The Influence of Fire and Land-use History on Stand Dynamics in the Huachuca Mountains of Southeastern Arizona

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Abstract.—Dendrochronological methods were used to reconstruct fire regimes and stand age structures in the Huachuca Mountains of Southeastern Arizona. Pre-settlement (i.e., before ca. 1870) fire intervals ranged from 4 to 8 years, with many fires spreading over the entire sample area. Stand age distributions show an increase in more shade-tolerant tree species. Although ponderosa pine still dominates stands, recent recruitment is predominantly southwestern white pine and Douglas-fir. Establishment of Ft. Huachuca in 1877 was a precursor to extensive use of timber, mineral, range and water resources in the Huachuca Mountains. The fire regime was clearly altered at this time, with only one subsequent widespread surface fire recorded in 1899. Settlement era land-use practices may be responsible for changes in stand structure and composition.

INTRODUCTION

It is widely thought that current conditions in most ponderosa pine *(Pinus ponderosa* Dougl. ex Laws.) forests are radically different than those that existed during pre-settlement times, i.e., prior to extensive Euro-American settlement in the late 1800s (Cooper 1961; Covington and Moore 1994). In particular, changes have been noted in forest structure (i.e., tree density, age distribution, species composition). Many forest stands in southern Arizona now contain an understory of dense, young ponderosa pines, as well as greater numbers of Douglas-fir *(Pseudotsuga menziesii* (Mirb.) Franco) and southwestern white pine*(Pinus strobiformis* Engelm.). These changes in structure and composition are a result of several historical factors, including decreased frequency of widespread surface fires, effects of human land-use, and variation in overall patterns of climate. Several studies in the Southwestern U.S. quantitatively described existing size and age structure of selected ponderosa pine stands (Pearson 1950; Cooper 1960; Schubert 1974; Savage 1991; White 1985; Fule and others 1995). Many of these studies point out that changes in forest dynamics are a result of both endogenous and exogenous factors, but few of them explicitly investigated these factors. Dendrochronology offers methods for simultaneously reconstructing tree age distributions, fire history, and climatic variations. By reconstructing stand history and making comparisons at different points in time we can quantify the extent of stand alterations and gain insight into the processes that created these changes.

This study was designed to characterize forest age structure and composition at the stand level and to use these data to improve our understanding of forest dynamics in the context of the historical fire regime and human land-use. Our sampling and analysis had two specific objectives. The first was to reconstruct the historical fire regime, including the occurrence, spatial distribution, and seasonality of past fires, over an elevational gradient using fire-scar analyses. The second was to determine the tree age structure and species composition in the area from which the fire-scarred samples were collected. Forest structure and composition were compared with the fire history, and with the land-use history derived from historical and current records of the site.

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SITE CHARACTERISTICS

The Huachuca Mountains are within the Madrean Archipelago or "sky islands" of southeastern Arizona. They are floristically diverse (Bowers and McLaughlin 1994; Wallmo 1955), as a result of the geographic conjunction of a variety of floristic types (e.g. Rocky Mountain, Cordilleran, Sonoran, and Chihuahuan), complex topography, and variation of precipitation and temperature with elevation. There is an upward transition from Sonoran Desert scrub at around 1,200 meters to mixed-conifer forest at over 2,800 meters. The study site is located at the juncture of the Garden Canyon and Ramsey Canyon watersheds (figure 1). Elevation of the area sampled for fire history ranges from 1,829 to 2,590 meters. Stand structure was sampled at the boundary between Fort Huachuca (FHA) and the Miller Peak Wilderness area (MPW) at 2530 meters elevation. Portions of the site are within the perimeter of the 1983 Pat Scott Peak fire and the 1980 Sawmill Canyon fire.

METHODS

Sixty-five full and partial cross-sections from fire-scarred logs, snags, and stumps, including partial cross-sections from 10 living trees were collected (Arno and Sneck 1977) along an elevational gradient from 1,830 to 2,500 meters. Approximately half of the samples were from the Garden Canyon watershed (Fort Huachuca) and the other half were from within and adjacent to the burned area centered around Pat Scott Peak in the Miller Peak Wilderness Area. This site was chosen due to ease of access, ability to compare sites across a management boundary, and because the site is fairly representative of the ponderosa pine forest in this mountain range.

