FOREST FIRE HISTORIES OF *LA FRONTERA*:
FIRE-SCAR RECONSTRUCTIONS OF FIRE REGIMES IN THE UNITED STATES/MEXICO BORDERLANDS

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INTRODUCTION

Fire is a dominant ecological process in almost all landscapes of *La Frontera*. Fire histories from throughout the region on the United States side of the border show that, before circa 1900, extensive surface fires occurred within pine-dominant forests at about the same frequency as wet-dry cycles related to the El Niño-Southern Oscillation, i.e., 2 to 7 year intervals (Swetnam and Betancourt 1990, 1998; Swetnam and Baisan 1996a, 1996b). Regionally synchronous fire events occurred at the rate of about 10 per century and often coincided with the most extreme wet-dry cycles. Extreme changes in fire regimes and ecosystems occurred during and following the Euro-American settlement period from circa 1870 to 1900 (Leopold 1924; Weaver 1951; Cooper 1960; Covington and Moore 1994). Tree-ring reconstructions of fire, climate, and tree population dynamics provide the most detailed and specific evidence of these changes over periods of centuries. When these reconstructions are compared and analyzed in the context of land-use histories it is possible to quantitatively assess the multiple factors causing past fire regime variability (Baisan and Swetnam 1997; Swetnam and Betancourt 1998).

La Frontera offers rich opportunities for the study of cultural and natural fire history. Divergent histories of land use in Mexico and the United States have caused striking differences in fire regimes and ecosystem structures (Leopold 1937; Marshall 1957, 1963; Minnich 1983; Dieterich 1983; Minnich and Bahre 1995; Swetnam and Baisan 1996b; Fulé and Covington 1994, 1996, 1997). Moreover, each of the sky island mountain ranges has a somewhat different topography and vegetation. Prior to circa 1900, fire regimes may have been regulated primarily by these unique physical and biological characteristics. However, the importance of humans --- specifically Native Americans --- in modifying pre-Euro-American settlement fire regimes in this region has often been emphasized (Dobyns 1981, Pyne 1982).

The purpose of this paper is to provide a historical perspective of past fire regimes in *La Frontera* and the causes of their variability. During the past two decades we (the authors, our students, and collaborators) have conducted many different tree-ring based fire history studies in the montane forests and woodlands of this region. Here we list the locations and characteristics of our study sites, and we describe fire interval statistics for each site. Each of our fire history reconstructions is a unique chronology of fire events in a specific location over a period of at least two centuries. Since we do not have the space here to describe all of the sites and reconstructions in detail, we have chosen fire histories from three different mountain ranges (Santa Catalina, Sierra de los Ajos, and Animas) that exemplify the general and specific patterns we have documented in *La Frontera*.

STUDY AREAS

Our 32 study sites are located in the montane forests of the “sky island” mountains of *La Frontera* (Figure 1). The sites range in elevation from about 1,600 to 3,080 meters and are located in a variety of topographic settings and forest vegetation types (Table 1). More detailed descriptions of these study sites and findings can be found in the references listed in Table 1. We have classified the forest vegetation of these sites into three broad types described below.

Pine/Oak

The overstory of these stands is dominated by low elevation pines that commonly include Chihuahua pine (*Pinus leiophylla*), Apache pine (*P. engelmannii*), and ponderosa pine (P. ponderosa) or Arizona pine (*P. ponderosa arizonica*). Mixtures of Madrean oaks (*Quercus* *arizonica, Q. emoryi, Q. hypoleucoides, Q. oblongifolia, Q. rugosa*), Arizona madrone (*Arbutus arizonica*), pinyon (*P. discolor*), junipers (*Juniperus spp*.), and various shrubs are present in the understory.

Ponderosa Pine (PIPO)

These stands are dominated by ponderosa pine or Arizona pine (or their hybrids). Some stands have other tree species (such as found in the Ponderosa Pine/Mixed-Conifer class described below), but most of these stands are pure or nearly pure ponderosa pine.

Ponderosa Pine/Mixed Conifer (PIPO/MC)

Ponderosa pine is the largest component of these stands, but other co-dominant trees may include Douglas-fir (*Pseudotsuga menziesii*), southwestern white pine (*Pinus strobiformis*), and white fir (*Abies concolor*). Before Euro-American settlement (i.e., before circa 1880) in the United States many of these stands were probably pure or nearly pure ponderosa pine, but in the 20th century more shade-tolerant, less fire resistant Douglas-fir and white fir have increased in numbers (Grissino-Mayer et al. 1995; Abolt 1997; Danzer 1998).

Mixed Conifer (MC)

Douglas-fir and white fir are dominant in these stands. Ponderosa pine and/or southwestern white pine may also be present.

METHODS

We collected and analyzed tree-ring specimens from a total of 654 fire-scarred trees in 32 sites (Table 1). A fire chronology was reconstructed for each site based on dendrochronological dating of these specimens. Each fire chronology constitutes a local, case history. We combine and compare fire history reconstructions across the region to investigate broader-scale patterns, such as the influence of climate and humans on past fire regimes. The key to this strategy is the high temporal resolution (annual or seasonal) and accuracy of dendrochronologically-dated fire events. Patterns of synchrony and asynchrony of well-dated disturbance events at multiple points in space, for example, reveal the relative importance of internal versus external controls, and the spatial-scale of the disturbance effects. These cross-scale analyses allow us to extend and generalize our interpretations of disturbance regime patterns and changes (Swetnam and Betancourt 1998).

Most of our collection sites are forest or woodland stands ranging in size from about 10 to 100 ha. Some of the fire-scar collections, however, are distributed over areas ranging from about 1,000 to more than 5,000 ha. in size (e.g., Rhyolite Canyon, Animas Mountains, Mica Mountain, Santa Catalina Mountains, and the Mogollon Mountains). These were minimal sizes of areas that the fire histories represented. Many of the fires recorded within sites, however, probably spread from distant locations and so it is quite likely that much larger areas burned during some years.

Collection and Analysis of Fire-Scar Specimens and Data

The 32 fire-interval distributions described here are based upon composite fire chronologies (*sensu* Dieterich 1980) from numerous fire-scarred trees collected within each of the *La Frontera* study sites (Figure 1, Table 1). We systematically searched for and collected fire-scarred trees with a maximum number of visible, well-preserved fire scars widely distributed throughout the study sites. Specimens were collected primarily from dead trees (stumps, logs, and snags), but some living trees were also sampled to improve spatial coverage within sites and to extend the fire histories to the present (Baisan and Swetnam 1990). Partial and full cross sections of trees, stumps, and logs were obtained using a chainsaw (Arno and Sneck 1977). The sections were finely sanded with belt sanders to observe cell structure and fire scars within the rings. Tree-ring widths were carefully crossdated using standard techniques (Stokes and Smiley 1968; Swetnam et al. 1985). The fire scars were dated to the calendar year and identified to approximate season of occurrence based upon observations of fire-scar position within annual rings (Dieterich and Swetnam 1984; Baisan and Swetnam 1990).

The fire-scar dates were entered in a specialized data-base format and analyzed with a graphical and statistical software package designed for this purpose (Grissino-Mayer 1995). Statistical descriptors of the fire-interval distributions for a common period (1700-1900) were estimated for all sites. These descriptors included measures of central tendency: mean, median, Weibull median probability interval (WMPI), range, and standard deviations. The WMPI was derived from a Weibull model fitted to the cumulative fire interval distribution (Grissino-Mayer 1995). It is the interval in years at which there was approximately a 50 percent chance of a longer or shorter interval occurring during the summarized time period (1700-1900).

We evaluated fire-interval distributions for three fire-extent classes based upon percentages of trees recording fire events in the same year. The classes were:

(1) All fire events, regardless of percentage of trees scarred. These were all fires occurring anywhere within the sampled area, including fires that were probably very small.

(2) Fires recorded by 10 percent or more of the fire-scarred trees, and a minimum of two trees scarred per fire. These fires included all fire events recorded within the sites except fires recorded by only a single tree or a small percentage of trees (i.e., less than 10 percent).

(3) Fires recorded by 25 percent or more of the sampled fire-scarred trees, and a minimum of two trees scarred per fire. These fires were interpreted as widespread fire events that probably burned throughout most or all of the sampled area.

The extent categories were relativistic estimates of probable fire extent within each of the collection sites. These estimates are potentially biased by the spatially non-random or uneven distributions of our samples and irregular preservation of the fire history record (see discussion in Swetnam and Baisan 1996a). However, given our limited ability to reconstruct detailed spatial patterns of past surface fires, we argue that, at this stage of progress in fire history research, they are a reasonable sorting of fire events into relative extent classes (Savage and Swetnam 1990; Grissino-Mayer 1995; Fulé and Covington 1994, 1996; Veblen et al, in press).

RESULTS

Statistical Descriptions of the Fire Interval Distributions

Summaries of fire interval statistics provide a generalized perspective of historical fire regimes in *La Frontera* (Table 2). These statistics suggest that some typical patterns were associated with changes in elevation, moisture, and forest type (see Swetnam and Baisan 1996a for an evaluation of these patterns in the American Southwest; also see Barton 1994). Overall, however, the picture is one of considerable site-to-site variability. This variability of fire regimes among the same or similar forest types was most likely due to unique site differences in topographic setting and land-use history. Some of these patterns will be discussed in following sections where we describe several case histories. In general, somewhat longer fire intervals occurred in higher elevation, relatively mesic, mixed-conifer forests (MC) than in lower elevation, relatively xeric, pine-dominant forests (PIPO). However, some MC and PIPO/MC stands sustained fire frequencies as high or higher than lower elevation PIPO stands (Table 2).

The fire history study on Mount Graham in the Pinaleño Mountains (Camp Point and Peter's Flat, Table 1) is an example where a relatively high elevation mixed-conifer forest had a fire frequency similar to lower elevation pine forests (Grissino-Mayer et al. 1995). Our interpretation of this pattern, in the context of the surrounding landscape, was that it was probably due to the close proximity of these mixed-conifer stands to dry steep slopes, where fire could easily ignite and spread from many directions into the mixed-conifer zone.

Surface fires were quite common in nearly all montane forest types prior to about 1900. The maximum interval between the relatively widespread fires (25 percent category, Table 2) typically ranged from about 10 to 30 years in the pine-dominant forests, but were up to 40 or 50 years in the higher elevation mixed-conifer forests. An unusually long interval (50 years) occurred in the mixed-conifer, pine-dominant forests of upper and middle Rhyolite Canyon (Chiricahua National Monument) during the early 1800s. Extensive sampling and study of both fire and flood-scarred trees in this canyon suggests that this interval may have been caused by a flood or debris flow event that interrupted fuel continuity (Swetnam et al. 1989, 1992). Exceptions to the more general patterns, such as this example, illustrate the importance of unique events at the local scale.

