Fire Histories of Montane Forests in the Madrean Borderlands[1]

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Abstract.—In this paper we summarize historical fire regime patterns reconstructed using fire-scarred tree-ring specimens from seventeen montane forest sites in the Madrean Borderlands. In addition to a brief description of general patterns we also illustrate, with examples, several unique fire occurrence patterns influenced by land-use history and landscape configurations. Mean fire intervals and other statistical descriptors of fire interval distributions show that widespread surface fires were frequent in nearly all forests before ca. 1900, with fires occurring at least once per decade. Most fires occurred during the arid foresummer and lightning fire season from April through June. High spatial and temporal variability of fire frequency and other fire regime properties point to the importance of unique site and time-specific factors in controlling fire occurrence. These factors include the continuity of fuels and topography, livestock grazing, and possibly, the burning of some areas by Apaches during certain time periods. Ponderosa pine and mixed-conifer stands in rugged mountain ranges, such as the Animas in New Mexico, sustained mixed-fire regimes of both surface and crown fires. Frequent, widespread, surface fires ceased to occur in most U.S. Borderland sites at about the time intensive livestock grazing began. In contrast, montane forests on the Mexican side of the border sustained continuous surface fire regimes throughout the 20th century. With the elimination of frequent, widespread surface fires on the U.S. side, woody fuels have greatly increased in amount and continuity, and as a consequence, the size and intensity of recent crown fires were probably historically and ecologically anomalous.

INTRODUCTION

Wildfires can be an awesome force in the dynamics of Madrean forests and woodlands. This fact was brought close to home in southern Arizona in 1994 and 1995 with the sight of mushroom clouds of smoke rising over the Santa Catalina and Rincon Mountains, just a few kilometers away from Tucson. More than 33,000 hectares were burned by intense surface and crown fires during those summers (Allen 1995). In an earlier era these fires would have been viewed almost universally as purely destructive. However, we have learned from abundant historical and ecological research that fire is not always an enemy of forests, woodlands, and grasslands. On the contrary, because of evolutionary adaptation over millions of years, many Madrean plant and animal species are resistant to fire, or depend upon fire for maintaining and sustaining presence and abundance within their biotic communities (Barton 1993, 1994, Brown 1982, 1994, Caprio and Zwolinski 1995, Humphreys 1984, Marshall 1963, McLaughlin and Bowers 1982, Rogers and Steele 1980, Wright and Bailey 1982, Zwolinski, this volume).

Still, we have cause for concern. The problem is the amount and magnitude of ecological change that humans have caused during the past century. The most important of these changes is the nearly complete elimination of frequent, low to moderate intensity surface fires that used to burn over enormous areas. With the cessation of episodic fires, woody fuels (both living and dead) have accumulated across Southwestern landscapes. These accumulations now fuel explosive wildfires of intensities and sizes that these areas have probably not sustained for many centuries, if ever.

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[1] *This research was supported in part by funds provided by the Rocky Mountain Forest and Range Experiment Sation, Forest Service, U.S. Department of Agriculture.*

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This situation creates a dilemma in our management of fire and landscapes. Fire is needed because certain plants and animals depend upon it, and because the accumulating fuels cannot be practically eliminated by any other means. Thus, we recognize that the fire process must be re-introduced in some areas. But by allowing lightning-ignited fires to burn, or by setting prescribed fires, we risk creating historically and ecologically anomalous patterns if these fires burn more intensely and in larger patches than biotic communities have previously sustained and are adapted to. Even more worrisome, we also risk the loss of human lives and property, especially with the current proliferation of homes and other structures (e.g., telescopes) within these flammable landscapes. On the other hand, even if we continue to aggressively attack fires with all means available, we will continue to have increasingly dangerous and destructive wildfires as long as fuel accumulations are allowed to persist and build. For example, studies of trends in fire statistics in the greater Southwest indicate that large, high intensity fires are increasing in frequency (Covington and Moore 1994, Sackett and others 1994, Swetnam 1990).

One of the main purposes of our research program is to place current fire regimes into historical context. Reconstructed fire histories (from tree-rings in this case) provide a baseline, or set of reference conditions, for understanding past fire regimes. These histories provide hard data and evidence for comparisons between current and past fire regime patterns. These comparisons tell us when, where, and how much fire regimes have changed, and help us determine if current patterns are unprecedented or unusual over the long term (i.e., historically or ecologically anomalous). In some circumstances, such unprecedented conditions are unlikely to be sustainable. We agree with Kaufmann and others (1994) and others (e.g., Allen 1994, Morgan and others 1994, Swanson and others 1994), that knowledge of historical-ecological "reference conditions" (or range of historical or "natural" variability) is essential for informed, science-based ecosystem management planning and decisions.