Cross-sections were surfaced with progressively finer sandpaper using a belt sander to clearly reveal the wood structure, then crossdated. Crossdating compares patterns of narrow and wide rings between samples allowing for exact calendar years to be assigned to annual growth rings (Stokes and Smiley 1968). Once crossdated, the years in which fire scars were present were recorded for each individual tree (Dieterich and Swetnam 1984). Other characteristics recorded were intra-ring fire-scar position and occurrence of injuries by unknown factors (Baisan and Swetnam 1994). Thirty living trees were cored to develop a local tree-ring width chronology to facilitate crossdating samples with fire scars.

Statistical analysis was performed on the fire interval data using FHX2 software (Grissino-Mayer 1995) that analyzes fire history data both temporally and spatially. Three measures of central tendency were computed: mean fire interval (MFI), median fire interval and the Weibull median probability interval (WMPI - Grissino-Mayer 1995). Other parameters calculated, were the standard deviation, coefficient of variation, skewness, kurtosis, and minimum and

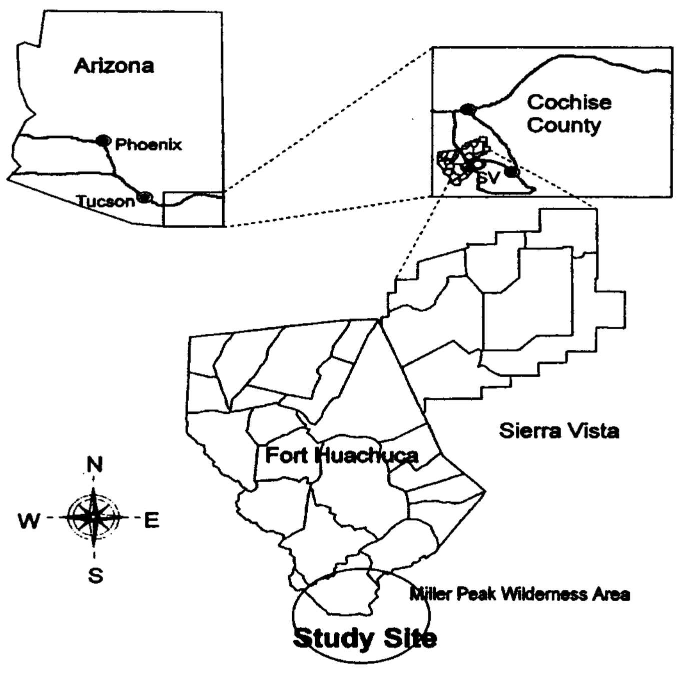

Figure 1—Location of study site at boundary between Fort Huachuca and the Miller Peak Wilderness area.

Table 1. Fire statistics using period of best sample replication 1689 to 1880. *ALL* is based on all fire events; *10%* (medium fires) and *25%* (large fires) with a sample depth of 3 or more trees scarred per fire event.

Statistic	All	10 pct.	25 pct.
Mean Fire Interval	4.5	4.9	8.4
Median Fir‹ Interval	4.0	4.0	5.5
WMPI (Weibull Distribution)	4.4	4.7	7.6
Standard deviation	2.3	2.4	6.4
Coefficient. of variance	0.51	0.49	0.76
Skewness	1.1	0.94	1.7
Kurtosis	0.5	0.06	1.72
Minimum interval	1	1	3
Maximum interval	11	11	26

maximum intervals between fires (table 1). Season of fire occurrence was estimated by the relative positions of fire scars within the annual ring. The seasonal estimates were based on knowledge of cambial growth in southwestern Arizona conifers (Baisan and Swetnam 1994; Dieterich and Swetnam 1984; Grissino-Mayer *et al.* 1994; Fritts 1976).

Six 100 meter transect plots were established to sample the age and size distribution of the forest community within the area of the fire-scarred samples. Trees >12 centimeters in diameter were cored and tagged with a metal tag every two meters along the length of each transect. This sampling strategy was chosen to yield a sufficient number of samples representative of tree composition, ages, and sizes for this area (Avery and Burkhart 1994). Cores were mounted and finely surfaced to define ring boundaries, then crossdated against the established chronology. Height of core from ground surface, diameter at core height, species, and distance from transect were recorded for each tree.