The minimum interval for the "all" fires category was 1 or 2 years at all sites. Thus, even within the smallest study sites, when we consider fires that scarred any tree, very short intervals occasionally occurred. Many of these fires were, however, probably small and/or patchy within sites. Using the 25 percent category for relatively widespread fire events, the minimum fire intervals ranged from 1 to 10 years.

Interestingly, the smallest minimum fire interval for the 25 percent category --- 1 year --- occurred in the lower Rhyolite Canyon and Rustler Park sites. We suspect that high fire frequencies in these Chiricahua Mountain sites, particularly in the late 1800s, reflect increased fire occurrence due to anthropogenic burning (Swetnam et al. 1989; 1992; Seklecki et al. 1996; Kaib 1998). Both areas were used as Apache camps (i.e., rancherias) and they were along often-used travel routes (Kaib 1998). Additional research could further test the hypothesis that Native Americans increased fire frequency, or otherwise changed fire regimes, by sampling and comparing fire histories from different sites along gradients of heavy to light usage (Barrett and Arno 1982; Clark and Royall 1995; Wilkinson 1997) and by comparing with independent climate histories (Wilkinson 1997; Veblen et al. in press).

Several measures of central tendency are listed in Table 2 (mean, median, and Weibull median probability interval, or WMPI). Usually the measures of central tendency were within one to a few years of each other. These measures were useful for generalizing typical fire intervals. The higher moments of the fire interval distributions (i.e., variance, range, skewness, kurtosis, etc.), however, may be of greater ecological importance than the central tendency descriptors (Clark 1996). Moreover, distributions with similar means (medians, WMPIs, etc.) can have very different shapes (Figure 2). Plant responses to fire regimes may be most closely linked to the relatively rare occurrence of long intervals between fires (the right tail of distributions in Figure 2) (Clark 1996). Such intervals may have been particularly important in determining the successful recruitment and survival of individual plants or cohorts, especially when coupled with more favorable climatic conditions (White 1985; Fulé and Covington 1994, 1997; Savage et al. 1996; Villalba and Veblen 1997; Swetnam and Betancourt 1998).

The distribution of seasonal timing of past fires, as inferred from the intra-ring position of fire scars, shows that most fires in the borderlands occurred in the dry late spring to early summer (Figure 3). Of 3,701 fire scars that were examined, 2,656, or 72 percent, were classified according to one of the five intra-ring position classes. The remaining 28 percent were not confidently classified because of very small rings, decay, etc. The percentages shown (Figure 3) are for the classified scars only (i.e., the classes sum to 100 percent). Approximate season of timing shown above the classes is based upon our knowledge of cambial phenology of trees in southern Arizona (Fritts 1976). This knowledge is improving as we continue to gather data from a set of trees monitored with dendrometers and dendrographs in the Chiricahua Mountains (Baisan and Swetnam 1994).

The resolution of our seasonal timing estimates are about two weeks to one month. The approximate seasonal dates of fires overlap for each succeeding intra-ring position, due to variability in the cambial growth onset dates, rates, and cessation in different years, sites, and species. In general, most fires occurred sometime between late April and late June (Figure 3). This generally corresponds to the typical dry period of late spring to early summer and the 20th century lightning fire season (Barrows 1978) (Figure 3). There were differences, however, in the seasonal timing of fires between specific years (e.g., Swetnam et al. 1989; Baisan and Swetnam 1990), time periods (Grissino-Mayer 1995; Grissino-Mayer and Swetnam 1995), and sites (Seklecki et al. 1996; Wilkinson 1997), all of which provide clues about the nature of fire regimes and possible changing influences of humans and climate.

The ecological implications and importance of different fire interval distributions and fire seasons at these temporal scales are not well understood. Research combining data on such ecological patterns and process in the Southwestern United States and Mexico over periods of centuries is just beginning (but see Barton 1993; 1994; Fulé and Covington 1994; 1996, 1997; Danzer et al. 1996; Villanueva-Diaz 1996; Abolt 1997; Danzer 1998; McPherson and Diaz, this volume).

Summaries or generalizations of the fire interval and seasonal distributions over time are necessary first steps in our search for fire regime and ecosystem patterns. There is, however, another aspect of fire history that is equally important. This is the historical and chronological nature of fire regimes. The importance of these historical aspects is evident when the specific chronology of fire events (or intervals between events) is shown to be contingent upon climatic events (e.g., droughts and wet periods) and land-use history (e.g., introduction of intense livestock grazing). In the following sections we further document and describe *La Frontera* fire regimes with specific fire chronology examples. The general patterns shown by each case history are indicated by the headings of the following subsections.

Frequent, Low Intensity Surface Fires, Interrupted Circa 1870-1900

Fire-scar chronologies from forest stands in the Santa Catalina Mountains illustrate typical Southwestern fire regime patterns (Figure 4). The sites (forest stands) sampled along this 850 m elevational transect extend about 11 km across the main ridge line of the Santa Catalinas. The highest elevation site at the top of the mountain is relatively mesic, mixed conifer, while the lowest site is xeric, pine-oak forest. Only a slight difference in fire frequency is evident along the elevational gradient, with somewhat fewer fires occurring at the highest elevations (Figure 4).

Another feature of this chronology, which is typical of other large and continuous pine and mixed-conifer forests we have studied, is the remarkable synchrony of fire-scar recorded events along the entire transect (Figure 4). Fires could easily spread along the transect because there are no continuous fire barriers (e.g., cliffs). Therefore, it is very likely that these synchronous fire scars were created by the same widespread fires. Even if the same, spatially-continuous fire events did not create some of the highly synchronous fire scars, it is still logical to infer that relatively large areas burned during these years.

We have found excellent correspondence between fire-scar dates and documentary records of fires during the late 19th through 20th centuries. Documentary records include calendar dates and place names of fires in newspapers, and mapped perimeters of large fires in government agency fire atlases (see references in Table 1). Large fires were reported, for example, during 1879, 1880, 1887, 1900, and 1910 in the Santa Catalina mountains by Tucson newspapers (Bahre 1985), government documents, and other sources (DuBois and Smith 1980). All of these fires were recorded by the fire-scarred trees. The consecutive-year fire events of 1879 and 1880 were both recorded, but as we might expect given the short time for fuels to accumulate between fires, the two events were recorded by different sets of trees (Figure 4). Recent wild fires and prescribed fires within our study areas have also demonstrated the reliability of the fire-scar record in many instances. The 1985 fire scars near Rose Canyon in the Santa Catalina mountains (Figure 4), for example, were caused by a prescribed burn in precisely this year and area (personal communication, Ted Moore, USFS fire management officer).

The 1900 fire is a particularly well documented event. This widespread fire-scar event (Figure 4) was very probably the same surface fire photographed in May 1900 (Figure 5) by a government survey crew (Holsinger 1901). These fire scars occurred primarily in the "dormant season" intra-ring position, or within the first part of the earlywood of the 1900 ring. These positions correspond to the growth period from about late April through May (Figure 3). We have reported numerous other examples of correspondence between fire-scars and documentary fire records, including seasonal timing (e.g., Baisan and Swetnam 1990; Ortloff et al. 1995, Swetnam and Baisan, unpublished data), showing that fire-scar records are accurate and consistent recorders of fires.

The Santa Catalina chronology and other similar chronologies (see particularly Swetnam and Dieterich 1985 and Baisan and Swetnam 1990), also firmly establish that fire-scarred trees were not merely recording small, "spot" fires. Some of the less synchronous fire dates, and particularly those recorded by single trees or small numbers of closely spaced trees, may indeed have been small, spot fires. It is also likely that some of the synchronous fire-scar dates recorded within and between our sites sampled at the scale of watersheds and portions of mountain ranges (such as in Figure 4) resulted from different fires originating from different ignitions. Nevertheless, our interpretation that relatively large areas burned during the highly synchronous years is quite reasonable, even if the burns were not entirely continuous between all trees or sites. This interpretation is also supported by the documentary record when it is available (e.g., the 1900 fire in the Santa Catalina mountains).

A common misconception is that fire scars are caused only by relatively high intensity fires, i.e., those fires that were intense enough to burn through protective bark at the base of trees. Although this is often true for the first scarring event on a tree, a sufficient intensity for scarring can be achieved by a chance accumulation of fuel at the base of the tree (e.g., a fallen branch or log adjacent to the lower bole). After the first scarring event, however, fire-scarred trees become highly susceptible to re-scarring by subsequent fires. Even very low intensity fires (such as shown in Figure 5) may be recorded because the exposed wood in the fire scar cavity and pitch that oozes out of the wound boundary are easily ignited. This high susceptibility to re-scarring by fires of any intensity has been demonstrated repeatedly in our data sets by fire-scar events corresponding with known low intensity wild fires and prescribed fires. The vast majority of the fire-scar events in our chronologies were recorded by trees that had already been scarred by one or many previous fires (e.g., Figure 4). Hence, these chronologies represent fires of all intensities.

Another feature of the extensive Santa Catalina chronology that is typical of many Southwestern United States fire histories is the abrupt cessation of widespread surface fires after circa 1900. This pattern is most clearly seen in the composite line graph at the bottom of Figure 4. We have documented dozens of cases in the United States where the historical decline of widespread surface fire regimes was coincident with the boom in the livestock industry during the last decades of the 1800s and the first decade of the 1900s (see references in Table 1, and in Swetnam and Baisan 1996a). The rise in numbers of sheep, goats, and cattle around the turn of the century in *La Frontera* forests on the United States side of the boundary was contingent on several factors, including decreased hostilities with Apaches and larger-scale economic forces, such as access to emerging markets and railroads (Denevan 1967; Wagoner 1952; 1961; Bahre 1991, 1995, 1998; Wilson 1995). On the United States side of the border, there is abundant historical evidence that during the late 1800s livestock numbers were many times higher than they are today (Leopold 1924; Wagoner 1961; Bahre 1991; Wilson 1995). In addition to cattle, large herds of sheep and goats grazed many areas in southern Arizona (Hadley et al. 1991; Bahre 1995; Wilson 1995; Bahre 1998).

In a few special cases, which also further establish the central role of intense livestock grazing, we have documented 17th to 19th century declines in surface fire regimes coincident with the introduction of livestock into specific mountain areas of northern New Mexico and Arizona by Hispanic settlers and Navajos (Savage and Swetnam 1990; Touchan et al. 1995; Baisan and Swetnam 1997).

