AN ASSESSMENT OF FIRE, CLIMATE, AND APACHE HISTORY IN THE SACRAMENTO MOUNTAINS, NEW MEXICO

Margot W. Kaye and Thomas W. Swetnam*
Laboratory of Tree-Ring Research
University of Arizona
Tucson, Arizona 85721

Abstract: Fire historians typically attribute the causes of temporal change in past fire regimes to climatic variation, human land use, or some combination of the two. Most long-term historical reconstructions, however, lack time and place-specific chronologies for all three variables of fire, climate, and people. To test the hypothesis that Mescalero Apache of southeastern New Mexico influenced fire regimes of the Sacramento Mountains, we reconstructed and compared chronologies of key variables for the period A.D. 1700 to the present. Fire-scarred trees were used to reconstruct fire frequencies and culturally modified (peeled) trees, and written histories were used to identify places and times of Mescalero presence. Independent precipitation reconstructions from tree rings were compared with fire and human histories. We found that Mescalero frequently visited the western escarpment of the Sacramento Mountains during the late 1700s through the late 1800s, especially the Dog Canyon area. Fire frequency was higher and seasonal timing of fires was different in sites near Dog Canyon compared to relatively distant sites. Interannual to decadal-scale drought might explain some temporal variability in fire and peeling activity, but these relationships were not consistent. We conclude that people increased fire occurrence during certain time periods in localized areas, but broad-scale and persistent human impacts did not occur until the end of the 19th century with the rise of livestock grazing by European settlers and fire suppression by government agencies. [Key words: Culturally modified trees, historical fire regimes, fire-climate-human interactions, Apache, New Mexico.]

INTRODUCTION

A powerful approach for studying ecological systems is the reconstruction and comparison of their natural and cultural histories. Historical comparisons can reveal the conditions under which ecosystems were sustained or changed by natural and human processes over meaningful time periods (Allen et al., 1998). Long-term perspectives are particularly relevant for the study of population dynamics of long-lived species, such as trees. Moreover, the need for understanding the historical range of variability of ecosystems in a human context has been emphasized recently in guidelines for ecosystem management planning (Swanson et al., 1993; Kaufmann et al., 1994, 1998; Morgan et al., 1994; Swetnam et al., 1999). Reconstructions of historical fire regimes from tree rings provide information to evaluate variations and trends in frequency, seasonality, and synchrony of fires on local to

*Margot Kaye is currently at the Department of Forest Sciences, Colorado State University, Fort Collins, CO 80524.

Physical Geography, 1999, **20**, 4, pp. 305–330.

regional scales. These data also are useful for identifying relationships between climate and fire (Swetnam and Betancourt, 1990; Swetnam, 1993; Veblen et al., 1999). However, if paleoecological reconstructions are to be used to define the "natural" range of conditions, or to investigate climate-fire relations, the potential confounding or interacting effects of human activities on past fire regimes also must be assessed (Baisan and Swetnam, 1997; Kitzberger and Veblen, 1997; Veblen et al., 1999). The extent of human impacts on pre-Columbian landscapes, particularly via altered fire regimes, has become a subject of considerable debate, with important implications for land management and conceptions of "naturalness" and "wilderness" (Denevan, 1992; Vale, 1998).

The historical impacts of humans on 20th century fire regimes are fairly well established. A typical finding of fire-history studies in pine-dominant forest ecosystems, for example, is that late 19th and early 20th century Euro-American settlement led to a nearly complete elimination of frequent, widespread, and low-intensity surface fires (e.g., Agee, 1993; Swetnam and Baisan, 1996a). Structural changes in ponderosa pine forests followed the removal of frequent surface fires and have resulted in increasing numbers of high-intensity crown fires in the late 20th century (Covington and Moore, 1994). In the Southwestern United States, we know that these changes were typically initiated by intensive livestock grazing and followed by organized, government fire suppression (e.g., Leopold, 1924; Savage and Swetnam, 1990; Touchan et al., 1995; Swetnam et al., 1999). Less well known, however, is the role of Native Americans in controlling or altering fire regimes in pre-settlement landscapes of the Southwest. (Note that the "pre-settlement" era in the Southwest varied greatly from one area to another within the region, with Spanish settlement beginning in some areas as early as the late 1500s.)

There is abundant evidence that Native Americans of the Southwest used fire for many purposes (Sonnichsen, 1973; Pyne, 1982; John and Wheat, 1989; Kaib, 1998). Dobyns (1981) and Pyne (1982) state that various Apache groups used broadcast fire extensively and frequently as a tool for modifying Southwestern landscapes. However, there are remarkably few reliable, eyewitness accounts of Apache setting fire to large areas of the landscape (i.e., broadcast burning). Nineteenth-century newspapers often reported hearsay accounts of "Apache-set" fires (Bahre, 1985), but the assertion of Apache origin for all or most of these fires must be questioned given the context of racism prevalent during those violent times, and the fact that most reports were during the normal lightning-fire season (i.e., May to July).

In a recent study of Southwestern archival documents (more than 200 text quotations), Kaib (1998) found that about 80% of historical references to fires set by people were in the context of warfare. All of the cultures involved (i.e., Apache, Spaniards, Mexicans, and Americans) used fire against their enemies, particularly for purposes of escape, for driving the enemy out of hiding, and for burning habitations, forage, and belongings. Among the many potential non-warfare uses of fire, broadcast burning for intentional vegetation manipulation at extensive spatial scales was not documented. It is unfortunate that, early in this century, professional ethnographers paid almost no attention to traditional Apache uses of fire. It is now

Fig. 1. A fire-scarred (left) and a peel-scarred ponderosa pine tree (right). Fire scars usually extend to the ground, and often have multiple overlapping ridges representing scarring by different fires through time. When scarred by more than one fire, the wood within the open wound is usually heavily charred. The tree in the photograph (left) shows a recent fire scar as the whitish colored wood around the perimeter of the old, charred wound. This scar was created by a recent prescribed burn. Peel scars (right) usually do not extend to the ground and typically were the result of a single peeling event. Peel scars also sometimes have evidence of cutting by sharp tools along the lower or upper margins of the wound. Charring is sometimes present on peel scars because surface fires in the vicinity of recently peeled trees easily ignite the copious resin flow and burn onto the old peel wound.

too late to interview the Apache survivors of the 19th century and ask them directly why, how often, and how extensively they used fire.

While collecting fire-scar specimens in the Sacramento Mountains for this fire-history study, we recognized a new and unique opportunity for assessing Native American influences on historical fire regimes. Pine trees scarred by the peeling of bark from the lower bole were found throughout the study area. Scars left from these peels are distinguishable from fire scars and other types of tree scars (Martorano, 1981; Swetnam, 1984) (Fig. 1). The peeling of tree bark by people to access the soft cambium is a widespread custom practiced by native cultures in Scandinavia and North America (Thwaites, 1905; Eidlitz, 1969; Barrett, 1985; Niklasson et al., 1994). Throughout the western United States, Native Americans peeled trees and harvested the products for a variety of nutritional, medicinal, and other uses (White, 1954; Martorano, 1981; Churchill, 1983; Swetnam, 1984; Corral, 1997).

We found documentary sources specifically referring to these practices by the Mescalero Apache in the Sacramento Mountains (Bailey, 1902; BIA, 1981).

Dendrochronological dating of peel scars can provide annually to seasonally resolved dates for the peeling events. Hence, chronologies of peeling events provide a means to identify specific times when Native Americans were in particular locations (Swetnam, 1984). We exploited this opportunity to compare fire history from fire-scarred trees with the evidence of Mescalero Apache presence from peel-scarred trees. We also used a comparative, spatial approach similar to that employed by Barrett and Arno (1982). They used documentary evidence and inference to identify fire-history study sites with different frequency of use by Salish and Kootenai peoples of western Montana. We used a combination of documentary and tree-ring (peeled trees) evidence to identify and evaluate sites with different frequency of use by Apache. We also evaluated possible temporal associations of fire and peel events with climatic variations. For this analysis we used a recent tree-ring reconstruction of annual precipitation and drought indices for southern New Mexico. In addition to discussion of climate-fire-Apache relations, we also review our current understanding of peeled ponderosa pine trees and their historical importance.

STUDY AREA

Physical Setting

The Sacramento Mountains are located at the far southeastern corner of the Basin and Range province in south-central New Mexico. The north-south—oriented massif has a steep escarpment on the west side rising abruptly above the Tularosa Basin, and a gradual eastern slope descending into the Pecos River drainage and the Great Plains (Pray, 1961). The west escarpment has a stepped profile with a large bench forming the prominent step. The bench ranges in elevation from 2380 to 2430 m and is dissected by a series of deep east-west canyons that alternate with high ridges. Ridges and canyons below the bench are steep with vertical cliffs and outcrops, making them impassable except on foot in some places. In contrast, the slopes above the bench are relatively unbroken. Our collection sites are located within and above the deep canyons that dissect the west face of the central portion of the Sacramento Mountains (Fig. 2).

