Fire History in the Pinaleño Mountains of Southeastern Arizona: Effects of Human-Related Disturbances

Henri D. Grissino-Mayer, Christopher H. Baisan, and Thomas W. Swetnam[1]

Abstract.—We reconstructed the history of fire at two sites in the mixed-conifer forests of the Pinaleño Mountains of southern Arizona from 90 fire-scarred living and dead southwestern white pine (*Pinus strobiformis*) and ponderosa pine (*Pinus ponderosa*) trees. We used dendroecological techniques to date nearly 2000 fire scars to their exact year of formation, and obtained age structure information from over 600 increment cores and cross-sections collected from Engelmann spruce (*Picea engelmannii*) and corkbark fir (*Abies lasiocarpa*). We compared the age structure data with the reconstruction of past fires to determine which fires may have had an effect on the higher-elevation forests. During the pre-settlement period (prior to 1880), low-intensity surface fires occurred once every four to six years, based on the median probability interval derived using the Weibull distribution. The age structure of the spruce-fir forest suggests that the forest established after a stand-replacement fire that occurred in 1685, considered one of the most widespread and intense of any reconstructed fire event. Fires had occurred predominantly in the early portion of the growing season (May and June) similar to current dominant season of fire activity. The cessation of episodic fires after 1893 can be attributed to a combination of human-related disturbances, especially grazing and fire exclusion. The absence of ecologically-significant fires during the last 100 years in the Pinaleño Mountains should be considered when developing land and fire management plans for this environmentally sensitive area.

INTRODUCTION

With few exceptions, most Southwestern U.S. fire history studies have been conducted in ponderosa pine-dominated habitat types (Swetnam 1990). Hence, little is known about the frequency and scale of fire events in Southwestern mixed-conifer and spruce-fir forests prior to the Euro-American settlement era (ranging from the late 1500s to late 1800s in different areas of the Southern Rockies). However, fire regimes in mixed-conifer habitat types are generally thought to be a mixture of moderate frequency, low-intensity, surface fires and infrequent, stand-replacing crown fires, while fire regimes in spruce-fir forests generally consist of infrequent, intense, stand-replacing crown fires. Research into the fire history and fire ecology of these habitat types in the Southwestern U.S. will therefore provide valuable information that can be used by land management agencies for initiating programs that satisfy mandate requirements of the Ecosystem Management policy.

The purpose of this study was to reconstruct the history of fire in mixed-conifer/spruce-fir forests in the vicinity of Mount Graham in the Pinaleño Mountains of southeastern Arizona (fig. 1) from fire scars dated using well-established dendrochronological techniques. We also incorporated information about the current age structure of the adjacent spruce-fir forest to analyze the history and/or possible effects fire may have had upon these higher-elevation forests. Our historical study of pre-settlement fires offers both a long-term perspective of past forest dynamics as well

[1]*Laboratory of Tree-Ring Research, University of Arizona, Tucson, Arizona 85721.*