Thoroughly organized, systematic, and continuous suppression of fires by government agents did not begin in most mountain areas of the Southwest until after 1910 (Pyne 1982; Baker et al. 1988; Tucker 1989). During the early years of the Forest Reserves and National Forests (circa 1892-1910) forest rangers extinguished small fires when they could reach them relatively quickly. They occasionally organized crews from nearby ranches and towns to aid in fighting large burns. After a large fire was spotted, it usually took days to round up crews and supplies and to move them into the remote mountains where the fires were burning. Typically, by the time they arrived in force the fires were already very large. “Suppression” of such fires amounted to minor holding actions along the burn perimeter after the fire had already made extensive runs (Baker et al. 1988; Tucker 1989).

Fire-scar records from *La Frontera* mountain ranges show that these ad hoc fire fighting efforts had limited effects on the extent of some fires during the period from the 1890s through circa 1910 (e.g., Swetnam and Dieterich 1985). The 1900 fire in the Santa Catalinas (Figure 5), for example, was fought by the Holsinger government survey crew, but it was still recorded by fire-scarred trees as a very extensive fire event across the main ridge line of the mountain (Figure 4). The ineffectiveness of early fire suppression efforts became very clear after the devastating fires of 1910 in the western United States killed more than 80 people and burned several million ha. of forest and range lands (Pyne 1982). The main problem with this early style of fire fighting is reflected in an old saying familiar to all wildland fire fighters: "If you don't catch them small you won't catch them at all." (Pyne 1982). Fire suppression became effective only after (1) livestock grazing helped reduce the ignition and spread of fires, and (2) government agencies (mainly the Forest Service) stationed organized crews within the forested areas during the fire season and built lookout towers, guard stations, and trails. Most of these improvements came during and after the Civilian Conservation Corps era of the 1930s (Pyne 1982).

Leopold (1924) was one the first to clearly describe the initial role of intensive livestock grazing in causing the end of frequent surface fires in *La Frontera*. He witnessed these effects first hand. However, even before Leopold wrote this classic paper, the fire suppressing effects of livestock grazing was common knowledge among his contemporaries. This quote from a memo written by Apache National Forest Supervisor John D. Guthrie, dated January 23, 1912, reflects this understanding (Tucker 1989, page 238):

> "Mr. Becker [a long-time, local resident] told me on January 20 that prior to 1881 few if any stock of any kind ranged on the White Mountains, and that up to that time fires ran over the Mountains each spring, that from May 15 until the summer rains the Mountains were smoking from fires set by Indians on the Reservation, that from that time (1881) on, stock were driven on the Mountains and the fires began to be stopped, and the young timber began to start, that most of the young growth has started since 1880."

The fire suppressing effects of livestock grazing was partly due to removal of fine fuels (grasses and forbs) essential for carrying frequent surface fires (Leopold 1924; Humphrey 1958). Total removal of grasses was not necessary in many arid and semi-arid landscapes; surface fires could no longer ignite or spread great distances where already sparse surface fuels were further reduced by grazing. Numerous trails, wagon roads, and livestock driveways also disrupted fuel continuity, and hence the ability of fires to spread over large areas. An example of this effect is described in a statement by Arthur Noon, one of the first rangers in the Huachuca Forest Reserve (established 1906). He noted that the Huachucas were so full of cattle and cattle trails that the trails served as good fire breaks (cited by Bahre 1991, page 128, from the Fred Winn papers, Arizona Historical Society).

We lack detailed land-use histories for most of the borderlands mountain ranges, but where the documentary record is available for direct comparison with the fire-scar record we find that the effects of livestock grazing on fire regimes was consistent. For example, because of the rugged terrain of the Santa Catalina and Rincon mountain ranges, and the Apache threat, upper elevation forests were not used extensively for summer pastures until after most Apache groups were moved to distant reservations. The last widespread surface fires recorded by many of our fire-scar study sites within these mountain ranges were in 1900 and 1893, respectively (Table 1, Figure 4). Intense grazing clearly did not begin in the higher elevations of the Santa Catalinas until after 1900. This is supported by Holsinger's 1901 report, where he stated: "The central district affords abundant pasture, but the stock-men avoid it because cattle allowed to range there become wild and unmanageable and must be hunted and shot like wild game. Only the foothills are now considered available as public range." Likewise, R. S. Kellogg (1902a), another government agent reporting on tree regeneration conditions in the Santa Catalinas, stated: "Little damage has been done by stock, since sheep are rare and few cattle frequent the higher mountains." By the 1920s Forest Service grazing examiners reported that in the Catalina Division "several ranges show excessive heavy use in the past and from which [effects?] … forage has not recovered." (Cooperrider and Hussey 1924). Unfortunately, the specific locations of these ranges were not indicated.

In contrast, parts of the Huachuca and Santa Rita Mountains were heavily grazed beginning in the late 1870s. In 1877 Fort Huachuca was established at the base of the Huachucas, and large ranching operations (Empire and Cienega Ranches) began around and within the Santa Ritas (Wagoner 1961; Bahre 1991, 1998; Wilson 1995). In a government survey report, for example, R. S. Kellogg (1902b) stated: "The country included in the Santa Rita forest reserve is one which has been used for many years as a range for cattle, horses, and sheep…Previous to the drouth [sic] of 1891 and 1892, this range carried fully 25,000 head of cattle and horses and 5,000 sheep." Kellogg describes in some detail the heavy impacts of cattle on vegetation in the Santa Ritas, particularly in areas where they concentrate, such as near water and in level saddles between ridges. The last widespread fire-scar event in the Josephine Saddle area of the Santa Ritas was in 1877 (Ortloff et al. 1995).

A few widespread fires occurred after the late 1870s on upper slopes and ridge top sites in the Huachuca mountains, but fire frequency clearly decreased circa 1880 (Danzer et al. 1996; Danzer 1998). Forest rangers (e.g., the 1906 Arthur Noon quote above) and government reports confirm that many parts of the Huachuca Mountains, including the high elevations had been heavily overgrazed for some decades before the early 1900s (Cooperrider and Hussey 1924, Tucker 1989).

As previously mentioned, the decline of the Apache threat in the late 1800s was a factor in the rise of the livestock industry. The diminishing presence of Apaches also raises the question: To what extent was the absence of Apache-set fires after the late 1800s a factor in the decline in widespread surface fires? There is probably no simple answer to this question, but it is notable that in some areas widespread surface fires continued to occur during the one or two decades after almost all hostilities with Apaches had ceased and before intensive livestock grazing began. For example, between the 1880s and early 1900s several widespread fires occurred in the Santa Catalina Mountains (Figure 4) and in the Mogollon Mountains of the upper Gila River (Swetnam and Dieterich 1985; Abolt 1997). This fact argues that intensive livestock grazing, rather than lack of fire ignitions by Apaches, was the primary factor causing the end of frequent, widespread surface fires. We will return to the topic of Native American effects on fire regimes in the next section.

Climate change is an unlikely explanation for the abrupt elimination of widespread surface fires documented in the fire histories. If climate change was a primary cause we would expect regional climatic records (e.g., rainfall, temperature, or drought indices) to also show a major trend or shift at this time. In general, they do not. Most of the 1880s decade was wet, then a severe drought gripped the Southwest for a few years in the early 1890s. Extreme seasonal droughts occurred in 1902 and 1904. An extreme wet period occurred during the late 1910s and early 1920s (Sellers et al. 1987; Fritts 1991; Meko et al. 1993). Fire regime changes in most sites were not synchronous with any of these climatic events. In contrast, as discussed above, the ending dates of widespread surface fires corresponded consistently and closely with the rise of intensive livestock grazing in each area. Moreover, surface fire regimes continued unaltered in some high elevation, remote mountain areas on the Mexican side of the border (as discussed below). Frequent fires also continued to occur in rare, isolated locations in the United States where intensive livestock grazing and/or effective fire suppression never occurred but where similar regional climatic patterns prevailed (Grissino-Mayer 1995).

Frequent, Low Intensity Surface Fires, Continuous Through the 20th Century

Fire-scar specimens have been collected in only a few mountain areas in northern Mexico. Research in the Sierra de los Ajos (Dieterich 1983; Baisan and Swetnam 1995; Kaib 1998) shows that surface fires occurred in these forests for many centuries (since at least the mid 1400s). The most interesting and important feature of this history is the continued occurrence of frequent surface fires in all 3 sites at least through the mid-20th century (Figure 6). Fire histories reconstructed by Fulé and Covington (1994, 1996, 1997) show a similar continuation of widespread surface fires in pine forests in the state of Durango until about the 1940s. Both Kaib (1998) and Fulé and Covington (1997) suggest that late 20th century fire regime changes in these forests were related to communal land developments (ejidos) in the 1940s and a rise in livestock grazing and logging activities. Other, recent fire-scar collections and observations in Mexican mountain ranges (i.e., Sierra San Luis, Sierra el Tigre, Sierra Bacadehuachi) indicate that surface fire regimes continue unaltered in some forest areas (Kaib, pers. obs.).

In contrast to Fulé and Covington's (1994, 1996, 1997) findings in Durango, and ours in the Sierra de los Ajos, Minnich et al. (1997) state that they detect no effects of 20th century livestock grazing on fire regimes in the Sierra San Pedro Martir in northern Baja California. Their extensive fire history research in this mountain range is based primarily on aerial photographic interpretations. The earliest photographs are from the 1930s, but most of this coverage is for the late 20th century when changes in fire regimes may already have occurred. Minnich et al. refer to a fire-scar chronology compiled for a portion of the same area (Burk et al. 1991) in support of their claim for no 20th century change in the fire regime. As illustrated in the Burk et al. report, however, this chronology shows a decline in fire frequency in the late 20th century that appears similar to the decline documented in Fulé and Covington's chronologies (1996, 1997).

We sampled three sites in the Sierra de los Ajos; two in pine and mixed conifer at the upper elevations and one in pine-oak forest within a canyon at a lower elevation (Figures 1, 6). One of the high sites was located in a single large forest stand on a saddle near the highest peak in the mountains (Las Flores, 2,620 m). The other high site was dispersed among three adjacent forest stands along a ridge to the northeast of this peak. These two sites were about 4 km apart. The burning appears to be uninterrupted through the late 20th century at the saddle site, but fire occurrence decreased on the ridge site after the 1930s (Table 2, Figure 6). The decrease in fire frequency on the ridge may be partly related to a decrease in sample size in the late 20th century (Figure 6). We sampled only dead trees (i.e., snags, stumps, and logs) at the ridge site, so only a few specimens extended through the late 20th century.