Mean annual precipitation of the Sacramento Mountains is 659 mm (Karl et al., 1983). Sixty to 70% of precipitation derives from monsoonal storms in June through September (Alexander et al., 1984). The remaining annual precipitation (210 to 300 mm) falls in the winter in the form of rain and snow originating in continental and polar air masses from the northwest and west. Lightning strikes in late spring and through the summer are characteristic of Southwestern mountains and are a primary cause of wildfires (Barrows, 1978). Lightning is remarkably frequent during the summer in New Mexico, with many hundreds of strikes per week occurring at the scale of the Sacramento Mountains (Gosz et al., 1995).

Ponderosa pine (*Pinus ponderosa* var. *scopulorum*) stands on the west escarpment extend downslope into the shallow canyon heads. These "gallery forests" are

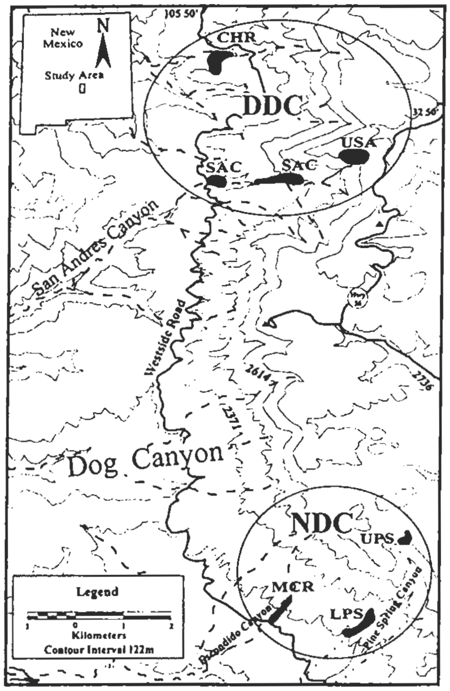

Fig. 2. Location of the study area on the west-facing escarpment of the Sacramento Mountains, New Mexico. Sites were located near the mouth of Dog Canyon (NDC) and relatively distant from Dog Canyon (DDC). The Dog Canyon area was often used by the Mescalero Apache because of its vantage point and a reliable water source.

surrounded by piñon-juniper stands (*P. edulis* and *Juniperus deppeana*) on the bench, and by extensive gambel oak (*Quercus gambelii*) clones on the slopes above. Other conifer species mix with ponderosa pine in the uppermost heads of the canyons extending to the top of the escarpment. On cooler north-facing slopes, these mixed-conifer stands include varying proportions of ponderosa pine, Douglas-fir (*Pseudotsuga menziesii*), Southwestern white pine (*P. strobiformus*), white fir (*Abies concolor* var. *concolor*), and quaking aspen (*Populus tremuloides*).

The six collection sites were upper and lower Pine Spring Canyon (three-letter codes in Fig. 2 are UPS, LPS), a southern fork of Escondido Canyon (MCR), Cherry Canyon (CHR), and upper and lower San Andres Canyon (USA, SAC). The canyons are located within 8 km of each other. The lower and upper elevation sites range approximately from 2100 to 2750 m. The lower elevation sites (LPS, MCR, SAC, CHR) span the ponderosa pine/piñon-juniper ecotone and the upper elevation sites (UPS, USA) are located in mixed-conifer stands.

Land Use History

The Sacramento Mountains have a long history of human occupation extending back at least 12,000 years (Tagg, 1996). Here we review the best documented period of human activity within the study area from the 18th century to present (see also Kauffman et al., 1998). Three groups of people were responsible for the principal land uses during this period—Mescalero Apache, Euro-American settlers, and modern land managers.

The activities of the Mescalero Apache in the Sacramento Mountains were often related to conflict with Spaniards and neighboring indigenous groups, such as the Comanche. The Mescalero used the west escarpment as a stronghold and hideout. They took refuge here from attacks and brought goods taken from the nearby Spanish settlements (Thomas, 1969; Betancourt, 1981). Numerous documents note the presence of the Mescalero Apache in the vicinity of Dog Canyon in the second half of the 1700s, a period of frequent conflict between the Spaniards and the Mescalero (Thomas, 1969). Dog Canyon (Fig. 2) provides a narrow passageway from the Tularosa Basin to the higher, forested elevations of the Sacramento Mountains. The canyon provided an ideal natural fortress for the Mescalero because of its narrow defile. Enemies following the Apache up the canyon were forced to expose themselves to attack while climbing (Sonnichsen, 1973; Betancourt, 1981). During the late 1700s and through the 1800s Spanish and American soldiers reported Mescalero presence and campsites in the vicinity of Dog Canyon (Sonnichsen, 1973). It is likely that the Apache typically saw the Spaniards and Americans first because their high perch on the bench provided views extending dozens of miles across the Tularosa Basin. In addition to its defensible characteristics, the canyon had a reliable spring and the surrounding forested area had adequate forage (Basehart, 1974).

In 1862, the U.S. Army launched a campaign against the Mescalero. In a major battle near the lower end of Dog Canyon, a reported force of about 500 Mescalero Apache were "routed" (Betancourt, 1981). In 1863, about 300 Mescalero were relocated to a reservation at Bosque Redondo near Fort Sumner, New Mexico. In 1865, most of these people escaped back to the Sacramentos. During the 1870s, the Mescalero were moved back and forth to various reservations with individuals and groups of Apache often escaping and hiding out in the rugged canyons of the Sacramento Mountains.

Beginning in the late 1800s, European settlers and modern land management agencies became the dominant influence on the landscape of the Sacramento Mountains (Kaufmann et al., 1998). The first and most extensive impact was the grazing of large numbers of livestock. The Spaniards had introduced sheep and goats to New Mexico in the late 1500s, but not until the 1880s did the number of animals rise to very high numbers (Cox, 1959; Denevan, 1967; Dahm and Geils, 1997). Grazing continued in New Mexico through the 20th century but sheep grazing declined after World War I (Alexander et al., 1984; Kaufman et al., 1998).

Logging was extensive in the Sacramento Mountains during the late 1800s and the 1900s. Timber was extracted for building and maintaining railroad and mining structures (Glover, 1984; Kaufmann et al., 1998). Organized fire suppression by government agencies began during the 1910s in the western United States, and has continued to the present (Pyne, 1982; Alexander et al., 1984).

METHODS

Field Methods

Collection sites were selected after conducting a thorough reconnaissance of the west slope of the mountains. We selected sites in ponderosa pine and mixed conifer forests across an elevation gradient. Accessibility and availability of fire-scarred specimens were important criteria in selecting sites. A chain saw was used to cut full and partial sections from fire-scarred logs, snags, and stumps. Partial sections were obtained from a few living trees (Arno and Sneck, 1977). Full and partial sections also were collected from dead peeled trees. Multiple increment cores were extracted from living peeled trees in order to date the peel scars (Swetnam, 1984).

Laboratory Methods

Dry cross sections were re-sectioned with a band saw to expose buried scars and to prepare a smooth surface for sanding. A belt sander was used with progressively finer grits from 150 to 400. Cores were dried, glued on routed wooden mounts, and sanded. All cross-sections and cores were crossdated using variations in ring width, latewood widths, and false ring patterns to assign calendar years to each growth ring (Stokes and Smiley, 1968; Swetnam et al., 1985). Calendar years were assigned to each peel and fire scar by observing their location in the dated annual rings.

The seasonal timing of fire and peel events was estimated by determining relative position of the scars within annual rings (Dieterich and Swetnam, 1984; Baisan and Swetnam, 1990). Scar position was divided into six categories—dormant (D), early earlywood (E), middle earlywood (M), late earlywood (L), latewood (A), and undetermined (U). We estimated the approximate calendrical periods for each of the scar positions based on our knowledge of cambial phenology of Southwestern conifers (Fritts, 1976; Baisan and Swetnam, 1994).

Statistical distributions of historical fire intervals were described for each of the six collection sites for the period of analyses. The period of analysis in a collection site began and ended on the first and last fire year represented by more than two samples. Mean fire interval (MFI) and standard deviation, as well as maximum and minimum fire intervals, were determined for the six collection sites using the program FHX2 (Grissino-Mayer, 1995). Median fire intervals and other measures of central tendency also were estimated using Weibull functions fitted to the interval distributions (Grissino-Mayer, 1995). Differences between other measures of central tendency and the MFIs were always relatively small (i.e., less than 1 year), so here we report only the MFIs. MFIs were based on all fires represented by fire-scarred specimens within the period of analysis. We also computed and plotted decadal sums of fire dates (i.e., decadal fire frequency) to assess temporal changes in fire frequency among all trees, sites, and groups of sites.

Spatial patterns were evaluated by grouping fire-scar data based on proximity to Dog Canyon—that is, inferred degree of influence of Mescalero Apache in the past. Three collection sites were located near the head of Dog Canyon, and three were located approximately 4 km north, at the head of an adjacent canyon (Fig. 2). Proximity and distance to Dog Canyon were considered to be of relevance because of the documented high use of the Dog Canyon area by the Mescalero, especially in the late 1700s. For comparative purposes, the two groups were called: NDC for "near Dog Canyon" and DDC for "distant from Dog Canyon" (Fig. 2). NDC was composed of the three collection sites: MCR, LPS, UPS; DDC was composed of the three sites: CHR, SAC, USA. Decadal sums of fire-scar dates were computed and plotted for the entire study area and the site groupings.