RESULTS

Fire History

The tree-ring chronology, developed from the increment cores and cross-sections, ranged from A.D. 1499 through A.D. 1995 (497 years). Of the 65 cross-sections obtained, 57 were used to reconstruct the fire history and to analyze spatial distribution of major fires in the Garden Canyon Watershed. The remaining samples were not datable for various reasons such as severely reduced ring growth, decay, or anomalous ring patterns. Figure 2 is a master fire

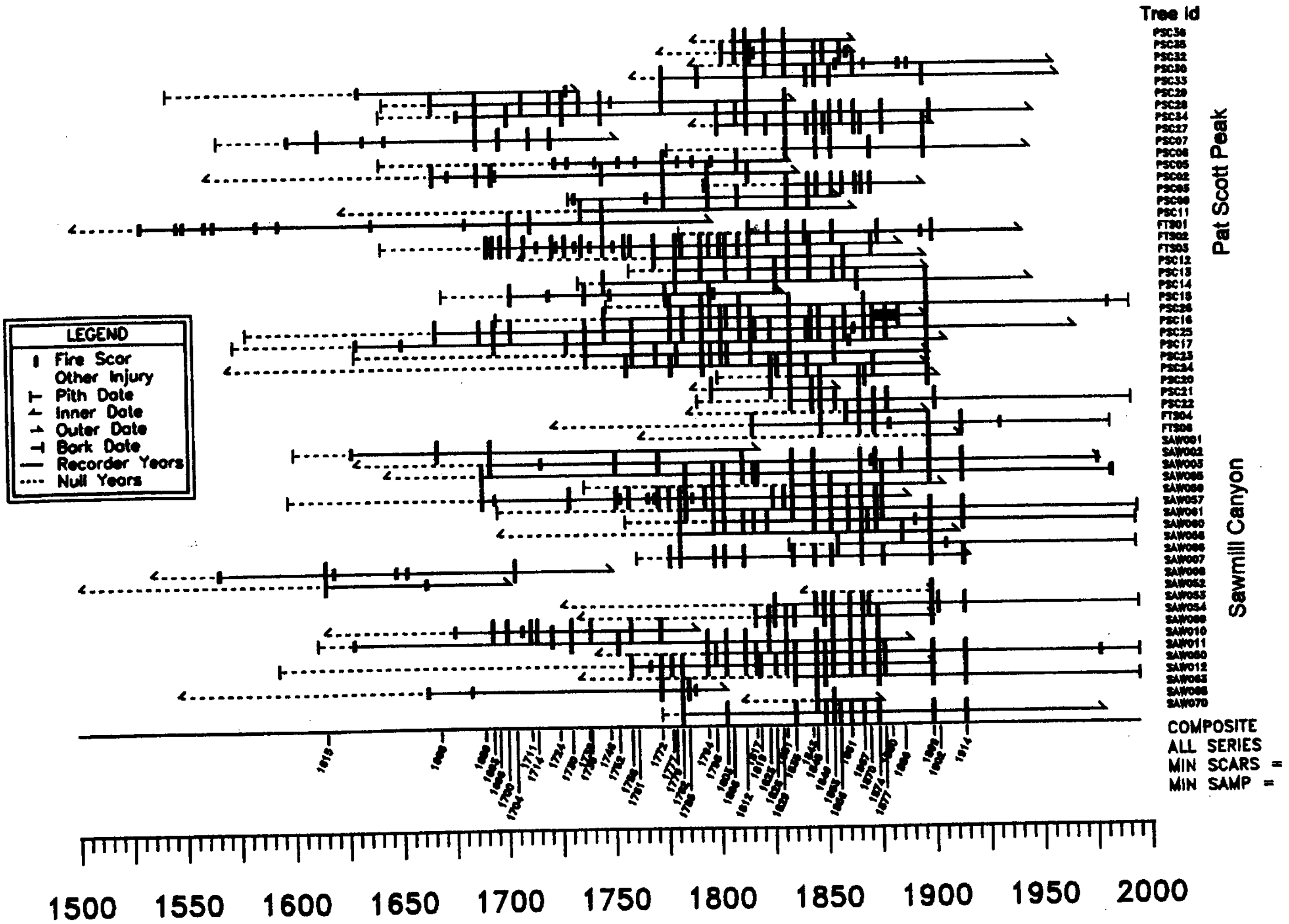

Figure 2. Master fire chronology of all trees, all fire events in the Garden Canyon Watershed. Each line represents a tree; each verticle line represents a fire scar.