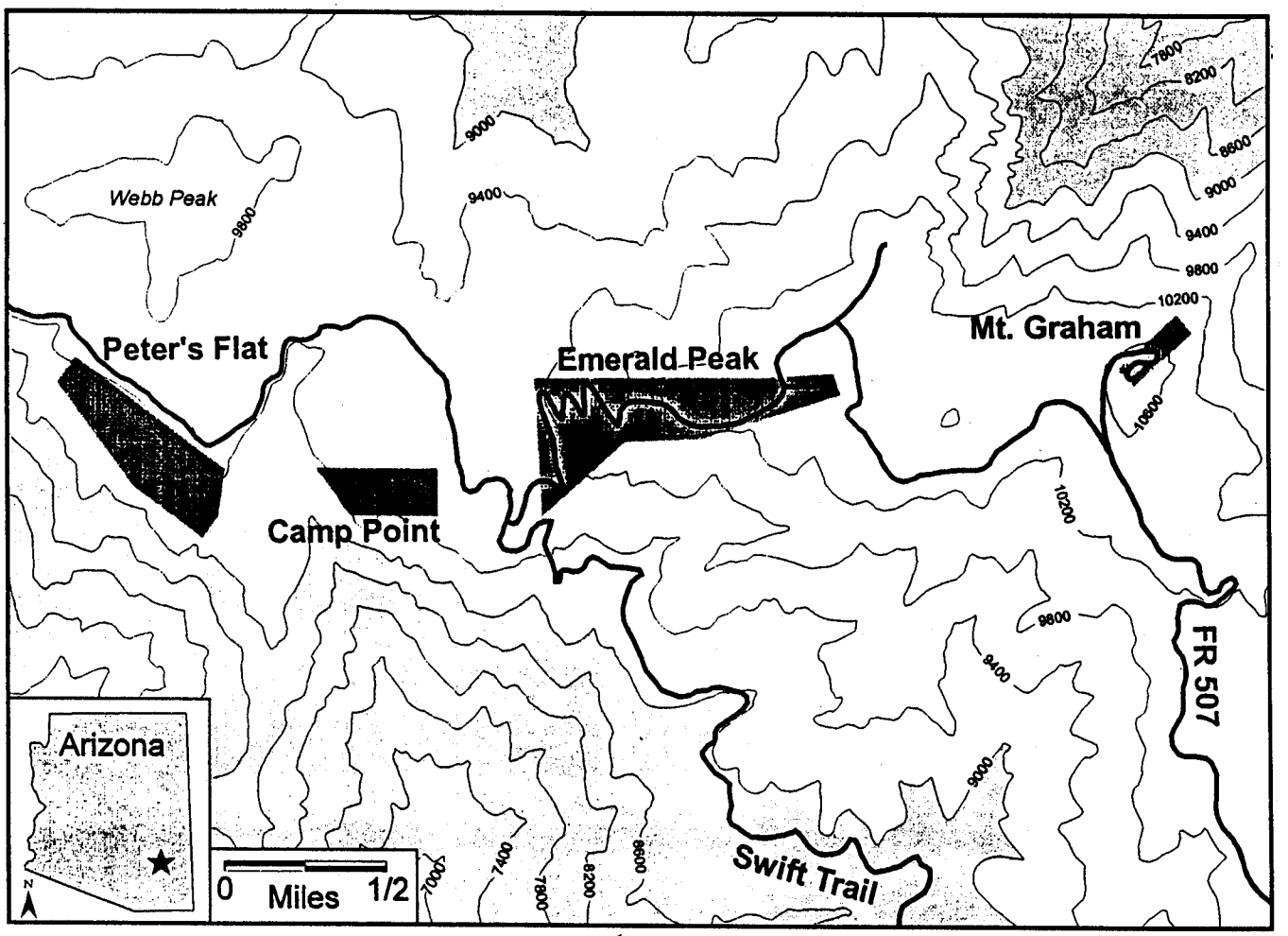

Figure 1.—Locations of the Peter's Flat (A), Camp Point (B), and Emerald Peak (C) fire history and age structure sites. The shaded area represents areas below 9000 ft (2750 m) emphasizing the semiplateau area in the higher elevations of the Pinaleño Mountains.

as a specific warning about the possible future trajectory of fire regimes and forests in the Pinaleño Mountains, with particular reference on potential impacts to the endangered Mount Graham red squirrel (*Tamiasciurus hudsonicus grahamensis*).

STUDY AREA

The Pinaleño Mountains are the highest and steepest range in southeastern Arizona, reaching elevations of 10,400 ft at Heliograph Peak in the center of the range and 10,717 ft at Mount Graham. The Pinaleños rise precipitously, especially on the southwest and north east flanks, until approximately 9,000 ft where the range becomes a "semiplateau" dotted by several high peaks (Martin and Fletcher 1943). We chose two sites for fire history analyses, Peter's Flat and Camp Point, and collected samples for age structure analyses along anelevational gradient that culminated at Emerald Peak (fig. 1). The two fire history sites are located near the edge of the semiplateau area in the mixed-conifer forest and mixed-conifer/spruce-fir transition zone at elevations ranging from 9,200 to 9,700 ft. Slope at these sites varies from zero to 60%. Both sites are classified as mixed-conifer forest. This forest type covers approximately 11,100 ac in the upper elevations of the Pinaleño Mountains (USDA Forest Service 1988b). The Emerald Peak area is predominantly spruce-fir forest, which covers approximately 500-600 ac in the Pinaleños (USDA Forest Service 1988b). The spruce-fir forests of the Pinaleños represent the southernmost extent of this forest type in North America (Pase and Brown 1982; Johnson 1988; Stromberg and Patten 1991).