It is also possible that this difference in late 20th century fire frequency between the ridge and saddle sites was related to topography and land-use history. The saddle site was subject to spreading fires from both sides of the main divide in this range, while the ridge site was probably subject to spreading fire primarily from one side. Road building, logging, and some livestock grazing in the lower elevations of the Sierra de los Ajos may have begun to limit effective fire ignition and spread by the late 1930s, but some fires continued to burn in the higher elevation forests. Organized suppression of fires by Mexican land management agencies in most forests of northern Mexico has been non-existent (Leopold 1937; Marshall 1957, 1963; Dieterich 1983) or limited to some private and communal lands (Kaib 1998). The woodlands at the base of the mountain were heavily cut over for fuelwood since the 19th century for mining operations and domestic uses (Bahre 1984). Historical records also suggest there was an increase in livestock grazing after World War II in northern Mexico associated with the development of United States markets (Kaib 1998).

Our lower elevation fire history site is in a canyon pine-oak forest. Intensive livestock grazing may have begun here after the 1930s when fewer fires were recorded by our specimens. Sample sizes, however, also decreased after this time (Figure 6). We sampled about 20 trees at this site, but because of difficulties in crossdating this tree-ring material (too many false rings) we accurately dated only 8 trees. Nevertheless, among three fire-scarred trees with tree rings extending into the late 20th century, only two fire dates were recorded after the 1930s. Additional sampling is needed to clearly reconstruct the 20th century fire history at this site.

A distinct contrast in grazing impacts at high and low elevations in northern Mexico was noted by Aldo Leopold in 1937. He marveled at the relatively open, grassy, and pristine forests at the high elevations in the Rio Gavilán area in the Sierra Madre Occidental (approximately 180 km southeast of the Sierra de los Ajos). His observations of the differences between high and low elevations, and the causes of these differences are worth repeating:

> "Let me hasten to add that this enviable contrast [between the United States and Mexico] holds only for the mountains. The low country on both sides of the line has been equally abused and spoiled. The Sierras escaped because of the mutual fear and hatred between Apaches and Mexicans. So great was the fear of Indians that the Sierras were never settled, hence never grazed, hence never eroded. This holds true up to Pancho Villa's revolution of 1916. During the revolution bandits performed the same ecological function as Indians. Since then, depression and unstable land policies have served to keep the mountains green."

Marshall (1957, 1963) also stated that livestock grazing during the 1950s was minimal or absent in some remote, dry mountain areas on the Mexican side of the boundary. He specifically described high elevation areas in the Sierra San Luis Mountains (about 100 km east of the Sierra de los Ajos) as ungrazed and with abundant evidence of recent fires. He did not specifically discuss livestock grazing in the Sierra de los Ajos, but he did refer to lush grass cover in some areas (Marshall 1957). He also mentioned a large fire in 1954, which is a fire-scar date recorded in both the saddle and ridge sites.

Marshall found striking differences in the montane vegetation and bird diversity and abundance on the two sides of the border. He particularly noted the more frequent presence of dense conifer stands on the Arizona side of the border. He concluded that these differences were due to the ecological effects of continued burning on the Mexican side owing to lack of heavy livestock grazing and fire suppression by people. Marshall emphasized the ecological importance of maintaining grass cover in pine-oak woodlands which helped sustain frequent fires and prevented the development of dense conifer stands. It is also clear from Marshall's (1957) descriptions that land-use varied considerably from one Mexican mountain range to another (and even within mountain ranges), with very extensive logging and grazing in some areas (e.g., the sierras near Cananea).

Even if Leopold's reasoning about Apaches and bandits did not apply to the Sierra de los Ajos, there are other reasons why livestock numbers may not have reached high numbers in parts of this mountain range in the past. For one, this is a very remote and rugged range that is very difficult to access and travel in. Today, only a single, very rough, four-wheel drive road ascends to the high elevations. Second, there are very limited water sources in this relatively dry range. Finally, Leopold's political and economic reasons for lack of grazing in the high mountains (last sentence of his quote above) could certainly have applied in this area. We conclude that the uninterrupted surface fire regimes in the Sierra de los Ajos (at least in the saddle site) reflect a lack of intensive livestock grazing in this area.

The upper elevations are currently grazed by a small number of cattle and there has been some timber harvesting, so it is possible that ranchers or loggers set some fires in the past. However, if either Apaches or Mexicans significantly influenced fire regimes in the past, and up to the present, we would expect greater variability in fire frequency through time than is evident in the fire chronologies (Figure 6). Apache movement and use of specific areas within Southwestern mountain ranges was probably sporadic, and partly dependent on changing political conditions (e.g., warfare). Morino [1996), for example, interpreted striking fire frequency changes within the Organ Mountains, New Mexico as reflective of Spanish/Mexican-Apache wartime and peacetime periods. Likewise, Kaib (1998, Kaib and Swetnam in prep.) has compiled tree-ring and archival documentary evidence supporting a hypothesis that fire frequencies were increased during wartime periods owing to intentional burning by both Apaches and European soldiers. These and other quantitative fire history studies in the region (Seklecki et al. 1996; Wilkinson 1997; Kaye and Swetnam in prep.) all conclude that, if Apaches or Europeans influenced pre-1900 fire regime patterns, these influences were probably very time and place specific, and not generalizable across broader temporal and spatial scales.

Another consideration in assessing natural versus cultural causes of fire regime variability are the rates of lightning strikes and lightning-ignited fires. Lightning-strike detection records for the southwestern United States show very large numbers of strikes during the summer months (e.g., Gosz et al. 1995). Government records of lightning-ignited fires that were detected and suppressed also indicate that, even if only a small percentage of fires had been allow to spread over large areas, they would be sufficient to account for the highest fire frequencies we document with fire scars (Baisan and Swetnam 1990). The seasonal distribution of lightning ignited fires in the 20th century also generally corresponds with the seasonal distribution of pre-20th century fires reconstructed by fire-scar analyses over the region (Figure 3). This suggests that either most pre-20th century fires were lightning caused, or that the majority of human-caused fires also occurred during the typical lightning fire season.

In summary, our explanation for continued, frequent surface fires in the Sierra de los Ajos (at least into the mid-20th century), is (1) the lack of intensive grazing by large numbers of cattle, horses, sheep, or goats in the higher elevations early in this century, and (2) a lack of effective, organized fire suppression. We doubt that the frequent fire regime recorded in our fire-scar history since the late 1800s was significantly influenced by fires set by Mexican ranchers or loggers. Even though small numbers of Apaches continued to live on the Mexican side of the border after Geronimo's surrender in 1886, it seems unlikely that they affected fire regimes in the Sierra de los Ajos, particularly in the latter half of the 20th century.

Mixed Surface Fire and Crown Fires in Rugged Topography

Fire chronologies for the Animas Mountains contrast with the more typical surface fire regimes reconstructed in most other Southwestern pine forests (Figure 7). This relatively complex history shows a pattern of “mixed” fire regimes, characterized by surface fires with 3 to 15 year intervals in individual forest stands, and widespread, higher intensity burns occurring at about 20 to 50 year intervals (Figure 7).

The Animas Mountains fire-scar collection is one the largest in *La Frontera*, both in the numbers of trees sampled and in broad spatial distribution. The master fire chronology (Figure 7) is aggregated into clusters of 3 to 10 fire-scarred trees sampled within widely distributed forest stands over and around the highest peaks of the range (Figure 8). This collection is comparable in extent to the fire chronology from the Rincon Mountains (Baisan and Swetnam 1990). The Rincon Mountain fire chronology (Mica Mountain, in Table 1) shows consistent, widespread fires (highly synchronous among trees and stands) at intervals of about 3 to 8 years. There is little evidence for large, high intensity, long interval fires in the Rincon Mountains. In contrast, the Animas chronology shows less synchrony of surface fire dates among dispersed stands than the Rincon or Santa Catalina chronology (Figure 4), but other evidence points to occasional, mountain-wide (synchronized), high intensity burns.

We think that the 1989 wildfire in the Animas Mountains was analogous in its extent and severity to earlier synchronous mountain-wide fires in the chronology (Figure 7). The 1989 fire was ignited by lightning on June 15 in the foothills along the northern margin of the range. Suppression efforts did not begin until the fire had spread over more than 10,000 ha., encompassing the whole array of plant communities from grasslands through mixed-conifer forests. Fire effects varied from light intensity surface burns with minimal impacts on overstory trees to total destruction of the forest canopy and understory vegetation (Figure 9). We do not have precise measurements of the sizes of the high intensity burn patches, but some appeared to be about 200 to 500 ha. in size. Our evidence for the 1989 analog inference is (1) the similarity in the synchroneity of certain fire years (particularly 1753, 1805, 1825, 1857, and 1879, and 1989), (2) dates of tree mortality events corresponding to some of these fires (unpublished data), and (3) dates of tree recruitment following some of these fires (Baisan and Swetnam 1995). Villanueva-Diaz’s (1996) data on tree-age structure from several stands in the Animas also suggest that tree recruitment tended to follow large fires, particularly the 1879 burn (see McPherson and Diaz, this volume). This is the recruitment pattern we would expect if stand openings were created by relatively high intensity burns.

Other spatio-temporal patterns in the chronology point to the importance of continuous fuels and land-use history. For example, surface fires were more frequent in some of the Animas Peak stands (upper 4 stands in Figures 7, 8) than in the stands located further south. This pattern was probably due to the continuous, unbroken topography and fuels extending up slope from grasslands and woodlands at the base of the mountains up to the summit of Animas Peak on this north side (Figure 8). Fires could spread (and did in 1989) unhindered by topography from any ignition point along this elevational gradient. It is notable that our northernmost sampled site (APN), located on a north-facing slope, is an almost pure ponderosa pine stand, with widely spaced trees and a grassy understory (Figure 10). In contrast, higher elevation north-facing stands in the area south of Animas Peak tend to be closed-canopy mixed-conifer. These conifer stands are relatively isolated from lower elevation spreading fires by natural fire barriers, such as cliffs along the west-facing escarpment of the range, and very steep, treeless, talus slopes in some areas along the east slope (Figure 8, 9). Other areas along the east and south sides of Animas

Peak are scattered oak-brush fields inter-mixed with talus slopes. Hence, stands in the southern end of this range are more isolated from spreading fires than those on the northern end of the range.