chronology showing all trees with all fire years. As observed in many other Southwestern fire history studies, there is high synchrony among fire dates (Swetnam and Baisan, in press). Of 112 fire events, 38 percent were synchronous throughout the entire sample area (*i.e.*, fires were recorded by trees in both the upper and lower watershed), 44 percent were present in the upper watershed only and 18 percent in the lower watershed only.

Figure 3 shows the estimated patterns of seasonal fire occurrence. At least 90 percent of fires probably occurred before the summer monsoons began, typically before late June or early July.

The fire intervals during the analyzed time period were positively skewed. Because the mean is a less robust estimate of central tendency when the data are skewed, the data were modeled with the Weibull distribution. The Weibull is a flexible model designed to estimate means of non-symmetric data. Both the MFI and the WMPI show a range of 4 to 8 years. Table 1 describes summary statistics for the period of best sample replication 1689 - 1880. The "All" category includes all trees and all fire events. The 10 and 25 percent categories include only those fire events that were recorded by a minimum of 3 trees, thus excluding many of the fires that were probably less important in the study area or spatially patchy. Fire years in which 10 to 25 percent of the sampled trees were scarred are interpreted as intermediate-sized fires, and fire years in which greater than 25 percent were scarred are interpreted as relatively large fires.

Stand Structure

Tree recruitment patterns can be useful in determining effects of disturbances. Figure 4 shows a cumulative age distribution for each site by species. If recruitment and mortality rates were constant through time, this graph should, theoretically, be a straight line. However, the exponential shape of these curves empirically describes the observed tree ages, with few trees represented in older age classes and many trees in younger age classes. This pattern suggests a forest recovering from disturbance (Parker and Peet 1984), in this case the fire of 1899. Fort Huachuca transects (FHA) show more or less continuous recruitment of ponderosa pine (PIPO) since the turn of the century, with southwestern white pine (PIST), Douglas-fir (PSME) and Gambel oak (*Quercus gambelii* Nutt.)(QUGA) as minor components, with a pulse of recruitment around 1920. Miller Peak Wilderness Area (MPW) transects show a steep recruitment event of PIPO after 1890 and of PIST around 1930.

The largest pulse of recruitment for ponderosa pine in each site occurred between 1900 and 1910, possibly in response to the 1899 fire. From 1910 to 1950 however, southwestern white pine, Gambel oak, and Douglas-fir became well established, with recruitment matching that of ponderosa pine during the same period of time, probably in response to lack of fire, and to increased shading which favor these relatively shade-tolerant species.

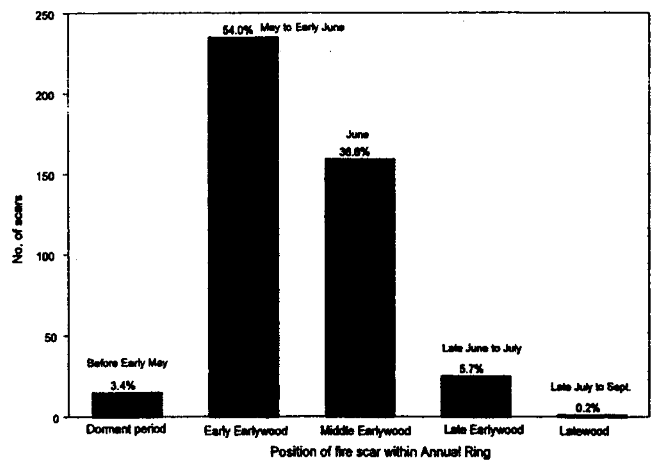

Figure 3. Estimated season of fire by identifying position of fire scar.