METHODS

We used a chainsaw to obtain entire and partial cross-sections from fire-scarred logs, remnant pieces of wood, snags, and living trees (Arno and Sneck 1977). We collected 40 samples from the Peter's Flat site and 36 samples from the Camp Point site. During construction of the access road leading to the astrophysical complex, 14 fire-scarred samples were collected in the spruce-fir transition zone to provide information on fires that possibly impacted the highest elevation forests. Most samples were collected from southwestern white pine (*Pinus strobiformis* Engelm.) and ponderosa (or Arizona) pine (*Pinus ponderosa* Lawson var. *arizonica* (Engelm.) Shaw). To provide information on the age structure of the spruce-fir forest, we collected cross-sections and increment cores from 168 Engelmann spruce (*Picea engelmannii* Parry) and 123 corkbark fir (*Abies lasiocarpa* (Hook.) Nutt. var. *arizonica* (Merriam) Lemmon) trees felled during construction of an access road and sites to be used by an international astrophysical complex (fig. 1, site C). All sections and cores were obtained as near to ground level as possible for maximum age determination.

In the laboratory, we sanded all surfaces with a 4" X 24" belt sander beginning with a coarse grit size (usually 40 grit) to plane the surface, then progressively used finer sandpaper until eventually using a 320 grit. This technique produces a surface on which the cellular structure of the wood is readily visible under 20-30X magnification. All cross-sections and increment cores were then crossdated, assigning each tree ring to its exact year of formation (Stokes and Smiley 1968; Swetnam *et al.* 1985), after which each fire scar was dated (Dieterich and Swetnam 1984).

To compare the seasonality of past fires with our current knowledge on the seasonality of fire activity, the season of fire occurrence was determined by noting the position of the fire scar within the annual ring (Dieterich and Swetnam 1984; Baisan and Swetnam 1990). We determined the dominant season of fire occurrence by compiling and graphically displaying the frequency distribution of the intra-annual positions of all dated fire scars. Fire scar positions and their seasonal designations followed Baisan and Swetnam (1990) and Swetnam et al. (1992) with minor modifications for the higher elevations of the Pinaleños. Fire scars were noted as occurring in: the dormant season (D) between the latewood of the previous year and earlywood of the current year; the early one-third portion of the earlywood (EE); the middle one-third of the earlywood (ME); the late one-third portion of the earlywood (LE); and, the latewood portion of the annual ring (L).

We combined data from the Peter's Flat and Camp Point sites to provide a comprehensive overview of fire occurrence in mixed-confer forests of the Pinaleños over a broader spatial scale than is provided by each individual site. We used the FHX2 fire history analysis computer program (Grissino-Mayer 1994) to provide a quantitative description of the combined fire regime based on the distribution of fire intervals. We used the Weibull distribution to model fire interval data because this distribution can model a variety of negatively and positively skewed distributions, and often provides a superior fit to fire interval data than does the normal distribution (Clark 1989; Johnson 1992; Baker 1992). We used FHX2 to calculate the fire interval associated with the 50% level of exceedance probability, termed the Weibull Median Probability Interval (WMPI), analogous to the Mean Fire Interval calculated for fire interval distributions based on the assumption of normality. We conducted two sets of analyses, the first based on *all* fire scars, regardless of the number of trees scarred in any fire year, and the second based on those fire years in which at least 10% of the trees at either site were scarred. This 10% cutoff emphasized widespread and/or more intense fires while de-emphasizing fires that affected only a very trees (Swetnam 1990; Grissino-Mayer and Swetnam, in press).

Ages for all individual spruce and fir trees from the transition zone and true spruce-fir forest determined from the crossdated pith dates obtained at ground level were input into a spreadsheet sorted by species. Age distributions in 20-year age classes were plotted to investigate changes in tree populations over time due to differences in life history strategies between the two species or due to disturbance events. Dates of past fires that occurred in the spruce-fir transition zone were compared with age distributions to investigate possible impacts these fires may have had on the spruce-fir forests.

RESULTS

We crossdated nearly 2000 fire scars that yielded 629 fire events from the 90 samples collected at Peter's Flat and Camp Point, and dated an additional 88 injuries possibly related to fire (table 1). In the combined record for both sites, 79 fire years (12.8%) occurred during the period 1376

to 1993. All statistical analyses were conducted beginning in 1584 because this was the first year in our collection in which fire scarred multiple samples at either site. The pre-settlement period was designated as ending in 1880 because human-related disturbances (especially grazing) began to significantly affect the environment during the period 1875 to 1885 (Bahre 1991).