This recognition of the value and uses of reference conditions is not an attempt to restore some kind of mythical, pristine past. In some circumstances, historically or ecologically anomalous conditions may not be cause for concern, or call for special management actions. This depends upon a number of factors, such as:

1. The management objectives for the particular landscape in question,
2. How extreme the ecosystem changes are relative to the pertinent historical reference period,
3. Whether the new conditions are a detriment to sustainability of desired biota or other resources (e.g., watershed values or soils), and
4. Whether these changes are evidently caused by past human actions that presumably can be modified (e.g., total fire suppression efforts), or by natural forces beyond human control (e.g., unusual weather events, etc.).

Furthermore, reference conditions do not necessarily establish a template for management targets, or desired future conditions. Again, this depends upon the land being managed and the management objectives established for it. For example, reference conditions may be more directly relevant and applicable for setting restoration targets or goals in designated wilderness, parks, and natural areas than for other types of public lands. However, many of these conditions may be consistent with objectives and goals of restoring and sustaining productivity and biodiversity on other public and private lands as well. Although the historical record may not provide us with specific management targets, or tell us precisely how to restore desired conditions, it does provide a key element that is needed for understanding current ecosystems and landscapes: *historical perspective*. By understanding how ecosystems operated in the past, and knowing how we arrived at current conditions, we will be much better informed and prepared to restore and manage these ecosystems in the future.

The purpose of this paper is to provide a historical perspective of past fire regimes in the Madrean Borderlands. Over the past 15 years 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. (Additional descriptions and comparisons of the range and variability of pre-settlement fire regimes of these Borderlands sites and more than 40 other sites in Arizona and New Mexico are described in Swetnam and Baisan [1996]). In this paper we lists the locations and characteristics of study sites, and we describe fire interval statistics for each site. Each of these fire history reconstructions is a unique narrative of fire events that occurred in a specific location over periods of at least two centuries. Hence, each history offers a somewhat different insight on the role of landscape patterns (vegetation, elevation, topography), land-use history, and climate in controlling past fire regimes. Since we do not have the space here to describe all of the sites in detail, we have chosen a set of three different study areas that exemplify both general and specific patterns we have observed in the Madrean Borderlands. These case histories serve as a vehicle to point out the influence of land-use history and topography on fire regimes.

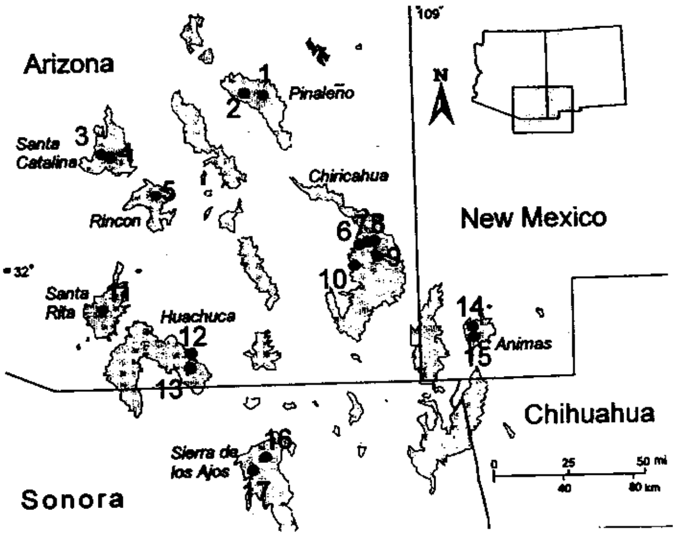

Figure 1. Map of the Borderlands area of southern Arizona and New Mexico and northern Sonora and Chihuahua, with woodlands and montane forests shown by shaded areas, and fire history study sites shown by dots. The numbers adjacent to the dots refer to sites listed in Table 1.

STUDY AREAS

Our fire history study sites are located within the montane forests of the "sky island" mountains (Fig. 1). The sites range in elevation from about 1,700 to 2,900 meters, and are located in a variety of topographic settings and forest vegetation types (Table 1). More detailed descriptions of these fire history study sites and findings are contained in the cited references in Table 1 (see papers in this volume by Danzer and others, Kaib and others, and Seklecki and others). In general, sites are located in montane forests within canyons, on ridges, saddles, or slopes. We have classified the forest vegetation in these sites into three types:

1. **Pine/Oak** — The overstory is dominated by lower elevation pines, such as Chihuahua pine (*Pinus lieophylla*) and Apache pine (*P. engelmannii*), but also ponderosa pine (*P. ponderosa*). Various mixtures of Madrean oaks (*Quercus spp.*), Arizona madrone (*Arbutus arizonica*), pinyon (*P. discolor*), junipers (*Juniperus spp.*), and various shrubs are sometimes co-dominant, or present in the understory of these pine-dominated stands.
2. **PIPO** — These are stands dominated by ponderosa pine. Some stands have incidental occurrence of other tree species (such as found in the PIPO/MC class described below), but in general these are pure or nearly pure ponderosa pine stands.
3. **PIPO/MC** — These are mixed-conifer stands, but ponderosa pine is the largest component. Other co-dominant tree species may include Douglas-fir (*Pseudotsuga menziesii*), southwestern white pine (*P. strobiformis*), and white fir (*Abies concolor*). In the pre-fire suppression era, many of these stands were probably pure or nearly pure ponderosa pine stands, but with fire suppression the more shade-tolerant, less fire resistant Douglas-fir and white fir have increased in numbers.
4. **MC** — These are mixed conifer stands where Douglas-fir and white fir are the largest components, but ponderosa and/or southwestern white pine are present as smaller components.

Since the fire histories are based upon tree-ring analyses of fire-scarred trees, we are limited to vegetation zones where woody trees produce clearly defined annual rings. This restriction has prevented our direct reconstruction of past fire regimes in lower deserts, grasslands, and woodland savannas (however, see Kaib and others, this volume.) Unfortunately, most of the woodland tree species in southern Arizona, New Mexico, and northern Mexico are not (yet) useful for accurate tree-ring analyses because growth rings are very indistinct, and in some cases, are probably not annual. These species include most of the evergreen and deciduous oaks (*Quercus spp.*), except *Q. gambelli*, which is generally found at elevations above the woodlands. Because of numerous false rings (intra-annual latewood bands), none of the Borderlands junipers (e.g., *Juniperus monosperma, J. deppeana*) have been reliably dated, and Arizona cypress (*Cupressus arizonica*) has been used only in two studies (Moir 1982, Swetnam and others 1989). Mesquite (*Prosopsis glandulosa*) growing in relatively mesic sites has shown some promise for dendrochronological applications (Flinn and others 1994). Several riparian species in the Borderlands may be useful in future fire history studies (e.g., Arizona sycamore [*Platanus wrightii*], Fremont cottonwood [*Populus fremontii*]), but fire scars on these trees are rare and typically associated with such extensive heartrot that useful specimens are difficult to find.

METHODS

Site Selection Strategies

The study sites were selected in montane forest and woodland types and landscape situations that were common and thought to be generally representative of the management units where the studies

Table 1. Fire-scar study site names and descriptions. Map numbers in parenthesis next to site names refer to locations in Figure 1. See text for explanation of forest type abbreviations.

Site name (Map no.) Mountain range	Forest type	Min. elev (m)	Max. elev. (m)	Number of trees sampled	Inner ring date	Outer ring date	Reference
Rhyolite Lower (6) Chiricahua	Pine/Oak	1707	1804	12	1466	1987	Swetnam and others 1989; 1992
Pine Canyon (10) Chiricahua	Pine/Oak	1707	1829	27	1540	1995	Kaib and others, this volume, Kaib, in prep.
Rhyolite Middle (7) Chiricahua	PIPO/MC	1804	1920	30	1466	1987	Swetnam and others 1989, 1992
Sierra Ajos Ridge (16) Sierra Ajos	Pine/Oak	1981	2073	13	1438	1989	this paper
Sierra Ajos Saddle (17) Sierra Ajos	Pine/Oak	2100	2100	12	1438	1989	Dieterich 1983, Baisan and Swetnam 1995
Rhyolite Upper (8) Chiricahua	PIPO/MC	2073	2134	16	1466	1987	Swetnam and others 1989, 1992
Josephine Saddle (11) Santa Rita	Pine/Oak	2073	2195	17	1452	1979	Ortloff and others 1995
Sawmill Canyon (12) Huachuca	Pine/Oak	2012	2225	23	1499	1994	Danzer and others, this volume, Danzer, in preparation
Rose Canyon (4) Santa Catalina	PIPO	2134	2316	11	1558	1986	this paper
Animas North (14) Animas	PIPO	2438	2438	18	1538	1992	Baisan and Swetnam 1995
Animas South (15) Animas	PIPO/MC	2438	2438	56	1445	1992	Baisan and Swetnam 1995
Rustler Park (9) Chiricahua	PIPO/MC	2438	2591	58	1614	1995	Seklecki and others, this volume
Mica Mountain (5) Rincon	PIPO/MC	2070	2600	44	1481	1983	Baisan and Swetnam 1990, Baisan 1990
Pat Scott Peak (13) Huachuca	PIPO/MC	2545	2652	34	1499	1994	Danzer and others, this vol., Danzer, in prep.
Lemmon Peak (3) Santa Catalina	MC	2667	2731	16	1597	1920	this paper
Peter's Flat (2) Pinaleno	MC	2804	2880	40	1376	1993	Grissino-Mayer and others 1995
Camp Point (1) Pinaleno	MC	2900	2926	50	1543	1993	Grissino-Mayer and others 1995

