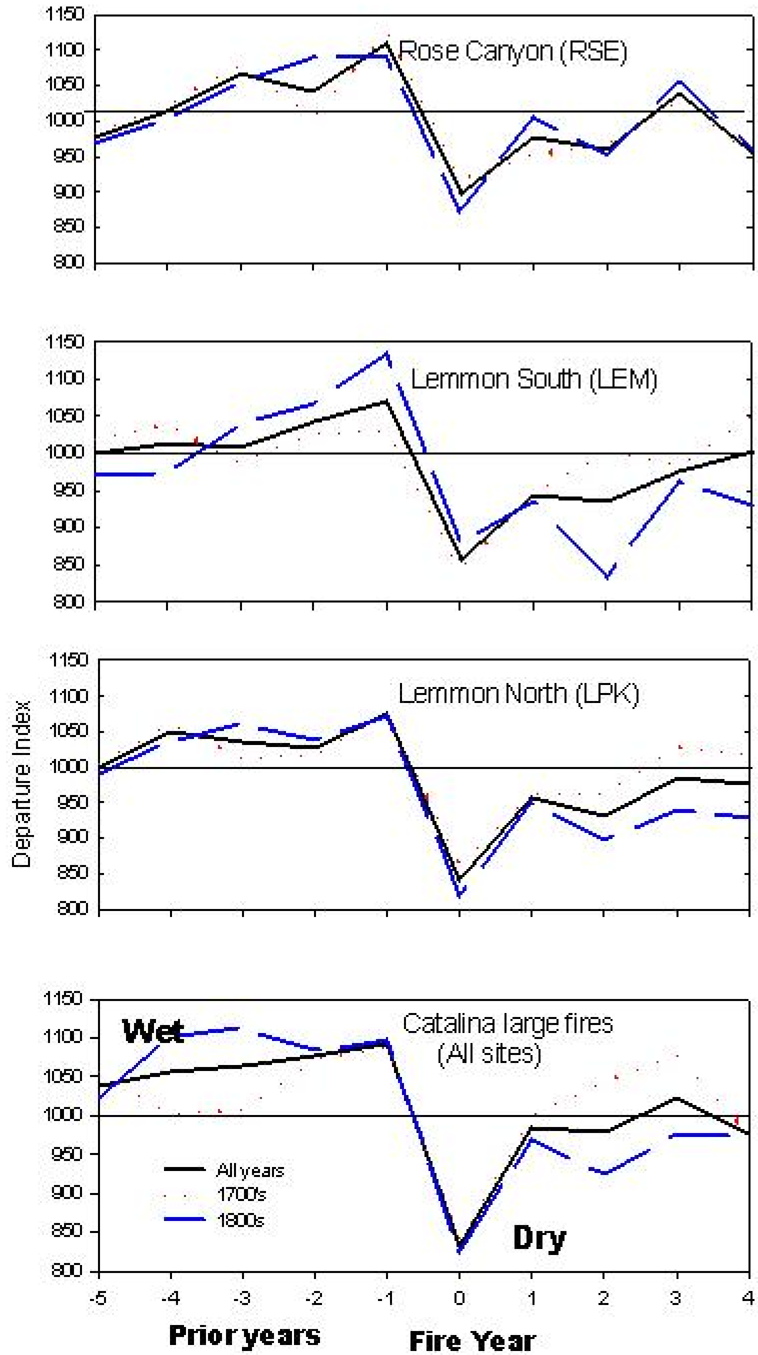

Figure 9. Average conditions prior to, during, and following fire occurrence at several sites and for the largest reconstructed fires. Note that fire years were typically dry and were preceded by one to several years with wetter-than-average conditions.

Fire-Climate Relations

Long-term climate and short-term weather conditions both affect the probability of fire occurrence. Although daily weather cannot be reconstructed to determine past conditions, in many cases annual or seasonal climate can be. In the southwest in particular, estimates of seasonal or annual precipitation can be reconstructed from tree-rings (Fritts, 1976, 1991). Such proxy records can then be compared to past fire occurrence to analyze fire-climate relationships.

In the Catalinas, a general pattern prevails throughout the sites consisting of wetter than average conditions for several years prior to fire occurrence and winter/spring drought the year of the fire(Figure 9). This pattern is most pronounced in the data from Rose Canyon and, during the 19th century, on the south side of Mt Lemmon. The north site on Mt. Lemmon shows a strong association only with drought on the fire year. These patterns are typical of fire regimes in semi-arid pine and mixed-conifer forests and show the increasing importance the availability of fine fuels (grass and needles) plays at lower elevations and more arid sites. Mesic sites with longer fire intervals are less limited by fuel amount and respond mainly to the dryness of the available fuel (Baisan 1990, Swetnam and Betancourt 1990, Swetnam and Baisan 1996).

The change in pattern from one century to the next at the drier sites is co-incident with the general change in fire regime that occurred at this time. It may reflect a change from high-amplitude, high-frequency oscillation in conditions to more persistent behavior with wetness or dryness tending to last for longer periods.

Conclusions

The data presented in this report clearly documents the important role played by fire in the forests of the Catalina Mountains over the past 500 years. Fires were common in the past, occurring every year or so somewhere on the mountain. Larger fires typically occurred every four to seven years and the largest fires, those affecting all sites sampled occurred every 18-20 years on the average. Most fires occurred between late April and early July, as is still typical today. Larger fires typically occurred following a dry winter and spring that had been preceded by one to several wet years. The reconstructed fire history shows changes in character with time, shifting from a regime characterized by frequent, patchy fires to one dominated by less frequent and more widespread fires. It is likely that this shift is a response to changes in climate such as the early 19th century Little Ice Age cooling. The shift in fire size was co-incident with changes in fire seasonality and fire-climate relationships at some sites, additional indicators of a changing fire environment.

Although it is clear that, in the past, the fire regime has changed through time, the dramatic decline in fire activity at the beginning of the 20th century clearly represents an unprecedented change with far-reaching consequences for all components of the mountain ecosystem. Continued efforts to re-introduce fire on a landscape scale are thus clearly in tune with the long-term history of fire in the Catalina Mountains.

Acknowledgments

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