We compared tree-ring-reconstructed annual precipitation (from August of the previous year through July of the current year, Grissino-Mayer et al., 1997) with fire and peel histories to assess possible climate relations. We also compared fire and peel data with a reconstructed June to August Palmer drought severity index (PDSI) (Cook et al., 1999). These two reconstructions were of excellent quality (by dendroclimatic standards). The percentage of variance explained (R^2) in the calibrations with 20th century meterological data was about 80% for the precipitation reconstruction and about 60% for the PDSI reconstruction. The temporal variations in the two reconstructions were similar ($r = .71$), as were the results of their comparisons with the fire and peel data, so here we illustrate only the precipitation/fire/peel comparisons. The tree-ring based precipitation and drought reconstructions were independent of the fire and peel history reconstructions because they were based on measured ring-width chronologies from hundreds of trees in numerous sites distributed throughout southern New Mexico.

Time series plots of decadal fire and peel frequencies and smoothed annual precipitation values were graphically compared to evaluate long-term patterns and trends. Superposed-epoch analyses (Baisan and Swetnam, 1990; Swetnam and Betancourt, 1992, 1998; Grissino-Mayer, 1995; Veblen et al., 1999) were conducted to test for possible relations between inter-annual precipitation and fire/peel patterns. In these analyses the mean and variance were computed for precipitation and drought indices in years before, during, and after a set of widespread fire years. The widespread fire years were defined as fire years recorded by fire-scarred trees in two or more of the sampled sites. A similar set of analyses was conducted using all peel dates, and peel dates recorded by two or more trees. Monte Carlo simulations were used to determine the probability levels for the mean drought conditions during event years and lagged years (Swetnam and Betancourt, 1992).

RESULTS

Fire-Scar Data

The fire-history reconstruction in the Sacramento Mountains was based on 183 fire-scarred samples from 124 trees in six sites (Table 1, Fig. 3). Of the sampled fire-scarred trees, 71% were ponderosa pine, 17% Southwestern white pine, 5% piñon pine, 5% Douglas-fir, 1% white fir, and 1% gambel oak. Fire dates were determined for 765 fire scars, spanning the period A.D. 1580 to 1915. Mean fire intervals (MFIs) for the collection sites ranged from 3.7 to 7.2 years (Table 1). The periods of analysis ended in the late 1800s for all collection sites, concurrent with Euro-American settlement of the Sacramento Mountain area. The striking effects of early intensive live-

Table 1. Summary of Collection Sites and Fire-History Data

Site	Site name	Elevation (m)	Vegetation type[a]	No. of trees sampled	Period of analysis (yrs)	MFI (±SD)[b] (yrs)	Range of intervals (yrs)
CHR	Cherry Canyon	2,190–2,260	PIPO	9	1763–1886	7.2 (5.3)	2 to 23
MCR	Lower Escondido Canyon	2,200–2,250	PIPO	29	1754–1879	3.8 (3.5)	1 to 18
LPS	Lower Pine Spring Canyon	2,230–2,320	PIPO	17	1716–1879	3.7 (2.8)	1 to 12
SAC	Lower San Andres Canyon	2,300–2,490	PIPO	26	1748–1886	4.1 (2.8)	1 to 11
UPS	Upper Pine Spring Canyon	2,710–2,740	MC	24	1648–1899	4.1 (2.6)	1 to 13
USA	Upper San Andres Canyon	2,710–2,790	MC	21	1627–1879	5.7 (4.1)	1 to 18

[a]PIPO = Ponderosa pine forest; MC = Mixed-conifer forest.

[b]Mean fire interval (MFI) plus or minus standard deviation (SD) based on all fires in period of analysis.

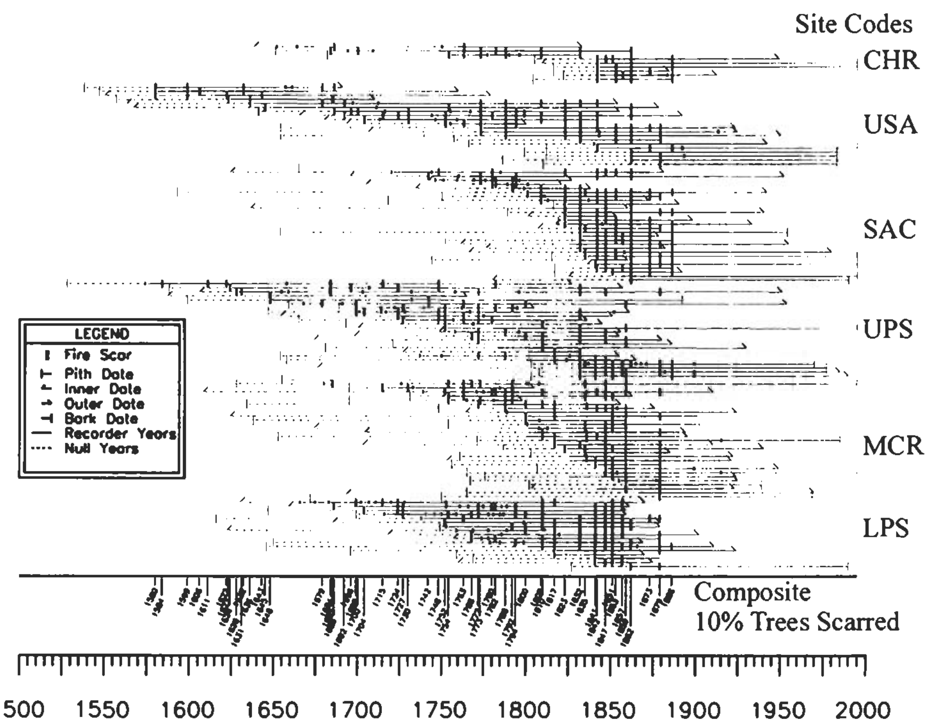

Fig. 3. Master fire chronology for all sites and fire-scarred trees within the study area. Horizontal lines are the sampled time spans for individual trees and vertical black tick marks are fire dates recorded on those trees. A composite record of fire dates is shown at the bottom. The composite dates are relatively widespread fires recorded by at least two trees and at least 10% of the trees susceptible to scarring (i.e., they had been scarred at least once before). The longer tick marks correspond to these widespread fires, whereas the short tick marks are fires recorded by less than one tree or fewer than 10% of susceptible trees. The site codes corresponding to the locations on the map (Fig. 1) are shown on the left.

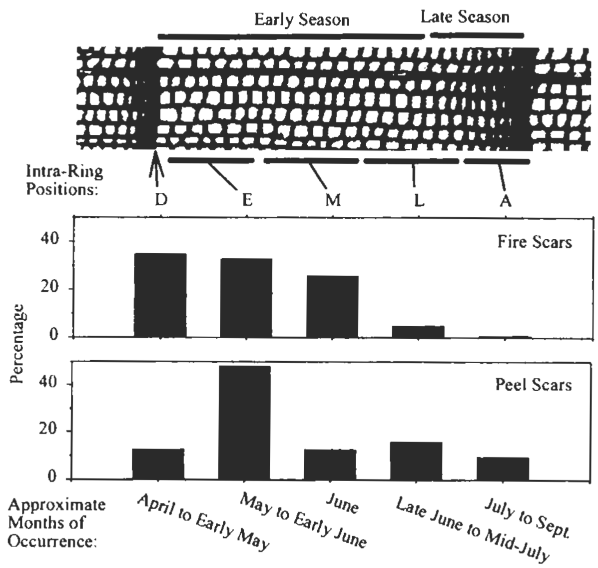

Fig. 4. Intra-annual positions of fire and peel scars. The percentage for each position was computed by dividing the number of scars in a given class by the total number of scars with identified position. The relative position within the annual ring and estimates of approximate calendrical dates are shown by the graphic at the top and the x-axis labels. The labels for the positions are: (D) dormant-season scars located on the boundary between two annual rings; (E) early-earlywood scars located within the first one-third of the earlywood; (M) middle-earlywood scars located within the second one-third of the earlywood; (L) late-earlywood scars located within the third one-third of the earlywood; and (A) latewood scars located within the latewood.

stock grazing and later fire suppression is very obvious in the master fire chronology chart as a near complete elimination of frequent, widespread fires after 1886 (Fig. 3).

Intra-annual ring positions of scars were determined for 92% of the fire scars; the positions of the other scars were unclear because of decay or suppressed growth in the area of the fire scars (Fig. 4). Of the 628 fire scars with ring position identified, 94.5% occurred in the dormant, early-earlywood, and middle-earlywood portion of the rings (DEM)—that is, the early portion of the growing season. Only 5.5% occurred in the late-earlywood and the latewood portion of the rings (LA). We interpret the DEM categories of fire scars to typically represent fires that occurred approximately from late April through June and LA fires from late June to September. The calendar dates for the different intra-ring positions shown in Figure 4 are estimates for typical years, although the actual timing during some extreme dry or wet years could have been different. For example, during very dry years we have noted that growth initiation may be delayed well into May or even June.