The WMPI values for both scarred classes (4.23 yrs based on all trees scarred, and 5.23 yrs based on at least 10% trees scarred) were lower than MFI values derived from the simple arithmetic mean (table 2) because the Weibull is better able to model positively skewed distributions, making the WMPI a more robust estimator of central tendency in the fire interval distributions. The WMPI for both scarred classes increased dramatically when the full period (1584 to 1993) was analyzed compared to the pre-settlement period (1584-1880) (table 2) as the 20th century fire regime is characterized by unusually long fire-free periods. Based on exceedance probabilities during the pre-settlement period, significantly long fire intervals exceeding the 95% confidence level were 10.6 yrs for all trees scarred and 12.4 yrs for the 10% scarred class (table 3). These long intervals were rarely exceeded during the pre-settlement period, but have been greatly exceeded during the 20th century (figs. 2 and 3).

Seasonality of fires was determined on 468 of the 629 fire scars (74%) from samples in the Pinaleños. The dominant season of past fire occurrence was early in the growing season (44% of all scars), or approximately from early May to mid-June (fig. 4). In general, almost all fires (94%) occurred from just prior to the beginning of the growing season (dormant season scars) until midway through the growing season (middle earlywood scars). This percentage corresponds well with the seasonality of pre-settlement fires for the Rincon Mountains determined by Baisan and Swetnam (1990) in which they confirm a late spring through mid-summer fire season. In addition, Barrows (1978) noted that 60% of the annual total of area burned during the period 1960 - 1974 in the Southwest occurred during June despite the fact that the highest rate of ignitions occurred in July just before the height of the monsoon season (Baisan and Swetnam 1990).

The oldest trees sampled in the spruce-fir dominated forests were consistently Engelmann spruce. The age distribution of all spruce and fir trees collected revealed that many more old-aged

Table 1.—Summary information for the Peter's Flat and Camp Point Fire History Sites.

	Peter's Flat Point	Camp
Beginning year	1376	1534
Last year	1993	1993
Chronology length (years)	618	460
Total number of samples at site	40	50
Total number of fire scars	363	266
Total number of all indicators	424	293
Total number of years with fire	65	44
Percentage of years with fire	10.5	9.6
Percentage of years without fire	89.5	90.4

Table 2.—Descriptive statistics for fire interval data in the Pinaleño Mountains during the pre-settlement period 1575 - 1880 and the full period 1575 to 1993, based on all fire years and on those years in which at least 10% of all trees sampled were scarred.

	Pre-settlement		Full Period	
	All	10%	All	10%
Total Intervals :	59	46	67	48
Mean Fire Interval :	4.86	6.24	6.10	8.52
Weibull MPI (WMPI) :	4.23	5.77	4.84	6.47
Median Fire Interval:	4.00	5.00	4.00	5.50
Standard Deviation :	3.29	3.65	6.65	14.13
Coef of Variation :	0.68	0.58	1.09	1.66
Skewness :	0.71	1.02	3.87	5.77
Kurtosis :	-0.40	1.47	19.73	34.38
Minimum Interval :	1	1	1	1
Maximum Interval :	13	19	47	100

Table 3.—Exceedance probabilities from the Weibull function for fire interval data in the Pinaleño Mountains during the pre-settlement period 1575 - 1880 and the full period 1575 to 1993, based on all fire years and years in which at least 10% of all trees sampled were scarred. Exceedance probabilities (X 100) are equivalent to percentages. The WMPI is associated with the 50% exceedance level.

Exceedance Probability	Pre-settlement Intervals		Full Period Intervals	
	All	10%	All	10%
0.999	0.07	0.19	0.05	0.11
0.990	0.30	0.64	0.26	0.45
0.975	0.53	1.03	0.50	0.81
0.950	0.83	1.49	0.81	1.26
0.900	1.30	2.16	1.33	1.98
0.800	2.08	3.20	2.22	3.17
0.750	2.44	3.65	2.65	3.72
0.667	3.02	4.36	3.35	4.62
0.600	3.49	4.92	3.92	5.34
0.500	4.23	5.77	4.84	6.47
0.400	5.04	6.67	5.86	7.71
0.333	5.64	7.34	6.64	8.64
0.250	6.53	8.28	7.79	10.01
0.200	7.17	8.95	8.63	10.99
0.100	8.97	10.79	11.04	13.77
0.050	10.58	12.37	13.22	16.24
0.025	12.06	13.79	15.25	18.52
0.010	13.86	15.48	17.76	21.29
0.001	17.87	19.12	23.47	27.47