Differences in 20th century fire occurrence patterns between the northern and southern stands also reflect disparate land-use histories. Large-scale ranching in the Animas Valley probably began in the late 1880s (McPherson and Diaz, this volume). The last widespread fire before 1989 in the southern stands was in 1879. However, some fires continued to occur in the northern stands (Figure 7). Again, we ascribe this pattern to the continuity of topography and fuels. Despite the effects of an unknown, but probably low level of livestock grazing in this remote part of the mountain, there was still sufficient fuels to carry fire within and between open grassy forests on these northern slopes. Fires may have come from, or burned down into the lower elevation woodlands and grasslands on this side of the mountain. In comparison, fire regimes in the isolated, southern stands seem to have been affected immediately by the onset of livestock grazing in the 1880s, with a cessation of widespread fires until 1989 (Figure 7).

Springs in the relatively flat and grassy saddle between the north and south stands, and on the east side of the saddle, may have been the impetus for concentrating livestock in this area. Livestock grazing and related effects (e.g., numerous trails) may also have had a pronounced effect in the southern stands because they were already relatively isolated from spreading fires by natural barriers (i.e., cliffs and talus slopes). In other words, prior to livestock grazing there was probably sufficient fuel to sustain spreading fires within and between the southern stands, albeit at a somewhat lower frequency than in the northern stands (Figure 7). After livestock grazing began, fuel amounts (grasses and forbs) and continuity were reduced below a threshold necessary for carrying surface fires to these relatively isolated stands.

From the early 1910s to 1950s the Animas Mountains were under Forest Service jurisdiction (McPherson and Diaz, this volume). A primitive fire lookout was set up on South Animas Peak but was probably manned only periodically. Hence, the less frequent and synchronous fires between circa 1910 and the 1950s in the Animas Peak stands may reflect these minimal fire suppression efforts. After the Animas Mountains were transferred to private ownership state and federal agencies provided some fire suppression assistance, but some fires reached large sizes before much attention was paid to them (e.g., 1989).

Finally, we note that the mountain-wide, synchronous fires tended to occur during drought years. A comparison with regional, tree-ring based drought reconstructions (Meko et al. 1993) confirmed that the six mountain-wide fire events since 1700 all occurred during moderate to severe drought years. The 1879 and 1989 fire years were particularly notable as extreme drought and regional-scale fire years throughout the Southwest (Swetnam and Baisan 1996a; Swetnam and Betancourt 1998). Our interpretation of the decadal-length intervals between these widespread fires is that fuel amount and continuity between scattered conifer stands and brush fields built up relatively slowly, so that at intervals of about 20 to 50 years conditions were primed for widespread, mountain-wide fires. Drought conditions conducive to fire ignition and spread promoted these mountain-wide events. The 110-year hiatus between the 1879 and 1989 fires was probably due to the combination of livestock grazing on the mountain preventing the fuel build up grass fuels, the creation of fire breaks (e.g., trails), and limited fire suppression efforts.

DISCUSSION

Early in this century some forest managers dismissed the past as irrelevant to current management situations. This disregard for the importance and relevance of ecological history was partly to blame for land management policies (e.g., attempts to totally eradicate fire) that have led directly or indirectly to many of the severe fire, insect, and pathogen problems which we face today. Similarly, it is a mistake to disregard the value of historical-ecological perspectives because they are potentially complicated by multiple interacting factors, or confounded by issues of scaling, or past human influences (e.g., Native Americans). Change is a fundamental property of ecosystems -- even without human intervention (Sprugel 1991). It is also true that the frequency and magnitude of past ecological change on any landscape is dependent on the scale of analysis. Generally, longer temporal and broader spatial scales encompass changes of greater magnitude. These scaling complications, however, do not prevent us from using historical-ecological data to identify unsustainable recent or past changes, or for recognizing the causes and consequences of such changes.

The 20th century shift to increasingly large and intense crown fires in Southwestern ponderosa pine forests is a case in point (Covington and Moore 1994). This pattern is almost certainly due to elimination of frequent surface fires and subsequent accumulation of live and dead fuels. The historically and ecologically anomalous nature of these changes are demonstrated by documentary and ecological studies (e.g., Weaver 1951; Cooper 1960), and by numerous fire history studies in Southwestern ponderosa pine forests (Swetnam 1990; Swetnam and Baisan 1996a). These patterns are especially evident as pre-20th century histories are contrasted with stand-replacement fire regimes occurring with increasing frequency during the 20th century in the same forests.

Although we know a great deal about high intensity fires, we still do not have a clear understanding of the long-term role of mixed and stand-replacing fire regimes in the sky islands of *La Frontera*. For example, the size distribution of vegetation patches burned by high intensity fires is unknown. We suspect that the 1989-type burn that occurred in the Animas Mountains may not have been historically or ecologically anomalous in this range. We have grave doubts, however, that this is true for the 10,500 ha. 1994 Rattlesnake Fire in the Chiricahua Mountains, or other high intensity crown fires in southern Arizona ranges in the past decade.

Our doubts arise from two observations. First, we lack evidence for fires burning at the intensities and stand-replacing patch sizes of the Rattlesnake and other fires within these ranges in the past (i.e., before circa 1910). Such evidence would include very large aspen stands, or even-aged conifer forests in successional states, with at least fragmentary remnants (charred, snags, logs, or stumps) of the old, burned forest still present. Aspen stands are present in many of the sky islands, but their sizes are typically less than a few hundred ha. (Some aspens stands exceeding 1000 ha., however, established in the Mogollon Mountains following extensive and intense fires in 1904 [Abolt 1997]). Second, we have fire-scarred specimens from numerous locations in the Rincon and Chiricahua mountains where, clearly, only low intensity surface fire regimes persisted for the past three to five centuries. Some of these stands, including the fire-scarred trees that we sampled, were totally incinerated by recent crown fires.

Some may argue that such extreme, historical-ecological changes should not necessarily concern us. Is a brush field slowly succeeding to a conifer forest after a crown fire inherently less valuable or desirable than the conifer forest that burned? It is also argued that we should just step back and let nature take its course. However, catastrophic erosion is occurring in some locations. For example, within 2 years of the Rattlesnake Fire we have observed the formation of a 9 m deep, 18 m wide arroyo at 2740 m elevation in the Chiricahua Mountains. (In contrast, no such arroyos have formed following the 1989 fire in the Animas Mountains.) The sediments at the bottom of this arroyo are thousands of years old, and there are no other obvious arroyos of this size at these elevations (personal observations of the authors). This kind of extreme change will prevent parts of these ecosystems from returning to forest or woodlands for centuries, or millennia.

The greatest value of historical reconstructions and perspectives may be that they enable us to identify extreme, unsustainable changes and their causes (Dahm and Geils 1997; Kaufmann et al. 1998). Ultimately, land management decisions are largely subjective and based upon human desires and practical constraints. However, historical perspectives play a critical role by informing managers and the public about the nature and causes of ecological change (Kaufmann et al. 1994; Morgan et al. 1994; Swetnam et al. in revision).

SUMMARY

1. Before 1900, surface fires occurred frequently (at least one fire per decade) in nearly all *La Frontera* woodlands and forests with a pine component, but fire frequencies and sizes were highly variable in both space and time. Mean fire intervals and other measures of central tendency and higher moments (variance, skewness, etc.) of pre-1900 fire interval distributions show some patterns that, in part, are functions of vegetation, elevation, and moisture relations. For example, higher elevation, relatively mesic, mixed-conifer forests tended to have longer intervals between fires than lower elevation, relatively xeric, pine forests (Swetnam and Baisan 1996a). High variability in fire history between sites was probably due to unique historical patterns (contingencies), such as natural events (e.g., floods or debris flows in middle and upper Rhyolite Canyon), or human-caused patterns (e.g., Apache augmented fire occurrence in lower Rhyolite and Rustler Park).

2. Fire regimes in most *La Frontera* mountain ranges on the United States side changed suddenly around the turn of the century. Frequent, widespread surface fires in most pine and mixed-conifer forests effectively ceased between circa 1870 and 1900. This change was initially caused by intensive livestock grazing, and subsequently, a combination of livestock grazing and fire suppression efforts by government agencies. Climatic change was probably not a primary factor in the initial cessation of widespread surface fires around the turn of the century.

3. Frequent, widespread surface fire regimes persisted into the 20th century in some mountain ranges on the Mexican side of *La Frontera*. This was probably due to a lack of heavy livestock grazing or effective fire suppression by Mexicans. High lightning strike frequencies suggest that Apaches were not a necessary source of fire in these or other mountain ranges to maintain high fire frequencies. In certain places and times people may have increased fire frequencies above what they would have been with lightning ignitions alone.

4. Rugged mountain ranges, such as the Animas Mountains, sustained mixed fire regimes with both frequent surface fires and relatively long interval, patchy crown fires. The 1989 fire in the Animas burned as a high intensity crown fire in relatively small patches. These patches were embedded in a much larger matrix of low intensity surface fire. We interpret synchronous fire

dates at 20 to 50 year intervals before 1900 in the Animas to reflect fires of similar extent and intensity as the 1989 fire. On the other hand, high intensity fires in the late 20th century causing canopy destruction in large patches in other *La Frontera* mountain ranges appear to be highly anomalous.

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Table 1. Fire history site descriptions. See text for explanation of forest type codes.