Peel-Scar Data

We collected and dated 45 peel scars from 36 ponderosa pine trees and one Southwestern white pine (Table 2; Fig. 5). One tree had three peel scars, five trees

Table 2. Summary of Peel-Scar Data

Site code	No. of peels	Species[a]	Peel dates[b]
CHR	1	PIPO	1850
MCR	25	PIPO	1772, 1781, 1783, 1784, 1799, 1800(4), 1824(3), 1834, 1835, 1838, 1839, 1840, 1846, 1852, 1860, 1862, 1865, 1877(2), 1878, 1879
LPS	3	PIPO	1800, 1834, 1879
SAC	5	PIPO	1810, 1823, 1837, 1855, 1861
UPS	8	PIPO	1782, 1794, 1799(3), 1800, 1801, 1810
USA	3	PIPO PIST	1810, 1833(2)

[a]Species of sampled peeled trees. PIPO = *Pinus ponderosa* var. *scopulorum* Engelm; PIST = *P. strobiformus* Engelm.

[b]Numbers in parentheses represent number of peel scars for that year.

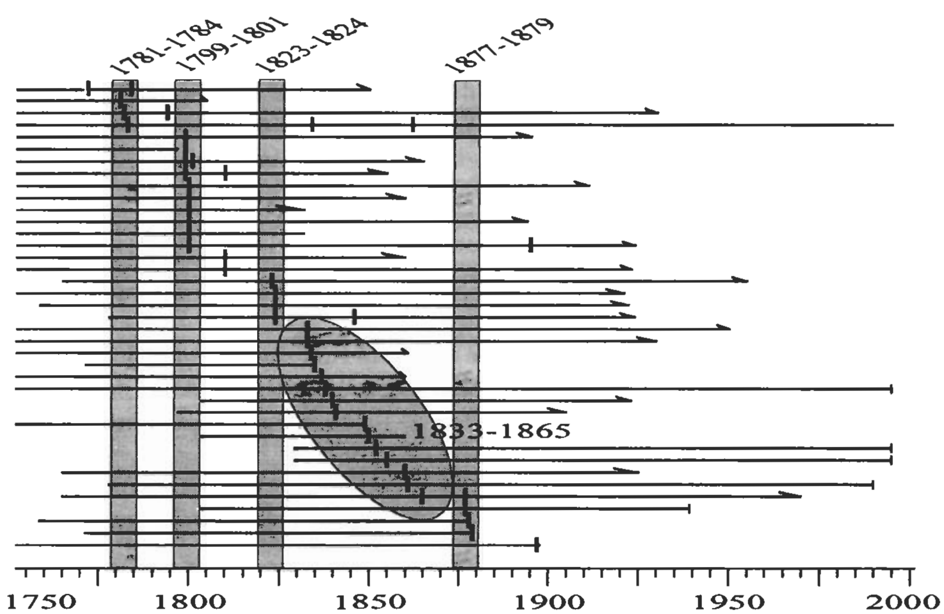

Fig. 5. Master chronology of peel-scar dates. Each horizontal line represents a tree and each vertical dash represents a peel-scar date on that tree. Gray areas highlight periods with either clustered peel dates (vertical boxes) or frequent, near-annual peel dates (oval area).

had two, and 31 trees had single peel scars. Peeled trees and remnants of peeled trees (i.e., logs and snags) were found in all six collection sites, and MCR had the largest number (20).

Intra-annual scar position was difficult to determine for many of the peel scars because of decay, insect galleries, and concentrated resin in the area of the scars. We determined position for 67% of the peel scars. The largest number of scars was located in the first one-third of the earlywood portion of the annual ring (E category, 48%) (Fig. 4). These peeling events probably occurred during middle to late spring—that is, from April (or earlier) to early June.

Although dates of peel scars were dispersed throughout the period from 1772 to 1879, four clusters of peel dates were apparent (Fig. 5). Four of 43 peel scars dated to the years 1781 to 1784, 11 dated to the years 1799 and 1800, 4 dated to the years 1823 and 1824, and 4 between the years 1877 and 1879. Between the years 1833 to 1865, peeling occurred almost annually on single trees, except two trees that were peeled in 1833. Consecutive-year sequences of peeling events occurred from 1833 to 1835, 1837 to 1840, and 1860 to 1862.

Comparison of Fires, Peels, and Droughts

Long-term changes in fire or peel frequencies suggest possible association with some decadal-scale droughts, but these patterns were not consistent through time (Fig. 6). The highest fire frequencies occurred in the 1750s through the 1790s and the 1840s to 1850s. The major droughts of the late 1770s to 1780s and 1840s to early 1860s coincide approximately with these peak fire frequencies. Contrary patterns, however, occurred during the wet periods between the late 1750s to early 1870s (high fire occurrence) and dry periods of the late 1720s to mid 1730s, 1800s, and late 1810s to early 1820s (low fire occurrence). Likewise, most of the clustered and consecutive-year peeling dates coincided with dry periods, but those during the 1830s and 1840s did not (lower graph, Fig. 6).

The results of the superposed-epoch (SEA) analyses indicated that inter-annual patterns of precipitation were not significantly associated with widespread fire events over the whole study area and time period of best sample replication in the fire-scar data set (1700 to 1900). However, when the analyses were performed using century-length periods before and after 1800, the fire years were found to be, on average, significantly drier than might be expected by chance ($p < .05$) during the post-1800 period (Fig. 7), but not the pre-1800 period. Wetter conditions were indicated in the year immediately preceding the fire years (lag year -1), but this pattern was not statistically significant ($p > .05$). Similar inter-annual patterns were revealed using the PDSI time series in SEA (results not shown) (i.e., dry fire years and the preceding year was wet), but the mean conditions during fire years and lagged years were not significantly different from the values that might occur by chance ($p > .05$) in either period (pre- or post-1800).

The SEA using peeled tree dates compared to the precipitation and PDSI time series showed no significant inter-annual patterns. Long-term (i.e., decadal-scale) droughts, however, coincided with most peeling episodes (Fig. 6). These contradictory results may have reflected the approach used in SEA of computing averages of conditions preceding, during, and following all events. The numerous peeling dates during the relatively wet 1830s, in particular, may have overwhelmed the drier con-

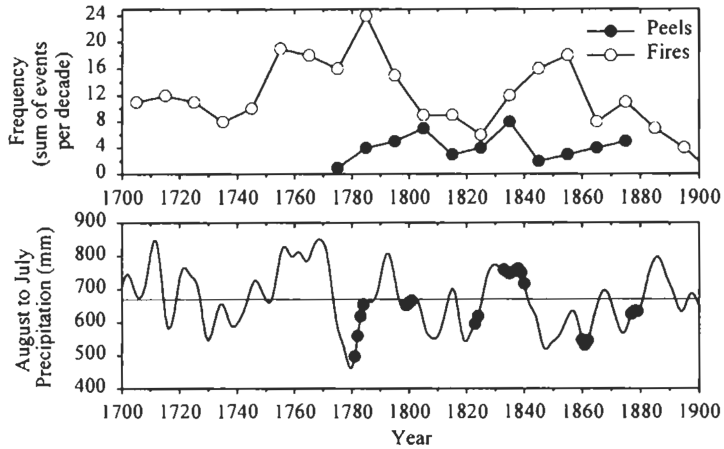

Fig. 6. Upper graph is the frequency of peel and fire events within the study area. The fire and peel frequencies are sums of all fire or peel dates per decade recorded by any tree and site. Decadal values are plotted at mid-decade (e.g., 1705, 1715) The lower graph is the annual precipitation (August through July) for the southern Rio Grande Basin (Grissino-Mayer et al., 1997). This series was smoothed with a 13-weight low-pass filter to emphasize decadal-scale variations. The black dots superposed on the precipitation series are the dates of all synchronous and consecutive-year peeling events.

ditions during other clustered peeling events. It is also possible that there was simply a lack of consistent inter-annual patterns among all of the peel events.

Spatial Differences in Peel and Fire Frequencies

Comparison of peel and fire-scar data from the site groups near (NDC) and distant from (DDC) Dog Canyon showed that timing and frequency varied between the two groups (Fig. 8). Peeling began at NDC in 1772 and continued through the 1870s, while peeling began at DDC only after 1800 and continued through the 1860s. Higher peel frequency also occurred in NDC than DDC during the 1860s. The earlier occurrence of peeling events in the late 1700s, and higher peeling frequency after the 1850s in NDC compared to DDC, coincides with differences in the timing and frequency of fires in the two areas (Fig. 8). Early-season fires tended to be more frequent in NDC than DDC through the 1700s and 1800s, except during certain periods (i.e., the 1740s to 1750s, 1790s, 1840s to 1850s, and 1880s). Late-season fires were infrequent in both areas, but during the 1760s to 1780s no fires were recorded in DDC, whereas a cluster ocurred in NDC. This peak in late-season fires approximately corresponds with the beginning of tree peeling at NDC (Fig. 8).