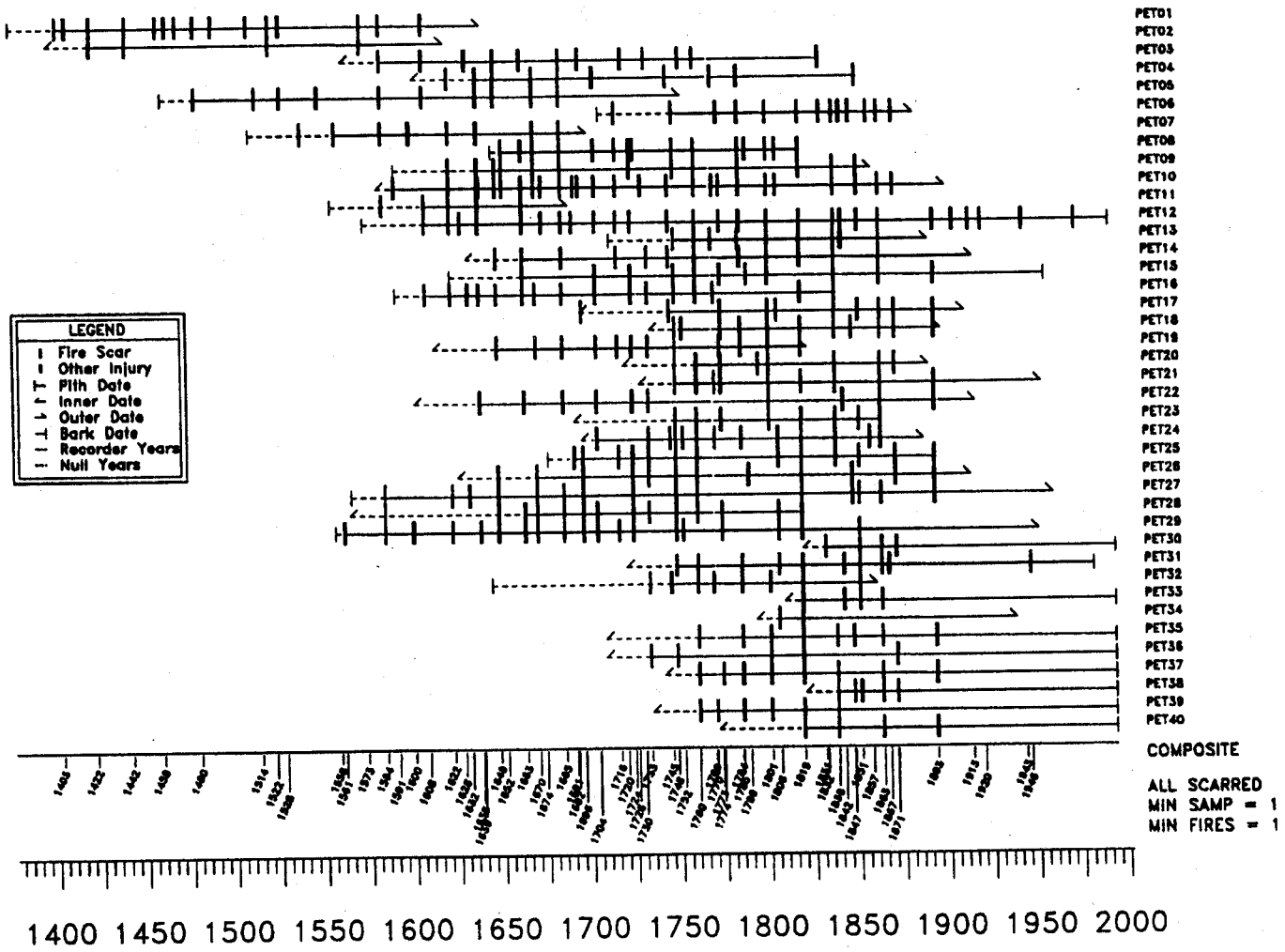

Figure 2.—The Peter's Flat fire history master chart. The horizontal lines represent individual trees with sample ID's given to the right of each line. Fire scar dates are indicated with solid vertical bars, while other injuries possibly associated with fires are indicated by open vertical bars.