Site Name (Map no.)	Mountain Range	Forest Type	Min. Elev. (m)	Max. Elev. (m)	Number of Trees Sampled	Inner Tree-Ring Date	O T D
Camp Point (1)	Pinaleno	MC	2900	2926	50	1543	19
Peter's Flat (2)	Pinaleno	MC	2804	2880	40	1376	19
Lemmon Peak South (3)	Santa Catalinas	MC	2650	2750	22	1436	19
Lemmon Peak North (3)	Santa Catalinas	MC	2700	2750	16	1597	19
Bear Canyon (4)	Santa Catalinas	Pine/Oak	2000	2100	7	1461	19
Rose Canyon Lower (4)	Santa Catalinas	PIPO	2100	2150	12	1463	19
Rose Canyon East (4)	Santa Catalinas	PIPO	2150	2200	7	1558	19
Rose Canon Upper (4)	Santa Catalinas	PIPO/MC	2100	2200	17	1477	19
Palisades (4)	Santa Catalinas	PIPO	2300	2350	4	1690	19
Mica Mountain (5)	Rincon	PIPO/MC	2070	2600	44	1481	19
Rhyolite Lower (6)	Chiricahua	Pine/Oak	1707	1804	12	1466	19
Rhyolite Middle (7)	Chiricahua	PIPO/MC	1804	1920	30	1466	19
Rhyolite Upper (8)	Chiricahua	PIPO/MC	2073	2134	16	1466	19
Rustler Park (9)	Chiricahua	PIPO/MC	2438	2591	58	1614	19
Pine Canyon (10)	Chiricahua	Pine/Oak	1707	1829	27	1540	19
Josephine Saddle (11)	Santa Rita	Pine/Oak	2073	2195	17	1452	19
Sawmill Canyon (12)	Huachuca	Pine/Oak	2012	2225	23	1499	19
Pat Scott Peak (13)	Huachuca	PIPO/MC	2545	2652	34	1499	19
Animas North (14)	Animas	PIPO	2438	2438	18	1538	19
Animas South (15)	Animas	PIPO/MC	2438	2438	56	1445	19
Sierra Ajos Ridge (16)	Sierra Ajos	Pine/Oak	1981	2073	13	1438	19
Sierra Ajos Saddle (17)	Sierra Ajos	Pine/Oak	2100	2100	12	1438	19
Sierra Ajos Canyon (18)	Sierra Ajos	Pine/Oak	1600	2000	8	1681	19
McKenna Park (19)	Mogollon	PIPO	2300	2400	12	1616	19

Langstroth Mesa (20)	Mogollon	PIPO	2300	2400	18	1570	19
Upp. Langstroth (20)	Mogollon	MC	2750	2800	6	1630	19
Lower Cub Mesa (21)	Mogollon	PIPO	2600	2600	9	1563	19
Upper Cub Mesa (21)	Mogollon	MC	2650	2700	7	1495	19
Snow Park (22)	Mogollon	MC	3080	3080	9	1540	19
Black Mountain (23)	Mogollon	PIPO/MC	2621	2800	27	1495	19
Gilita Ridge (24)	Mogollon	PIPO/MC	2500	2500	10	1644	19
Bear Wallow (25)	Mogollon	PIPO/MC	2950	3000	13	1553	19

Table 2. Fire interval statistics for *La Frontera* fire-scar chronologies for the period AD 1700 to 1900. All distribution statistics are in years. See text for explanation of the fire extent classes. The last widespread fire was the final fire--scar date recorded by at least 25% of scarred trees within the site.

Site Name	Fire Extent Class (%)	Mean	Median	WMPI	Min.	Max.	Stanc
Camp Point	all	6.82	5	5.75	1	23	
	10	8.52	8	7.73	2	23	
	25	12.67	12	11.45	3	34	
Peter’s Flat	all	6.1	4	5.24	1	22	
	10	9.45	8.5	8.91	3	22	
	25	12.6	12	12.35	3	22	
Lemmon Peak South	all	5	4	4.52	1	15	
	10	7.12	7	6.74	2	17	
	25	8.41	8	8.04	2	19	
Lemmon Peak North	all	6	5	5.53	1	13	
	10	8.61	9	8.04	2	17	
	25	10.42	12	9.72	2	24	
Bear Canyon	all	9.21	9	8.8	2	19	
	10	14.36	12	13.55	6	36	
	25	14.36	12	13.55	6	36	
Rose Canyon Lower	all	5.5	4.5	5.15	1	15	
	10	6.83	6	6.32	2	15	
	25	7.33	6	6.86	2	15	
Rose Canyon East	all	6.83	6	6.52	2	15	
	10	9.19	9	8.51	3	27	
	25	9.19	9	8.51	3	27	
Rose Canyon Upper	all	6.39	6	6.07	1	15	
	10	7.07	6.5	6.71	1	15	
	25	7.92	7	7.63	3	17	
Palisades	all	7.17	7	6.89	2	15	
	10	10.13	9.5	10.19	6	15	
	25	10.13	9.5	10.19	6	15	
Mica Mountain	all	2.95	3	2.67	1	9	
	10	6.13	6	6.02	2	13	
	25	7.32	7	7.13	2	13	
Rhyolite Lower	all	6.17	6	5.41	1	15	
	10	8.75	9	8.03	1	17	
	25	9.21	10	8.77	1	17	
Rhyolite Middle	all	8.3	7	6.78	1	33	
	10	15.25	13	14.2	4	50	
	25	17.9	14.5	17.08	9	50	
Rhyolite Upper	all	7.96	6.5	6.66	1	31	
	10	12.64	12.5	12.22	4	31	
	25	13.08	13	12.67	4	31	
Rustler Park	all	2.91	3	2.71	1	16	

	10	3.85	3	3.56	1	16
	25	4.59	4	4.36	1	16
Pine Canyon	all	4.2	4	3.97	1	9
	10	5.1	4	4.79	1	11
	25	5.96	5	5.9	3	11
Josephine Saddle	all	6.59	5	6.26	2	18
	10	8.24	7	7.94	3	21
	25	9.61	10	9.08	3	30
Sawmill Canyon	all	4.88	4	4.67	2	13
	10	5.93	5	5.57	2	22
	25	7.12	5	6.64	3	22
Pat Scott Peak	all	2.96	3	2.84	1	8
	10	5.13	4	4.74	1	19
	25	9.75	7.5	8.76	3	29
Animas North	all	5.35	4	4.31	1	16
	10	14.14	9	11.92	3	36
	25	16.5	12.5	14.65	4	41
Animas South	all	7.42	6	6.61	1	21
	10	14.33	14	12.66	2	32
	25	24.57	22	22.82	4	46
Sierra Ajos Ridge	all	4.26	4	4.01	1	18
	10	8.57	7	8.07	2	33
	25	9.6	8	9.12	2	33
Sierra Ajos Saddle	all	4.04	3	3.79	1	22
	10	5.54	4	5.14	2	22
	25	5.88	5	5.47	2	22
Sierra Ajos Canyon	all	5.93	5	4.62	1	38
	10	8.67	8	7.81	1	24
	25	8.67	8	7.81	1	24
McKenna Park	all	3.47	3	3.11	1	10
	10	6.3	5	5.53	1	16
	25	6.9	6	6.38	1	16
Langstroth Mesa	all	5.19	4	4.31	1	26
	10	8.14	6.5	7.09	1	26
	25	8.95	7.5	8.18	2	26
Upper Langstroth	all	8.5	7	8.24	3	18
	10	15.6	11	13.77	4	33
	25	15.6	11	13.77	4	33
Lower Cub Mesa	all	6.13	4	4.88	2	36
	10	8.64	7	7.16	2	36
	25	8.64	7	7.16	2	36
Upper Cub Mesa	all	6.79	5	5.69	2	36
	10	12.2	7	9.84	2	36
	25	12.2	7	9.84	2	36
Snow Park	all	8.7	7	8.21	3	19
	10	13.1	10	10.98	4	41
	25	13.1	10	10.98	4	41
Black Mountain	all	2.98	3	2.55	1	15
	10	5.79	3.5	4.94	1	20

	25	13.13	10	11.85	4	40
Gilita Ridge	all	4.51	4	4.03	1	18
	10	8.26	5	7.07	3	28
	25	8.72	5.5	7.57	3	28
Bear Wallow	all	6	5	4.96	1	21
	10	16.3	11.5	14.46	2	32
	25	23.29	19	22.69	10	41

Figure Captions

Figure 1. Locations of fire history studies in *La Frontera*. The numbers adjacent to the dots refer to sites listed in Table 1. Some of the individual sites within mountain ranges are listed under the same numbers as they are relatively close together.

Figure 2. Examples of fire interval distributions from four study sites. The arrowheads show three difference measures of central tendency: M = median, W = Weibull median probability interval, and X = mean.

Figure 3. A. Distribution of intra-ring fire-scar position for seventeen study sites in *La Frontera*. The intra-ring classes are: D = dormant season scar; on ring boundary, EE = early-earlywood scar; within first 1/3 of earlywood, ME = middle-earlywood scar, within second 1/3 of the earlywood, LE = late-earlywood; within third 1/3 of the earlywood, L = latewood; within the latewood. (See text for explanation of seasonal interpretations.) B. Monthly distribution (percent) of area burned and numbers of fires caused by lightning in the Arizona and New Mexico (1940-1976) (data from Barrows 1978).

Figure 4. Master fire chronology chart for an elevational transect in the Santa Catalina Mountains, Arizona. The horizontal lines are fire-scar records from individual trees and the vertical tick marks are fire-scar dates recorded on those trees. The black filled vertical tick marks are the widespread fire events across the transect, except the 1985 fire, which is discussed in the text.

Figure 5. Photograph taken by S. J. Holsinger in May 1900 near Mount Lemmon. This was evidently the last very widespread fire in the 20^{th} century along the main ridge line of the Santa Catalina mountains (see Figure 4) before the livestock grazing and fire suppression era began in this range. Note the relatively open ponderosa pine stand and very low intensity of the burn on the slope to the left. The fire fighters in this and other photographs from the Holsinger (1901) report appear to be using small, stripped pine trees or boughs to beat down the low flames along the perimeter of the burn.

Figure 6. Composite fire chronologies for three sites in the Sierra de los Ajos, Sonora. The vertical lines represent fires recorded by any of the sampled fire-scarred trees within the sites. The numbers above each of the chronologies are the effective sample sizes, i.e., the maximum number of fire-scar trees during each 25-year period that were susceptible to scarring (tree-ring material present and trees had been scarred at least once before).