DISCUSSION

Historical Fire Regimes

The most notable change in fire regime characteristics occurred at the beginning of the 20th century, concurrent with fire exclusion from most western North Amer-

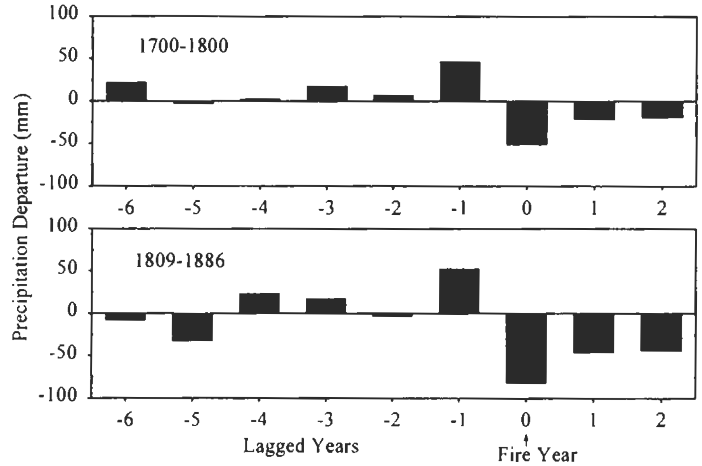

Fig. 7. Mean annual precipitation departures before, during, and after relatively widespread fire years. Twenty fire dates were composited for the early period (1700 to 1800) shown in the upper plot and 17 were composited for the later period (1809 to 1886) shown in the lower plot. Departures were computed as the difference between the mean precipitation during the composited years and the mean precipitation for the whole period of analysis. Only one significant departure (fire year, $p < .05$), indicated with an asterisk in the lower plot, was identified in the Monte Carlo simulation.

ican pine forests by Euro-American settlement and government agencies. Post-settlement fires were rare in all forest types. Prior to this extreme change, fires were generally frequent but variable through time (Figs. 3, 6, and 8). Historical ponderosa pine and mixed conifer fire regimes of the Sacramento Mountains were similar to those of other forests in the Southwestern United States (Swetnam and Baisan, 1996b).

Some of the variability in fire intervals through time (i.e., fire frequency) was linked to variability in precipitation. The pattern of higher fire frequencies during the middle and late 1700s and during the mid-1800s, with decreased fire occurrence during the early 1800s, was repeated in numerous mountain ranges throughout the Southwest. In regional studies of fire and climate patterns, Swetnam and Betancourt (1992, 1998; Grissino-Mayer and Swetnam, in press) found evidence that the amplitude of wet/dry oscillations on time scales of 2 to 7 years was highest during the high-fire-frequency periods of the mid- and late 1700s and 1800s, but lowest during a low-fire-frequency period of the early 1800s. We hypothesize that extreme wet years, followed by extreme dry seasons and years, were key climatic conditions promoting extensive burning. Other paleoclimatic reconstructions from around the world based on ice cores, corals, and tree rings suggest that the Southern Oscillation, which is associated with cool-season precipitation patterns in the Southwest, was reduced in amplitude during the early 1800s (Swetnam and Betancourt, 1998). In many Southwestern fire-history sites there is an obvious decreased fire frequency around 1800, with the longest fire-free intervals of the 18th or 19th century occurring between about 1780 and 1840. These sites also tend to show a

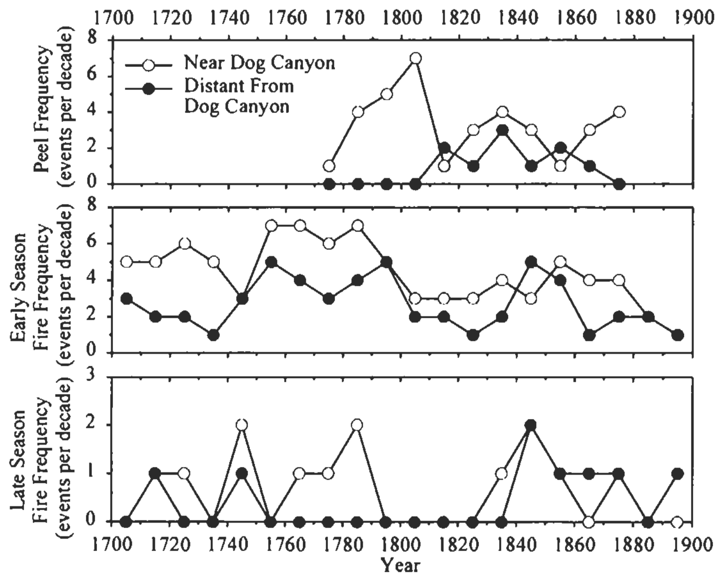

Fig. 8. Peel and fire frequencies plotted by sites grouped near to and distant from Dog Canyon. The lower two graphs show fire frequencies sorted by proximity to Dog Canyon and by seasonal timing. The fire and peel frequencies are sums of all fire or peel dates per decade recorded by any scarred tree. Decadal values are plotted at mid-decade (e.g., 1705, 1715). Early-season fires were recorded in intra-ring positions D, E, and M, whereas late-season fires were recorded in positions L and A (see Fig. 4, and the text for explanation).

pattern of greater synchrony among fire-scar dates during the mid- and late 1800s than before 1800 (Fig. 3).

Although the regional wave-like pattern (i.e., high-low-high) of 18th and 19th century fire frequency was generally duplicated in the Sacramentos, there also was a lack of consistency in climate-fire patterns at the decadal and inter-annual scales. This is not too surprising for a couple of reasons. For one, human effects on fire occurrence probably were important during certain times and places in our study area, as discussed further below. Local, human-caused changes may have overwhelmed or confounded the climate-fire patterns. Second, we would not necessarily expect climate-fire patterns to be expressed very strongly at the spatial scales of a watershed or single mountain range. At this scale, local topography, human land uses, and chance effects could easily overwhelm climate-fire patterns that are more obvious and consistent at regional scales in aggregates of many case histories (Swetnam and Betancourt, 1998; Veblen et al., 1999).

Peel Scars

Native Americans peeled the bark of trees for various products, including the bark, soft phloem and xylem layers (called inner bark), and the pitch or sap. The inner bark contains a transport system (phloem) for moving nutrient-rich fluids from the crown to the roots of a tree. These fluids and the unlignified xylem and phloem cells can provide a source of carbohydrates and nutrients useful to humans (Dimbleby, 1967; Martorano, 1981). Although many uses of peel products have been documented, the principal one was food (Swetnam, 1984; Wilkinson, 1997). Native Americans also peeled or scarred trees for other purposes, such as trail blazes, symbolic carvings of various types, and to induce trees to grow in certain shapes for products (e.g., bow staves, and canoe prows) (Mobley and Eldridge, 1992; Wilkes, 1998).

It is unclear at this time whether inner bark was a regularly exploited food, a hard-times food, or both. Based on our reviews of historical documents and modern studies of peeled trees (Swetnam, 1984; Wilkinson, 1997), we suspect that the predominate usage pattern varied from region to region, tribe to tribe, and from one time period to another. Overall, the nutritional value of pine inner bark seems to be relatively low compared to many other foods that normally would be accessible (Martorano, 1981).

It is evident that some Native American groups in northwestern North America commonly used inner bark as a seasonal food. White (1954), for example, reported that inner bark of pines was seasonally harvested with the bitterroot by the Flathead Indians in western Montana, which could explain the relatively large number of extant peel scars found today in the Northwestern region (e.g., Churchill, 1983). Several sites in northern New Mexico have more than 100 peeled trees (Swetnam, 1984; Corral, 1997), but overall, these features are rare in the Southwest. The groups of peeled trees we found on the west escarpment of the Sacramento Mountains are the largest we know of in southern New Mexico or Arizona. This suggests that tree peeling by Apache in this region occurred on an irregular and infrequent basis and perhaps most often was associated with hard times such as drought and warfare.

In a previous case study, Swetnam (1984) concluded that a small group of peeled trees in the Lilley Park area of the Gila Wilderness (approximately 300 km west of the Sacramentos) was probably used as a hard-times food by Gila Apache (possibly a sub-group of the Chiricahua Apache) during a single historic event. The dated peels had a common peeling date (1864) that coincided with a period of military persecution of the Gila Apache. Documentary evidence places the Gila Apache in this area at this time and supports the hard-times hypothesis. Specifically, a quote from the Apache leader of this group indicated that they were hungry and hiding out in this area in the spring of 1864 following bloody skirmishes with the United States Army during 1863. Other studies in the Southwest indicate that Native American groups used peels as a hard-times food, but not exclusively (Castetter and Opler, 1936; Basehart, 1974; Schroeder, 1974). The use of inner bark as a "regular," "seasonal," or "hard-times" food may have depended largely on the current state of the group in question. For example, pine trees may have been peeled regularly (i.e., every year) during particularly difficult decades, or perhaps intermittently as a delicacy or novelty item during easy times.

There are several possible explanations for the first appearance of peel dates within the study area in the Sacramento Mountains at the end of the 18th century: (1) the first arrival of the Mescalero in the area, (2) the beginning of a new cultural practice among the Mescalero who were already present, or (3) the absence of peel scars remaining on the landscape from the period prior to 1772 because of the loss of these trees through decay, fire, and logging. We think that the first or second explanations are the most probable. The first explanation is supported by historical documents indicating that Mescalero Apache had increased conflict with, and were driven to the mountains by, Spaniards during the second half of the 1700s (Opler and Opler, 1950). This timing also coincided with the beginning of peel dates in the study area and a maxima in fire frequency.