Engelmann spruce are present in the Pinaleños than corkbark fir (fig. 5). This suggests that corkbark fir was a minor component of the initial spruce-fir forest or that corkbark fir is not as long-lived as Engelmann spruce. Both spruce and fir are able to colonize areas cleared after disturbance, but Engelmann spruce is the dominant colonizer because it is better able to withstand environmental extremes that arise after disturbance (Peet 1988; Stromberg and Patten 1991). The age distribution for corkbark fir shows that this species was present in the post-disturbance forest from the onset (fig. 5), similar to the findings of Aplet *et al.* (1988) in Colorado subalpine forests. The lack of individual spruce and fir trees exceeding 300 years of age suggests that a catastrophic disturbance, most likely fire, may have occurred between 300 and 400 years ago within the study areas. We hypothesize that this event was the 1685 fire. Nearly all fire-scarred samples collected in the mixed-conifer and transition zone sites that extended prior to 1690 clearly showed that the 1685 fire was the most intense based on the amount of cambial surface killed on survivor trees. Furthermore, surviving Douglas-fir trees in the mixed-conifer/spruce-fir transition zone showed evidence of serious injury and canopy loss in this year documented as a dramatic and rapid reduction in growth beginning in 1685, often with several missing rings, relative to Douglas-fir trees collected at a control site that could not have been affected by this fire. Douglas-fir is considered a very fire-tolerant species because of its thick bark (Wright and Bailey 1982),

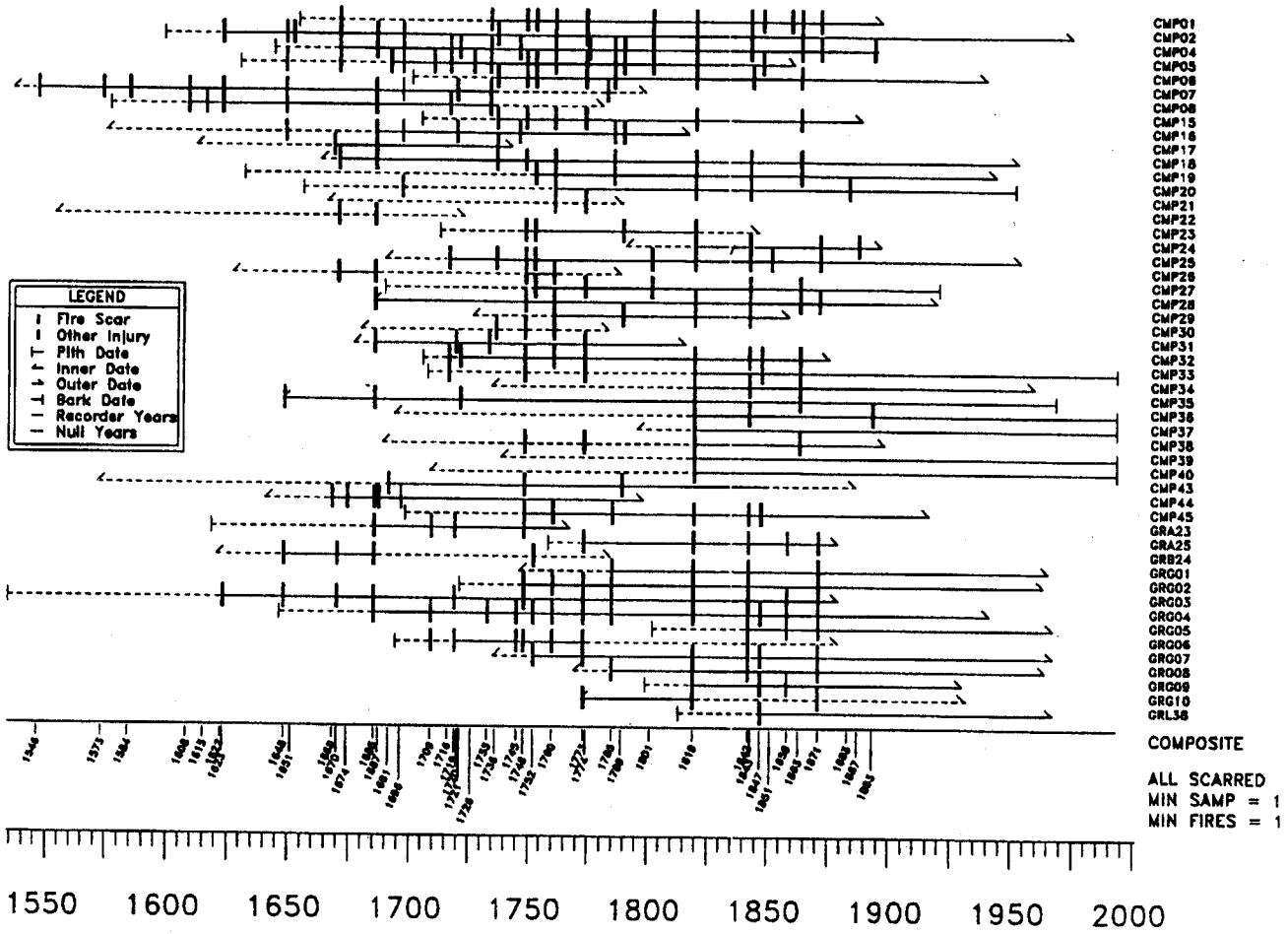

Figure 3.— The Camp Point fire history master chart. Samples GRA 23 through GRL 38 were collected within the transition zone along the access road leading up to the astrophysical complex within area (C) in figure 1.