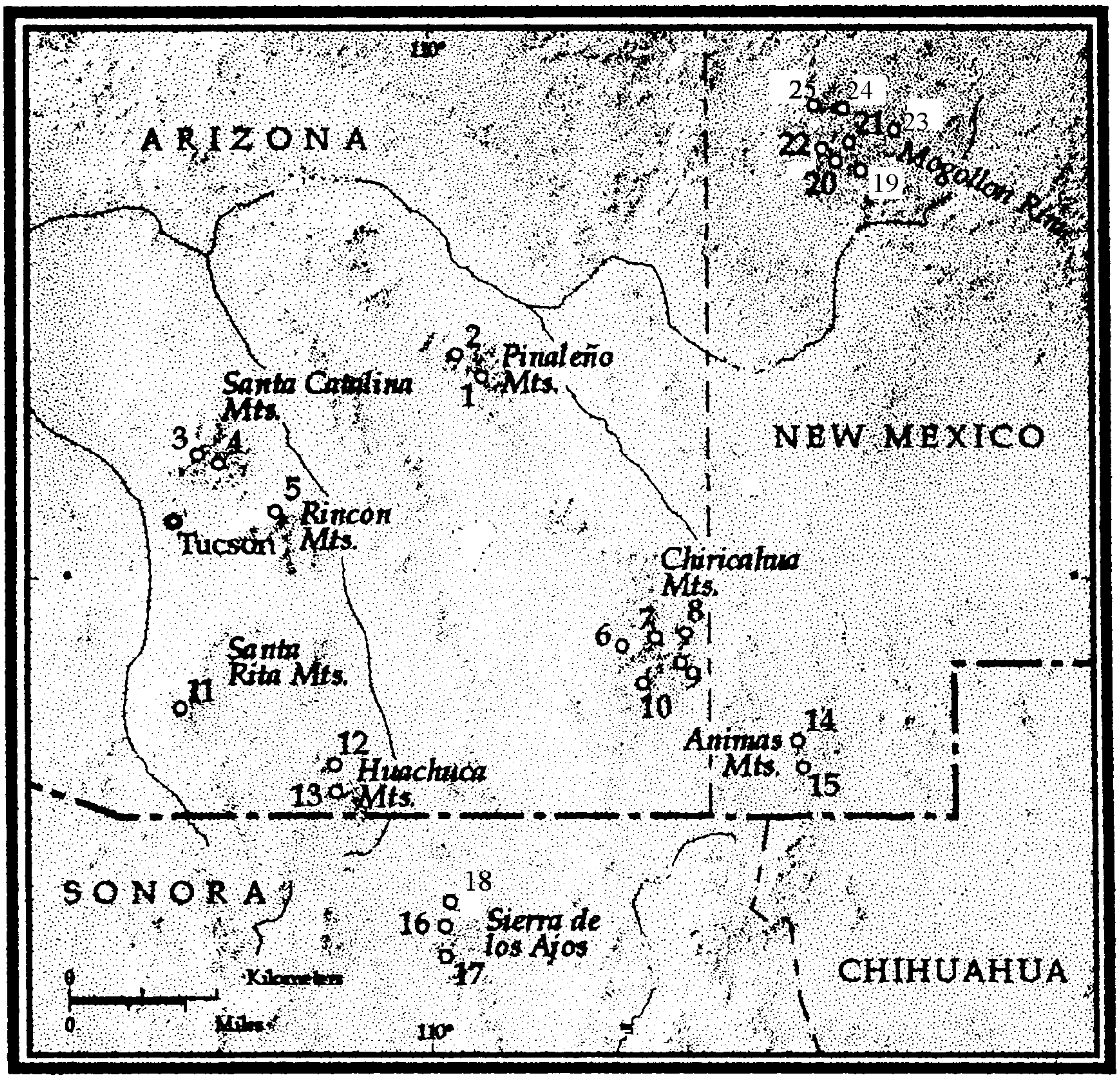
Figure 7. Master fire chronology chart for the Animas Mountains, New Mexico. See caption and legend for Figure 4. The horizontal lines in this case are composite fire-scar records from groups of fire-scarred trees (three to 10 trees) from small stands distributed around the top of this range. The long vertical gray lines show years in which fires swept through most or all stands. See Figure 8 for a map showing the relative spatial locations of sampled stands.

Figure 8. Topographic map of the Animas Mountains. Contour intervals are about 100 meters. Three letter codes show stand locations (corresponding to stand composites in Figure 7). The northern stands on Animas Peak were subject to fires igniting and spreading from any point along the elevational gradient on this side of the mountain, while the southern stands were somewhat protected from fires spreading from below by cliffs and talus.

Figure 9. View from near the summit of the Animas Mountains looking south towards Continental Divide Peak (rocky summit in upper center of the photograph). The 1989 fire burned with high intensity in patches on the relatively level portion of the saddle (center right) where fire-killed Chihuahua pine trees appear as gray and black stems. Lower intensity surface fire burned through the understory of other conifer stands within the view. A mixed-conifer stand on a northern aspect with Douglas-fir, Southwestern white pine, and ponderosa pine is visible in the center and lower left portion of the photograph. Fire-scar collection sites (labeled CIS, ANP, and CDP in Figure 8) are located in the stands just below Continental Divide Peak. The cliff barriers extending south of the Peak are also visible. This photograph and the one in Figure 10 were taken in June 1992.

Figure 10. Open ponderosa pine stand on the north-facing slope of Animas Peak. Fire-scar samples obtained from here show that at least six fires burned through this stand since1900 (APN on the chronology and map in Figures 7 and 8).

Figure 1.



110°
ARIZONA
25
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21
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19
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2
Pinaleño
Mts.
1
Santa Catalina
Mts.
3
4
NEW MEXICO
5
Rincon
Mts.
Tucson
Chiricahua
Mts.
7
8
6
Santa
Rita Mts.
9
11
10
14
Animas
Mts.
15
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Huachuca
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los Ajos
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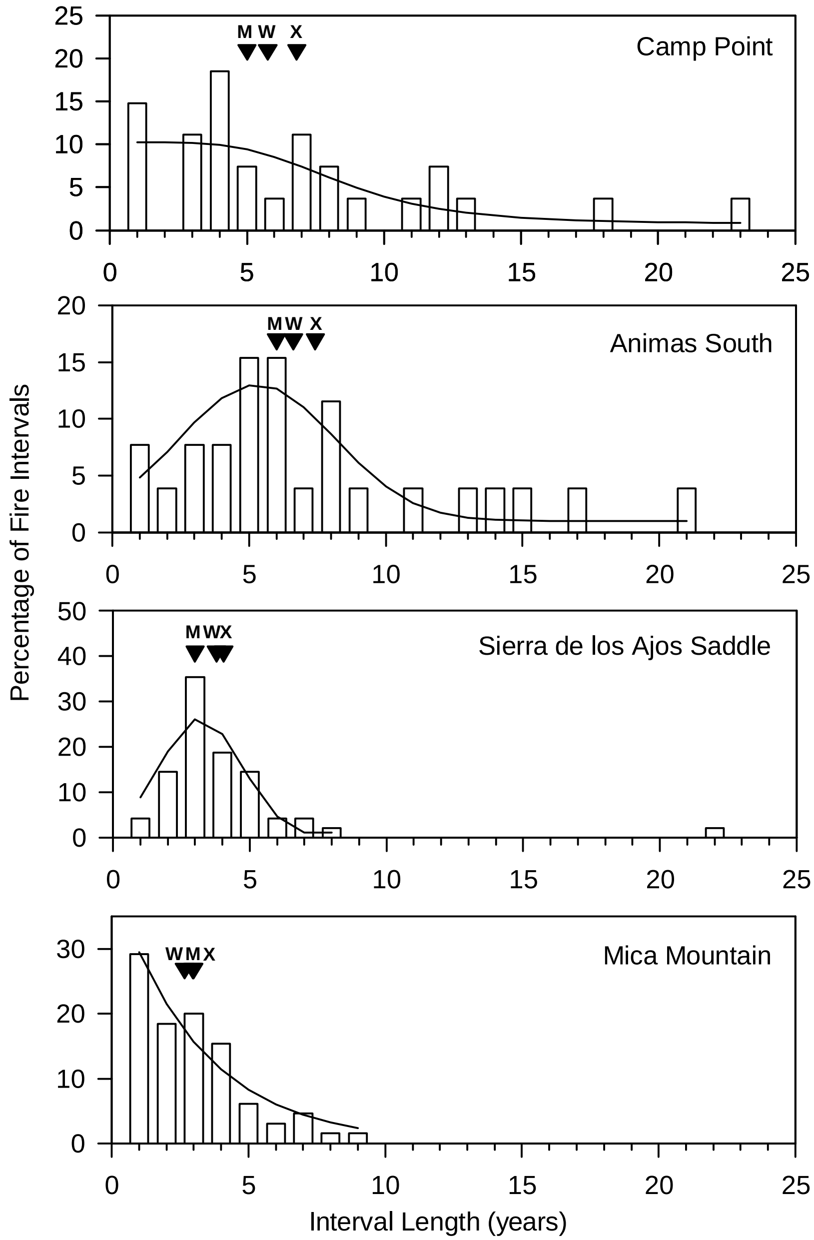
Figure 2


Camp Point
M W X
Animas South
M W X
Sierra de los Ajos Saddle
M W X
Mica Mountain
W M X
Percentage of Fire Intervals
Interval Length (years)
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5
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25
30
40
50

Figure 3

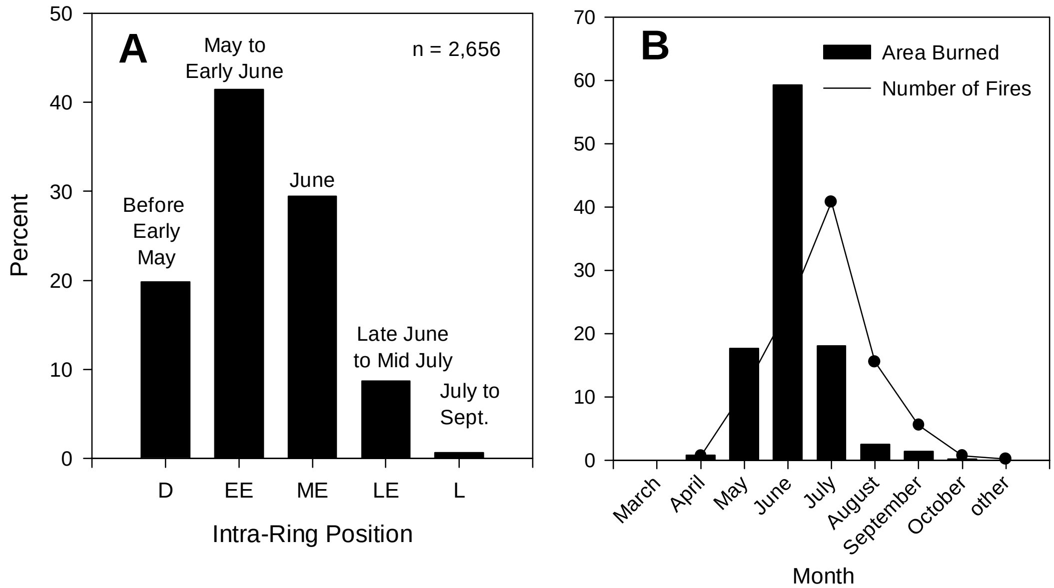

A
n = 2,656
Percent
Before Early May
May to Early June
June
Late June to Mid July
July to Sept.
D
EE
ME
LE
L
Intra-Ring Position
B
Area Burned
Number of Fires
March
April
May
June
July
August
September
October
other
Month