The second explanation is supported by an interesting observation of the entire set of peeling dates that we have amassed from the Southwest (Swetnam, 1984; unpublished peeled tree dates on file at the Laboratory of Tree-Ring Research, University of Arizonz, Tucson, AZ). Among the more than 150 peeling dates from 10 sites, no dates are earlier than 1772. There were only three peeling dates in the 1700s, and these are all clustered in the 1770s (1772, 1774, and 1777). These peeled trees were located in the three largest groups that we know about in the Southwest: respectively, (1) our study site in the Sacramentos; (2) near El Valle, New Mexico; and (3) in the Warm Springs area near Picuris, New Mexico. We have no reason to believe that loss of older peeled trees through natural tree mortality, decay processes, or logging were important in causing this pattern because many other older trees, including trees with much older fire scars, were abundant in these areas. Although more sampling and dating work is needed, the data so far suggest that peeling of ponderosa pine trees may have been introduced or began as a cultural practice in the Southwest in the late 1700s.

If peels provided a regular, seasonal food source in the Sacramento Mountains, it seems that there should be larger numbers of extant peeled trees throughout the mountains than are actually observed. Extensive pre-20th century fires and logging in the Sacramentos, however, could have removed peeled trees, so the possibility of more widespread peeling cannot be entirely excluded. The temporal distribution of peel dates from the west escarpment suggests that the products of peeling were not a consistently regular staple for the Mescalero in this area. Periods with clusters of peel dates (1781 to 1784, 1799 to 1800, 1823 to 1824, and 1877 to 1878) may be periods when the Mescalero peeled more trees because of hardship from factors such as warfare, famine, or disease. Even the relatively infrequent (one or two trees per year), but almost annual peeling periods (e.g., 1833 to 1865; Fig. 5) may be a reflection of hard times for the Apache, since this was a period of near constant conflict with Mexicans and Americans. The concentration of extant peeled trees on the west escarpment probably results from the fact that this area was a primary hideout and refuge for the Mescalero Apache during these times.

The largest number of peel scars were located in the early-earlywood portion of the annual ring, representing peel events that took place in the spring. This result concurs with historical accounts documenting tree peeling as a spring practice (White, 1954; Churchill, 1983; Corral, 1997). In spring, inner bark and cambium are most easily removed from the bole of the tree because of young cells still forming in the cambium, and protein and carbohydrate contents are at their highest (Martorano, 1981).

Assessing Mescalero Influence on Historical Fire Regimes

Multiple lines of evidence—including historical references, peel-scar dates, fire frequency, seasonality, and location data—allowed us to assess Mescalero Apache influence on historical fire regimes of the Sacramento Mountains. Comparisons between peel and fire frequencies at the scale of the entire study area showed no clear or consistent relationship. Stratifying collection sites based on geographical and historical characteristics, however, suggests that local presence of Mescalero Apache may have been related to variations in local fire regimes. Both historical references and physical evidence (i.e., peel scars) place the Mescalero Apache in the vicinity of Dog Canyon since the late 1700s. In contrast, there is no direct documentary evidence the Mescalero were frequently in the vicinity of the three collection sites relatively distant from Dog Canyon (DDC) during that period. Based on a greater frequency of peeled trees in the NDC area (36 of 45 peel dates), and documentary evidence, we suggest that Mescalero land use was concentrated in the area of Dog Canyon. Frequent use of fire by the Mescalero, and by their enemies, may have increased the number of ignitions to the landscape, and thereby increased fire frequency on a local scale.

In addition to fire-frequency variations, fire seasonality differed between sites near and relatively distant from Dog Canyon in the late 1700s. No late-season fires occurred in sites distant from Dog Canyon during this period, but four occurred in the sites near Dog Canyon. Seckleki et al. (1996) reported a similar shift in fire seasonality in a Chiricahua Mountain site that was probably often visited by Chiricahua Apache. In this case, however, a greater frequency of early-season fires was noted in the often-visited site relative to isolated sites. The different patterns of seasonality shift in the Sacramentos and Chiricahuas might be expected if an increased frequency of fires during some periods and in particular places was related primarily to warfare, as suggested by Kaib (1998). Fires set by people (i.e., Apache, Spaniards, Mexicans, or Americans) during war could have been set almost any time during the year. This contrasts with the lightning fire season, which is more temporally restricted (typically, late spring to summer). Also, more consistent temporal patterns than we found in our fire-history reconstruction might be expected for systematic, intentional burning by humans for manipulating vegetation.

Other fire-history reconstructions in the United States-Mexico borderlands provide evidence that Apache presence and intentional burning may have been episodic and important at local scales, but people were not the controlling factors in all places and times (e.g., Morino, 1996; Kaib, 1998). A recent tree-ring study in a remote mountain of northern Mexico, for example, shows uninterrupted, frequent surface fire regimes throughout the late 19th and early 20th centuries, despite the nearly complete removal of Apache from this region by 1886 (Swetnam, Baisan, and Kaib, in press).

Finally, new lightning detection systems (using satellites and radio waves) demonstrate that lightning strike density is extremely high in the Southwestern region (Gosz et al., 1995). Given this high incidence of lightning, and the possibility of extensive fire spread during the pre-settlement era, we infer that ignition sources were unlikely to be limiting during the early and middle part of the vegetative growing season in most locations during almost any year. It is more likely that natural fuel dynamics regulated by climate variation, topography, and previous lightning-ignited fire events were controlling fire regimes at broad temporal and spatial scales.

CONCLUSIONS

The presence of both fire- and peel-scarred trees in our study area allowed us to quantitatively address the question: did Mescalero Apache affect pre-1900 fire regimes? Independent climate reconstructions enabled us to evaluate the other major factor that can affect temporal variability in fire regimes. We conclude that Mescalero Apache (or their enemies) probably did alter fire regimes on a local scale during particular time periods. More specifically, during the late 1700s people may have elevated fire frequencies and altered fire seasonality in three collection sites located near Dog Canyon. However, we were not able to identify any human-related patterns on a broader scale of the entire study area before the late 1800s.

Although the patterns found in this study suggest a local influence on fire regimes by people, there are several viable alternative explanations for the temporal and spatial variations we detected in the historical fire regimes and tree peeling. Local differences in fire frequencies between sites near to and distant from Dog Canyon may have resulted from changes in fuel connectivity or vegetation composition relating to internal ecosystem dynamics (e.g., successional changes). We also found evidence that climatic variations were responsible for some of the patterns in fire occurrence. Relatively weak and temporally variable climate-fire patterns, however, suggests that climate effects were muted at the relatively fine spatial scale of the study area, and perhaps overridden by human effects during some periods. Fire-frequency estimates can be affected by the size of the sampled area (Arno and Peterson, 1983) and the numbers and quality of fire-scarred specimens obtained (Swetnam and Baisan, 1996a). Our study sites and the fire-scar collections from them were comparable in size and quality, but spatial distributions of trees within sites were necessarily different.

Our analysis of peel scars was limited by the incomplete inventory of peel dates from the study area resulting from probable loss of some peel scars over time from weathering and fire. Questions remain concerning the specific role of tree peeling in Native American cultures. For example, what were the specific uses for each group? Why and when did they use inner bark? Although the historical picture is fragmentary, in the case of the Apache of southern New Mexico and Arizona, the bulk of the evidence points to a hard-times usage pattern.

Peeled trees have been identified throughout the western United States and therefore offer many opportunities for study of these fascinating and somewhat mysterious artifacts. Dendrochronological dating of peel scars allows for the exact identification of the year and seasonality of the peeling event. This information, in turn, can be used to identify the location of cultural groups like the Apache, who were nomadic and left little physical evidence of their whereabouts.

The specific influence of Native Americans on historical fire regimes remains to be determined by empirical research for almost all areas in western North America. The strategy of comparing and contrasting tree-ring reconstructed fire frequencies and seasonality in heavily used versus remote, unused areas, as identified by peeled trees and historical documents, may assist in the endeavor to determine the extent of human influence on historical fire regimes. Combining these comparative studies with broader-scale perspectives of regional climate and fire patterns also will be necessary to help separate multiple causes.

Finally, we argue that sweeping generalizations concerning Native American influence on the landscape should be critically examined. The pendulum has swung in recent years from a general disregard of Native American impacts on pre-Columbian landscapes to another misguided but increasingly accepted viewpoint that no landscapes were free of pervasive and overwhelming human manipulation. It is argued, for example, that Native Americans were the dominating influence on fire regimes in virtually all of parts of North America in the pre-Columbian era (Pyne, 1982; Denevan, 1992; Pyne et al., 1996). This case study, and other fire-history research in the Southwest (also see Fish, 1996, for an archaeological and anthropological perspective), indicate that people had a complex and variable effect on past fire regimes and were a dominant factor only in certain times and places. We concur with Vale's (1998) assessment of this issue: "The pre-European landscape of North America was both pristine and humanized, varying through space and time and degree of conformity to the extreme conditions represented by purely naturalistic and purely anthropogenic." This issue will only be illuminated and resolved with further empirical, quantitative research based on evidence gathered from both the landscape and from documentary archives.

Acknowledgments: The U.S. Forest Service Rocky Mountain Research Station funded the research for this project and the Lincoln National Forest provided logistical support. Thanks to Craig Allen, Chris Baisan, Julio Betancourt, Mark Kaib, Kiyomi Morino, and Ron Towner for contributions to data analysis, collection of historical references, and manuscript improvement.

BIBLIOGRAPHY

Agee, J. K. (1993) *Fire Ecology of Pacific Northwest Forests.* Washington, DC: Island Press.