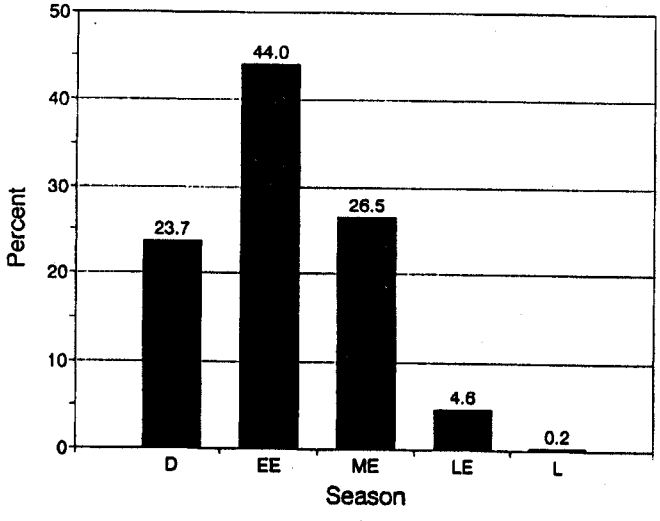

Figure 4. —The seasonal distribution of fire scars from 468 individual fire scar dates from 90 individual specimens, verifying an early spring to late summer fire season with the majority of fires occurring in the early portion of the growing season, from approximately early May to mid-June.

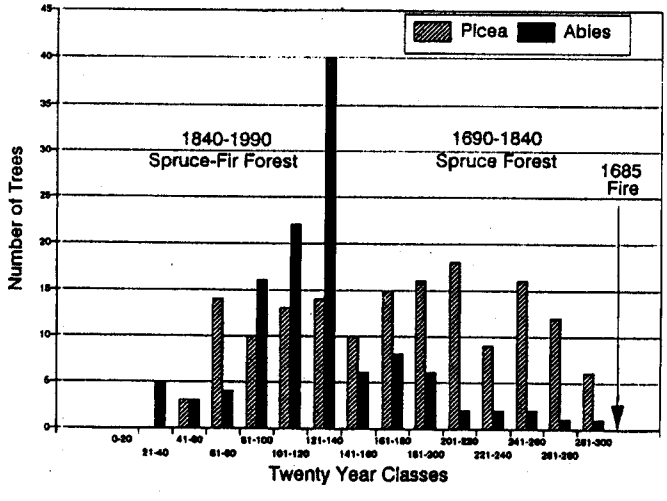

Figure 5.—Age distribution in 20-year age classes for Engelmann spruce and corkbark fir trees collected for this study. Corkbark fir was present in the post-disturbance area, but in low numbers.

yet individuals in the transition forest clearly were affected by the 1685 fire, confirming the high intensity and large areal extent of this fire. Whether or not a single catastrophic fire occurring in 1685 was responsible for resetting the successional pattern at the highest elevations, the age structure of the spruce-fir forests of the Pinaleños suggests a fire return interval of approximately 300-400 years.

DISCUSSION

Our results suggest that pre-settlement mixed-conifer forests in the Pinaleños burned as frequently (WMPI = 4.2 yrs) as some Southwestern ponderosa pine forests at lower elevations. The WMPI obtained for the mixed-conifer forests of the Pinaleños is considerably lower than the MFI obtained in previous studies in mixed-conifer forests of the southern and central Rockies. Dieterich (1983) determined that the MFI for widespread fires (20% scarred) for mixed-conifer forests in the White Mountains of eastern Arizona was 22 yrs (compared with the MFI of 11 yrs derived for our 20% scarred class). Ahlstrand (1980) estimated major fires had occurred once every 17 yrs in the Guadalupe Mountains National Park in southwestern Texas. Baisan and Swetnam (1990) derived a MFI of 9.9 yrs for mixed-conifer forests in the Rincon Mountains of southeastern Arizona. The short-interval regime in the mixed-conifer forests of the Pinaleños during the pre-settlement period suggests these forests were very open, characterized by relatively rapid fuel accumulation. Thus, the mixed-conifer fire regime suggests a forest structure similar to ponderosa pine forests at lower elevations but populated by mixed species.