Figure 4

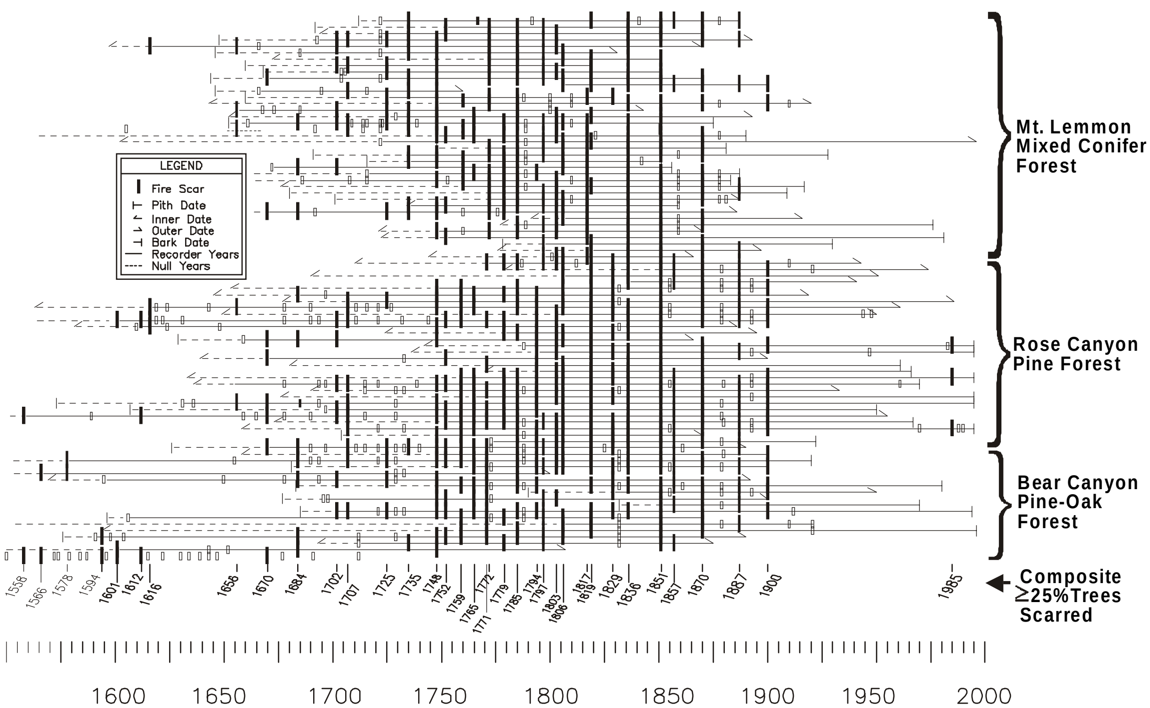
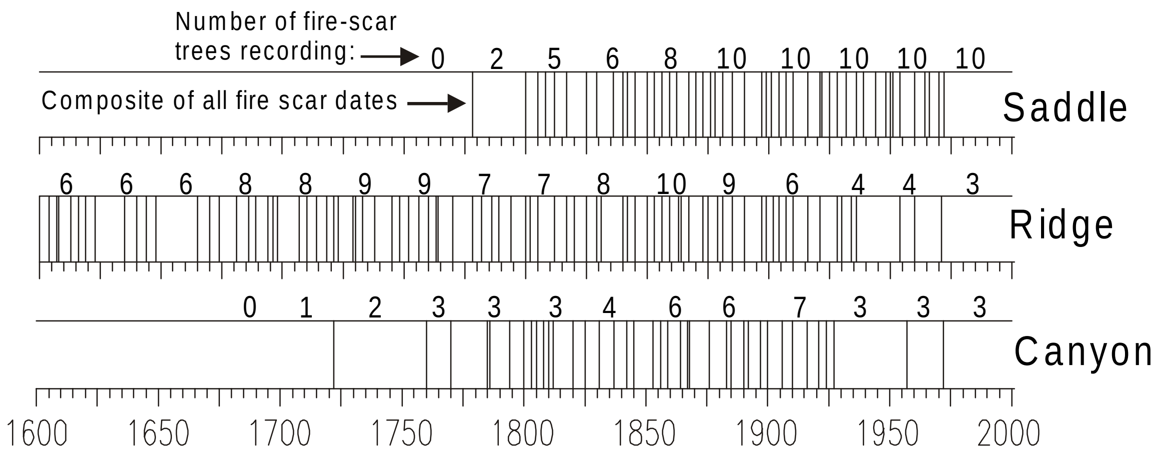

LEGEND
Fire Scar
Pith Date
Inner Date
Outer Date
Bark Date
Recorder Years
Null Years
Mt. Lemmon Mixed Conifer Forest
Rose Canyon Pine Forest
Bear Canyon Pine-Oak Forest
Composite ≥25%Trees Scarred
1558
1566
1578
1594
1601
1612
1616
1656
1670
1684
1702
1707
1725
1735
1748
1752
1759
1765
1771
1772
1779
1785
1794
1797
1803
1806
1817
1819
1829
1836
1851
1857
1870
1887
1900
1985
1600
1650
1700
1750
1800
1850
1900
1950
2000

Figure 5.

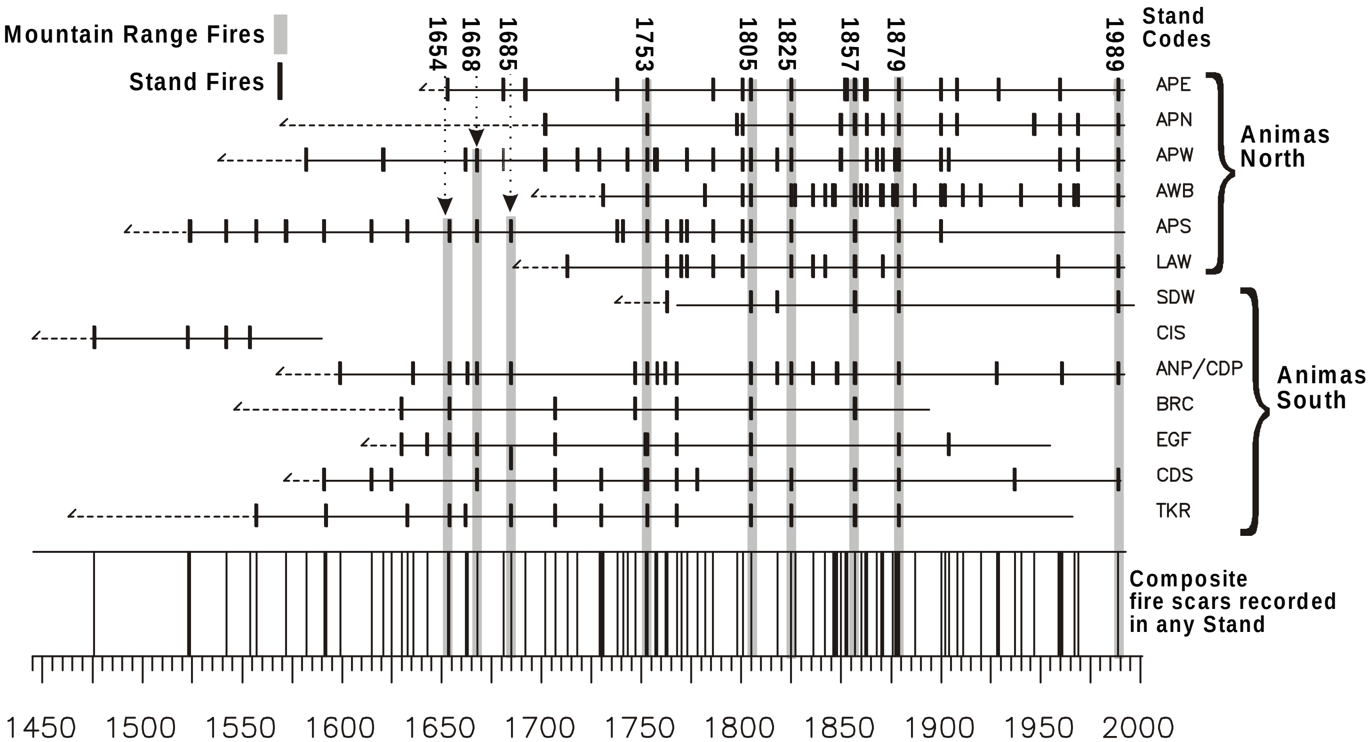
Holsinger Photo

Figure 6



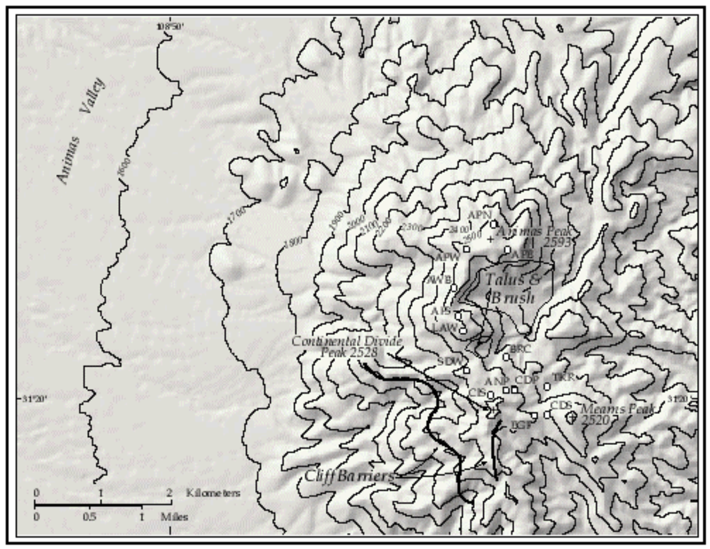
Number of fire-scar trees recording:
0 2 5 6 8 10 10 10 10 10
Composite of all fire scar dates
Saddle
6 6 6 8 8 9 9 7 7 8 10 9 6 4 4 3
Ridge
0 1 2 3 3 3 4 6 6 7 3 3 3
Canyon
1600 1650 1700 1750 1800 1850 1900 1950 2000

Figure 7



Mountain Range Fires
Stand Fires
1654
1668
1685
1753
1805
1825
1857
1879
1989
Stand Codes
APE
APN
APW
AWB
APS
LAW
SDW
CIS
ANP/CDP
BRC
EGF
CDS
TKR
Animas North
Animas South
Composite fire scars recorded in any Stand
1450
1500
1550
1600
1650
1700
1750
1800
1850
1900
1950
2000

Figure 8.



108°50'
Animas Valley
1600
1700
1800
1900
2000
2100
2200
2300
2400
2500
APN
Animas Peak
2593
APE
APW
AWB
Talus &
Brush
APS
LAW
Continental Divide
Peak 2528
BRC
SDW
ANP
CDP
TKR
CIS
CDS
Mearns Peak
2520
31°20'
Cliff Barriers
0
1
2
Kilometers
0
0.5
1
Miles

Figure 9. Photo looking south across saddle

Figure 10. Photo of north face of Animas Peak with open ponderosa pine stand