Alexander, B. G., Ronco, F., Fitzhugh, E. L., and Ludwig, J. A. (1984) *A Classification of Forest Habitat Types of the Lincoln National Forest, New Mexico.* Fort Collins, CO: Rocky Mountain Forest and Range Experiment Station, U.S. Forest Service General Technical Report RM-104.

Allen, C. D., Betancourt, J. L., and Swetnam, T. W. (1998) Landscape changes in the Southwestern United States: Techniques, long-term data sets, and trends. In T. D. Sisk, ed., *Perspectives on the Land-Use History of North America: A Context for Understanding Our Changing Environment.* Washington, DC: U.S. Geological Survey, Biological Resources Division, Biological Science Report USGS/BRD/BSR-1998-0003.

Arno, S. F. and Petersen, T. D. (1983) *Variation in Estimates of Fire Intervals: A Closer Look at Fire History on the Bitterroot National Forest*. Ogden, UT: U.S. Forest Service Research Paper INT-301.

Arno, S. F. and Sneck, K. M. (1977) *A Method for Determining Fire History in Coniferous Forests of the Mountain West*. Missoula, MT: Intermountain Forest and Range Experiment Station, USDA Forest Service, General Technical Report INT-42.

Bahre, C. J. (1985) Wildfire in southeastern Arizona between 1859 and 1890. *Desert Plants*, Vol. 7, No. 4, 190–194.

Bailey, V. O. (1902) *Physiography Report (Handwritten) on Mescalero Apache Reservation, New Mexico, September 9-14, 1902*. Washington, DC: U.S. Bureau of Biological Survey.

Baisan, C. H. and Swetnam, T. W. (1990) Fire history on a desert mountain range: Rincon Mountain Wilderness, Arizona, U.S.A. *Canadian Journal of Forest Research*, Vol. 20, 1559–1569.

Baisan, C. H. and Swetnam, T. W. (1994) *Assessment of Phenological Growth Patterns in Four Coniferous Species, Rhyolite Canyon National Monument*. Tucson, AZ: Unpublished Final Report to Southwest Parks and Monuments Association, Laboratory of Tree-Ring Research, University of Arizona.

Baisan, C. H. and Swetnam, T. W. (1997) *Interactions of Fire Regime and Land-Use History in the Central Rio Grande Valley*. Fort Collins, CO: U.S. Forest Service Research Paper, RM-RP-330.

Barrett, S. W. (1985) Living artifacts: Indian scarred trees. *American Forests*, Vol. 91, 7.

Barrett, S. W. and Arno, S. F. (1982) Indian fires as an ecological influence in the northern Rockies. *Journal of Forestry*, Vol. 80, 647–851.

Barrows, J. S. (1978) *Lightning Fires in Southwestern Forests*. Fort Collins, CO: Rocky Mountain Forest and Range Experiment Station.

Basehart, H. W. (1974) *Mescalero Apache Subsistence Patterns and Socio-Political Organization. Apache Indians 12, American Indian Ethnohistory: Indians of the Southwest*. New York, NY: Garland.

Betancourt, J. L. (1981) *A History of Mescalero Apache—U.S. Army Encounters in Dog Canyon, New Mexico: 1849–1880*. Albuquerque, NM: U.S. Forest Service, Southwestern Region, Cultural Resources Miscellaneous Papers, 35.

BIA (Bureau of Indian Affairs) (1981) *A History of Forest Management of the Mescalero Indian Reservation, New Mexico*. Albuquerque, NM: Historical Research Associates, Mountain Moving Press.

Castetter, E. F. and Opler, M. E. (1936) The ethnobiology of the Chiricahua and Mescalero Apache. *University of New Mexico Bulletin*, No. 297, Biological Series, Vol. 4, No. 1.

Churchill, T. E. (1983) Inner-Bark Utilization: A Nez Perce Example. Unpublished masters thesis, Departments of Anthropology and Geography, Oregon State University, Corvallis, Oregon.

Cook, E. R., Meko, D. M., Stahle, D. W., and Cleaveland, M. K. (1999) Drought reconstructions for the continental United States. *Journal of Climate*, Vol. 12, 1145–1162.

Corral, P. G. (1997) Bark Substance Utilization in the Warm Spring Area: A Northern New Mexico Example. Unpublished masters thesis, School of Behavioral Science, New Mexico Highlands University, Las Vegas, NM.

Covington, W. W. and Moore, M. M. (1994) Southwestern ponderosa forest structure: Changes since Euro-American settlement. *Journal of Forestry*, Vol. 92, 39–47.

Cox, J. A. (1959) *Historical and Biographical Record of the Cattle Industry and the Cattlemen of Texas and Adjacent Territory*. New York, NY: Antiquarian Press.

Dahm, C. W. and Geils, B. W. (1997) *An Assessment of Forest Ecosystem Health in the Southwest*. Fort Collins, CO: U.S. Department of Agriculture, Forest Service General Technical Report RM-GTR-295.

Denevan, W. M. (1967) Livestock numbers in nineteenth century New Mexico and the problem of gullying in the Southwest. *Annals of the Association of American Geographers*, Vol. 57, 691–703.

Denevan, W. M. (1992) The pristine myth: The landscape of the Americas in 1492. *Annals of the Association of American Geographers*, Vol. 82, 369–385.

Dieterich, J. H. and Swetnam, T. W. (1984) Dendrochronology of a fire-scarred ponderosa pine. *Forest Science*, Vol. 30, No. 1, 238–247.

Dimbleby, G. W. (1967) *Plants and Archaeology*. London, UK: Unwin Brothers, Pall Mall.

Dobyns, H. F. (1981) *From Fire to Flood: Historic Human Destruction of Sonoran Riverine Oases*. Socorro, NM: Ballena.

Eidlitz, K. (1969) Food and emergency food in the circumpolar area. *Studia Ethnographica Upsaliensia*, Vol. 32.

Fish, S. K. (1996) Modeling human impacts to the borderlands environment from a fire ecology perspective. In: P. F. Ffolliott, L. D. DeBano, M. B. Baker, G. J. Gottfried, G. Solis-Garza, C. B. Edminster, D. G. Neary, L. S. Allen, and R. H. Hamre, tech. coord. *Proceedings of the Symposium on Effects of Fire on Madrean Province Ecosystems, Tucson, AZ*. Fort Collins, CO: U.S. Forest Service General Technical Report RM-GTR-289.

Fritts, H. C. (1976) *Tree-Rings and Climate*. New York, NY: Academic Press.

Gaertner, E. E. (1970) Breadstuff from fir (Abies balsamea). *Economic Botany*, Vol. 24, 69–72.

Glover, V. J. (1984) *Logging Railroads of the Lincoln National Forest, New Mexico*. Albuquerque, NM: Cultural Resource Management, Report No. 4, U.S. Forest Service, Southwestern Region.

Gosz, J. R., Moore, D. I., Shore, G. A., Grover, H. D., Rison, W., and Rison, C. (1995) Lightning estimates of precipitation location and quantity on the Sevilleta, LTER, New Mexico. *Ecological Applications*, Vol. 5, 1141–1150.

Grissino-Mayer, H. D. (1995) Tree-Ring Reconstructions of Climate and Fire History at El Malpais National Monument, New Mexico. Unpublished doctoral dissertation, University of Arizona, Tucson, AZ.

Grissino-Mayer, H. D., Baisan, C. H., and Swetnam, T. W. (1997) A 1,373-Year Reconstruction of Annual Precipitation for the Southern Rio Grande Basin. Unpublished Final Report to Legacy Program, Directorate of Environment, Natural Resources Division, Fort Bliss, TX.

Grissino-Mayer, H. D. and Swetnam, T. W. (in press) Century-scale climate forcing of fire regimes in the American Southwest. *The Holocene*.

Hrdlicka, A. (1908) Physiological and medical observations among the indians of Southwestern United States and northern Mexico. *Bureau of American Ethonology Bulletin*, Vol. 34, 26–28.

John, E. A. H. and Wheat, J. (1989) *Views from the Apache Frontier, Report on the Northern Provinces of New Spain by Jose Cortes*. Norman, OK: University of Oklahoma Press.

Kaib, H. (1998) Historical Surface Fires in Canyon Pine-Oak Forests and the Intervening Desert Grasslands of the Southwestern Borderlands. Unpublished masters thesis, School of Renewable Natural Resources, University of Arizona, Tucson, AZ.

Kaib, H., Baisan, C. H., Grissino-Mayer, H. D., and Swetnam, T. W. (1996) Fire history in the gallery pine-oak forests and adjacent grasslands of the Chiricahua Mountains of Arizona. In P. F. Ffolliott, L. D. DeBano, M. B. Baker, G. J. Gottfried, G. Solis-Garza, C. B. Edminster, D. G. Neary, L. S. Allen, and R. H. Hamre, tech. coords., *Proceedings of the Symposium on Effects of Fire on Madrean Province Ecosystems, Tucson, AZ*. Fort Collins, CO: U.S. Forest Service General Technical Report RM-GTR-289.

Karl, T. R., Metcalf, L. K., Niconemus, M. L., and Quayle, R. G. (1983) *Statewide Average Climate History*. Ashville, NC: National Climate Data Center.