Furthermore, we hypothesize that the relatively open canopy, pre-settlement mixed-conifer forest in the semiplateau area of the Pinaleños, characterized by heterogeneous forest composition, age structure, and fuel components, acted as a "buffer zone" around the spruce-fir forest. It seems likely that many fires that burned in the mixed-conifer forest on the semiplateau originated on the plateau or on the steep slopes below. These fires typically burned on the forest floor throughout the mixed-conifer stands, but did not spread into the spruce-fir forest zone because of the cooler, moister conditions that exist there. Only during the severest droughts did stand-replacement fires spread into the canopies of spruce-fir forests. We therefore hypothesize that the high frequency of fires and heterogeneous nature within the mixed-conifer forest "buffer zone" served to promote the long-term stability within the spruce-fir forest. Therefore, alterations to the fire regime and heterogeneity of the mixed-conifer forest buffer are likely to have significant effects upon the spruce-fir forest as well.

The dissimilarity between the mixed-conifer and spruce-fir fire regimes in the Pi naleños reveals an important characteristic not previously reported for Southwestern forests. Fire regimes in the mixed-conifer study sites were characterized by a WMPI of 4.2 yrs. However, fire return intervals in the spruce-fir study area located less than two miles away (between Peter's Flat and Mount Graham) range between 300-400 yrs based on the last fire known to have occurred in the spruce-fir forest. This extreme difference in fire return intervals between adjacent habitat types suggests an extremely steep gradient in fire frequency can occur in areas separated by very short distances.

CONCLUSIONS

Our reconstruction of fire history for the Pinaleño Mountains emphasizes the long-term stability and resilience of the pre-settlement mixed-conifer and spruce-fir forests. During the pre-settlement period, wildfires were commonplace in the Pinaleño Mountains for at least 8,000 yrs (Anderson and Shafer 1991) and should therefore be considered a "natural" component of this forest community. The mixed-conifer fire regime of the past four or five centuries suggests that this community was relatively stable and highly resilient to the changes induced by fires. The frequent, low-intensity surface fires were probably important in maintaining a substantial component of pine within the stands, since they are generally more resistant and tolerant of this type of fire regime than Douglas-fir or true firs (Wright and Bailey 1982). Furthermore, this relatively high frequency fire regime was similar to pre-settlement ponderosa pine fire regimes reconstructed elsewhere in the Southwest. This finding suggests that, like pre-settlement ponderosa pine forest structure (*e.g.* Covington and Moore 1994), the pre-settlement Pinaleño mixed-conifer stand densities were probably lower and more spatially heterogeneous than todays stands, possibly with an important understory component of grasses. The cessation of spreading fires with the rise of

the livestock industry support the interpretation that grasses were important in the climate-fuel-fire dynamics of mixed-conifer forests.

High fuel loadings have increased the fire hazard in an area in which fire will con tinue to be actively suppressed due to its status as Fire Management Zone 1 (USDA Forest Service 1988a). The forest structure now favors the occurrence of high-intensity, stand-replacing fires in contrast to the low-intensity, stand-maintenance fires that occurred prior to Euro-American settlement (USDA Forest Service 1993). This hazard is further increased by the high flammability of Engelmann spruce and corkbark fir trees (Wright and Bailey 1982, p. 319) that exist upslope from the mixed-conifer study sites.

In the long-term, management of these forests should emphasize the restoration of greater stability and resiliency of the ecosystem (including both tree and squirrel populations) by reducing live and dead fuel loadings, particularly in the mixed-conifer zone. Re-introduction of fire by carefully planned and executed prescribed burning is one alternative for accomplishing this objective. However, the capriciousness of fire and weather will always add an element of hazard to this approach. The benefits of fire to ecosystems long adapted and dependent to some degree upon fire must be weighed against the hazards of prescribed fires "escaping" and becoming wildfires. These same hazards must also be weighed against the existing and perhaps increasing hazard of catastrophic fire sweeping across very large areas of both the mixed-conifer and spruce-fir forests of the Pinaleños. Not only is the red squirrel potentially endangered by high-intensity crown fires, but so is the astrophysical complex nestled among the spruces on the summit. In our opinion, with a continuation of current forest structures and increasing use of the mountain by recreationists and scientists, it is not a matter of "if" such fires will occur, but "when."

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