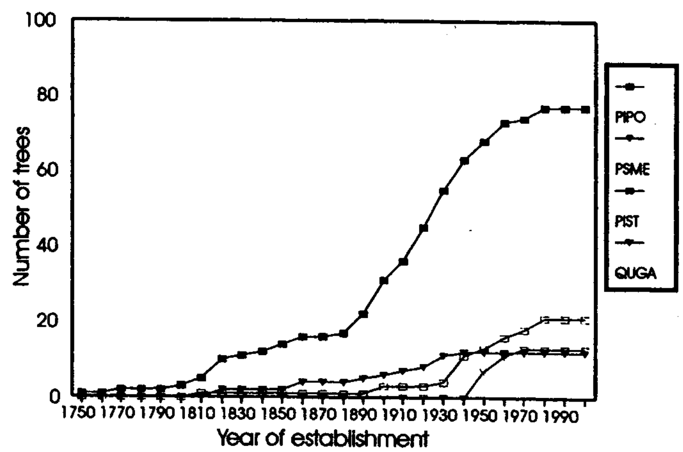

Figure 4. Cumulative 10-year age groups by species for each site (number of transects/site = 3).

DISCUSSION

The historical occurrence of widespread fires prior to 1880 suggests a continuity of fuels and few barriers to fire spread. The presence of multiple fire scars on many trees throughout the sampled area, and the presence of oaks many centuries old, are also an indication of widespread, low intensity fires. The 4 - 8 year mean fire interval is within the range of frequencies documented for similar studies in other Southwestern pine forests (Baisan and Swetnam 1990; Grissino-Mayer and others 1993; Swetnam and others 1992; Swetnam and Baisan, in press). The effects of past land use practices and fire suppression are reflected in these data. A pattern of very frequent fires of various sizes, both small and widespread, was interrupted in the late 1870s or early 1880s. Two widespread fires occurred after 1880, in 1899 and 1914. Following establishment of Fort Huachuca in 1877 there was extensive exploitation of timber, mineral, range and water resources in the Huachuca Mountains. The population of Euro-American settlers increased after this time, with the establishment of ranches on the plains surrounding the mountains, and development of sawmills and mines within the mountains (Bahre 1991; Hadley and Sheridan 1995).

Fuel consumption by the frequent surface fires most likely inhibited the occurrence of crown fires. In contrast to the low intensity pre-settlement fires, several large crown fires have occurred within the last 100 years in the Huachucas. The 1899 fire was the first in a series of severe, stand-replacing fires in the Huachucas that were probably associated with changes in forest structure. In the late 1800s logging was primarily carried out on "the Reef", a less precipitous area below Carr Peak. Logging was also conducted below Ramsey Peak on the military reservation. The 1899 fire terminated all large-scale logging operations (Wallmo 1955; Wilson 1995). Other catastrophic fires that occurred in the upper elevations of the Huachucas - Carr Peak in 1977 and Pat Scott Peak in 1983 - may have been due at least in part, to accumulation of fuels, both horizontally and vertically, leading to a cycle of infrequent, high-intensity fires.

Frequent fires before the 1880s served to keep fuel accumulation to a minimum and to keep stands relatively open by inhibiting establishment of less fire resistant species. Both the presence of Gambel oak and ponderosa pine individuals >200 years old on FHA suggest lower fire intensity and less human impact in this part of the watershed. While ponderosa pine is still the dominant tree species, lack of fire has probably encouraged growth of less fire resistant species such as Douglas-fir, Gambel oak, and southwestern white pine, and inhibited growth of ponderosa pine.

CONCLUSION

Fire is an important natural process that has influenced forest structural patterns and species composition in the Huachuca Mountains. During the last 100 years anthropogenic factors have also played an important role in structuring the forest community, promoting changes in the fire regime similar to those changes documented in other southwestern mountain ranges. The exclusion of fire has resulted in an encroachment of more shade-tolerant, less fire-resistant trees and a general decrease in the regeneration of ponderosa pine. Although areas within the study site that are still relatively open, (*i.e.*, wide grassy spaces between dominant ponderosa pine), other areas are becoming laden with fine fuels and needle cast, woody debris and multiple layers of fire-intolerant trees. Under the right climatic conditions or with careless human use of fire, these areas may be prone to another stand-replacing fire in the near future.

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