Kauffman, M. R., Graham, R. T., Boyce, D. A., Jr., Moir, W. H., Perry, L., Reynolds, R. T., Bassett, R. L., Mehlhop, P., Edminster, C. B., Block, W. M., and Corn, V. (1994) *An Ecological Basis for Ecosystem Management*. Fort Collins, CO: U.S. Forest Service General Technical Report RM-246.

Kauffman, M. R., Huckaby, L. S., Regan, C., and Popp, J. (1998) *Forest Reference Conditions for Ecosystem Management in the Sacramento Mountains, New Mexico*. Fort Collins, CO: U.S. Forest Service, Rocky Mountain Research Station General Technical Report RMRS-GTR-19.

Kitzberger, T. and Veblen, T. T. (1997) Influences of humans and ENSO on fire history of Austrocedrus chilensis woodlands in northern Patagonia, Argentina. *Ecoscience*, Vol. 4, 508–520.

Leopold, A. (1924) Grass, brush, timber and fire in southern Arizona. *Journal of Forestry*, Vol. 22, 1–10.

Martorano, M. A. (1981) Scarred Ponderosa Pine Trees Reflecting Cultural Utilization of Bark. Unpublished masters thesis, Department of Anthropology, Colorado State University, Fort Collins, CO.

Mobley, C. M. and Eldridge, M. (1992) Culturally modified trees in the Pacific Northwest. *Arctic Anthropology*, Vol. 29, No. 2, 91–110.

Morgan, P., Aplet, G. H., Haufler, J. B., Humphries, H. C., Moore, M. M., and Wilson, W. D. (1994) Historical range if variability: A useful tool for evaluating ecosystem change. *Journal of Sustainable Forestry*, Vol. 2, No. 1 and 2, 87–111.

Morino, K. A. (1996) Reconstruction and Interpretation of Historical Patters of Fire Occurrence in the Organ Mountains, New Mexico. Unpublished masters thesis, School of Renewable Natural Resources, University of Arizona, Tucson, AZ.

Niklasson, M., Zackrisson, O., and Östlund, L. (1994) A dendroecological reconstruction of use by Saami of Scots Pine (Pinus sylvestris L.) inner bark over the last 350 years in Sdvajaure, N. Sweden. *Vegetation History and Archeobotany*, Vol. 3, 183–190.

Opler, M. E. and Opler, C. H. (1950) Mescalero Apache history in the Southwest. *New Mexico Historical Review*, Vol. 25, 1–36.

Pray, L. C. (1961) *Geology of the Sacramento Mountains Escarpment, Otero County, New Mexico*. Socorro, NM: Bulletin 35, State Bureau of Mines and Mineral Resources, New Mexico Institute of Mining and Technology, Campus Station.

Pyne, S. J. (1982) *Fire in America: A Cultural History of Wildland and Rural Fire*. Princeton, NJ: Princeton University Press.

Pyne, S. J., Andrews, P. L., and Laven, R. D. (1996) *Introduction to Wildland Fire*. New York, NY: John Wiley and Sons.

Savage, M. and Swetnam, T. W. (1990). Early and persistent fire decline in a Navajo ponderosa pine forest. *Ecology*, Vol. 70, 2374–2378.

Schroeder, A. H. (1974) *A Brief History of Picuris Pueblo*. Alamosa, CO: Adams State College, Series in Anthropology, No. 2.

Seklecki, M., Grissino-Mayer, H. D., and Swetnam, T. W. (1996) Fire history and the possible role of Apache-set fires in the Chiricahua Mountains of Southeastern Arizona. In P. F. Ffolliott, L. D. DeBano, M. B. Baker, G. J. Gottfried, G. Solis-Garza, C. B. Edminster, D. G. Neary, L. S. Allen, and R. H. Hamre, tech. coord., *Proceedings of the Symposium on Effects of Fire on Madrean Province Ecosystems, March 11–14, 1996, Tucson, AZ*. Fort Collins, CO: U.S. Forest Service General Technical Report RM-GTR-289.

Sonnichsen, C. L. (1973) *The Mescalero Apache*. Norman, OK: University of Oklahoma Press.

Stokes, M. A. and Smiley, T. L. (1968) *An Introduction to Tree-Ring Dating*. Chicago, IL: The University of Chicago Press.

Swanson, F. J., Jones, J. A., Wallin, D. A., and Cissel, J. H. (1993) Natural Variability—Implications for Ecosystem Management. In M. E. Jensen and P. S. Bourgeron, eds., *Eastside Forest Ecosystem Health Assessment, Volume II. Ecosystem Management: Principles and Applications*. Portland, OR: U.S. Forest Service, Pacific Northwest Research Station.

Swetnam, T. W. (1984) Peeled ponderosa pine trees: A record of inner bark utilization by Native Americans. *Journal of Ethnobiology*, Vol. 4, No. 2, 177–190.

Swetnam, T. W. (1993) Fire history and climate change in giant sequoia groves. *Science*, Vol. 262, 885–889.

Swetnam, T. W., Allen, C. D., and Betancourt, J. L. (1999) Applied historical ecology: Using the past to manage for the future. *Ecological Applications*, Vol. 9, 1189–1206.

Swetnam, T. W. and Baisan, C. H. (1996a) Historical fire regime patterns in the Southwestern United States since A.D. 1700. In C. D. Allen, ed., *Fire Effects in Southwestern Forests, Proceedings of the Second La Mesa fire symposium,* *March 29–31, 1994, Los Alamos, NM*. Fort Collins, CO: U.S. Forest Service General Technical Report RM-GTR 286.

Swetnam, T. W. and Baisan, C. H. (1996b) Fire histories of montane forests in the Madrean Borderlands. In P. F. Ffolliott, L. D. DeBano, M. B. Baker, G. J. Gottfried, G. Solis-Garza, C. B. Edminster, D. G. Neary, L. S. Allen, and R. H. Hamre, tech. coord., *Proceedings of the Symposium on Effects of Fire on Madrean Province Ecosystems, March 11–14, 1996, Tucson, AZ*. Fort Collins, CO: U.S. Forest Service, General Technical Report RM-GTR-289.

Swetnam, T. W., Baisan, C. H., and Kaib, J. M. (in press) Fire histories of montane forests in La Frontera. In G. L. Webster and C. J. Bahre, eds., *Vegetation and Flora of La Frontera: Historic Vegetation Change Along the United States/Mexico Boundary*. Albuquerque, NM: University of New Mexico Press.

Swetnam, T. W. and Betancourt, J. L. (1990) Fire-Southern Oscillation relations in the Southwestern United States. *Science*, Vol. 249, 1017–1020.

Swetnam, T. W. and Betancourt, J. L. (1992) Temporal patterns of El Niño/Southern Oscillation—wildfire patterns in the Southwestern United States. In H. F. Diaz and V. M. Markgraf, eds., *El Niño: Historical and Paleoclimatic Aspects of the Southern Oscillation*. Cambridge, UK: Cambridge University Press.

Swetnam, T. W. and Betancourt, J. L. (1998) Mesoscale disturbance and ecological response to decadal climatic variability in the American Southwest. *Journal of Climate*, Vol. 11, 3128–3147.

Swetnam, T. W., Thompson, M. A., and Kennedy Sutherland, E. (1985) *Using Dendrochronology to Measure Radial Growth of Defoliated Trees*. Washington, DC: U.S. Forest Service Agriculture Handbook 639.

Tagg, M. D. (1996) Early cultigens from Fresnal Shelter, southeastern New Mexico. *American Antiquity*, Vol. 61, 311–324.

Thomas, A. B. (1969) *Forgotten Frontiers*. Norman, OK: University of Oklahoma Press.

Thwaites, R. G., ed. (1905) *Original Journals of the Lewis and Clark Expedition, 1804–1806. Vol. 3 and 5*. New York, NY: Dodd, Mead, and Company.

Touchan, R., Swetnam, T. W., and Grissino-Mayer, H. (1995) Effects of livestock grazing on pre-settlement fire regimes in New Mexico. In J. K. Brown, R. W. Mutch, C. W. Spoon, and R. H. Wakimoto, tech. coord., *Proceedings: Symposium on Fire in Wilderness and Park Management, Missoula, MT, March 30–April 1, 1993*. Missoula, MT: U.S. Forest Service General Technical Report INT-320.

Vale, T. R. (1998) The myth of the humanized landscape: An example from Yosemite National Park. *Natural Areas Journal*, Vol. 18, No. 3, 231–236.

Veblen, T. T., Kitzberger, T., Villalba, R., and Donnegan, J. A. (1999) Fire history in northern Patagonia: The roles of humans and climatic variation. *Ecological Monographs*, Vol. 69, No. 1, 47–67.

White, T. (1954) *Scarred Trees in Western Montana*. Bozeman, MT: Montana State University Anthropology and Sociology Papers No. 17.

Wilkes, P. J. (1998) Bow staves harvested from juniper trees by Indians of Nevada. *Journal of California and Great Basin Anthropology*, Vol. 10, 3–31.

Wilkinson, M. C. (1997) Reconstruction of Historical Fire Regimes along an Elevation and Vegetation Gradient in the Sacramento Mountains, New Mexico. Unpublished masters thesis, School of Renewable Natural Resources, University of Arizona, Tucson, AZ.