were conducted (e.g., National Forests and National Parks). These were also areas where it was possible to carry out fire history reconstructions because the required tree-ring materials were present (i.e., abundant and well-preserved, living and dead fire-scarred tree specimens). Theoretically, such subjective site selection limits the potential generality of the results owing to known and unknown biases in the data. This problem is commonplace in landscape ecology studies, and is not easily solved, notwithstanding randomized, landscape-scale sampling methods that have been described and advocated (e.g., Johnson and Gutsell 1994). These designs can be inappropriate for some objectives, or highly impractical, inefficient, or simply impossible to implement due to high variability of most mountainous landscapes, and the relative rarity of appropriate sampling sites and specimens needed for some types of studies. This is particularly true for paleoecological reconstructions, where a primary goal is to obtain the longest and most complete records of past environmental patterns and processes as can be found (Brown and Sieg 1996). Obtaining useful paleoecological records across landscapes calls for a "searching" strategy to locate the sites and specimens that will actually meet the data and sampling requirements. In practice, our strategy involved selecting representative sites within larger areas, as best we could subjectively identify them, and obtaining long and complete inventories of fire events by systematically searching for appropriate fire-scar specimens within sites.

Ultimately, our results from the selected sites constitute "case histories." We will demonstrate with examples how informative these case histories can be, both individually and in aggregate, about disturbance pattern and processes across a range of spatial scales from stands, to watersheds, to mountain ranges. The key to this strategy is the high temporal resolution and accuracy of dendrochronologically dated fire events (to the year or season) which facilitate inter-comparisons of numerous event inventories across space. Patterns of synchrony and asynchrony of such well-dated disturbance events across space reveal the extent of the disturbance process, the relative importance of internal versus external controls, and the spatial-scale of the disturbance effects. These cross-scale analyses allows us to extend and generalize our interpretations of disturbance regime patterns and changes (Baisan and Swetnam 1990, Grissino-Mayer 1995, Morino 1996, Swetnam 1993, Swetnam and Baisan 1996, Swetnam and Betancourt 1990, Touchan and others 1995, and other papers listed in Table 1).

Most study sites ranged in size from about 10 to 100 hectares. A few study sites encompassed collections from sets of fire-scarred trees in stands distributed over areas ranging from about 1,000 to 5,000 hectares (Rhyolite Canyon, Animas Mountain , and Mica Mountain sites). These were minimum sizes of areas that the fire histories probably represented, based upon polygons defined by the location of sampled fire-scarred trees. Many of the fires recorded within sites probably spread from distant locations, so the total area of the "fireshed" in which sites were located were much larger, but the size and boundaries of these firesheds cannot be accurately estimated with our current knowledge.

Collection and Analysis of Fire-Scar Specimens and Data

The seventeen fire interval distributions described here are based upon composite fire chronologies (Dieterich 1980) from numerous fire-scarred trees collected within each of the Madrean Borderlands study sites (Fig. 1, Table 1). We systematically searched for and collected fire-scarred trees with a maximum number of visible, well-preserved fire scars that were widely distributed throughout the study sites. Specimens were collected from dead trees (stumps, logs, and snags) and living trees in order to improve spatial coverage within sites, and to lengthen the temporal record of the fire histories (Baisan and Swetnam 1990). Partial and full cross sections were obtained using a chainsaw (Arno and Sneck 1977). The sections were finely sanded with belt sanders to see cell structure and fire scars within the rings The tree-ring widths were carefully crossdated using standard techniques (Stokes and Smiley 1968, Swetnam and others 1985). The fire scars were dated to the calendar year and identified to approximate season of occurrence based upon observations of the intra-ring position of the fire scars (Baisan and Swetnam 1990, Dieterich and Swetnam 1984,).

The fire-scar dates were entered in a specialized data base format and analyzed with a graphical and statistical analyses software package designed for this purpose (see Grissino-Mayer 1995; this software and manual are available via the Worldwide Web at http://www.ltrr.arizona.edu/). 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, derived from a fitted Weibull model to the cumulative fire interval distribution (Grissino-Mayer 1995), 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).

To evaluate fire interval patterns as a function of relative fire size we computed these statistics for interval distributions based upon fires recorded by:

1. All fires recorded, regardless of percentage of trees scarred; these were all fires occurring anywhere within the sampled area, regardless of inferred relative fire size;
2. Fires recorded by 10 percent or more of the fire-scarred trees, and a minimum of two trees; these were all fires recorded within the sites, except the smaller, and probably patchier 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; these were generally the widespread fires that probably burned throughout most or all of the sampled area.

RESULTS

Statistical Descriptions of the Fire Interval Distributions

Summaries of fire interval statistics provide a generalized perspective of historical fire regimes in the Borderlands region (Table 2). These statistics suggest that some patterns were probably associated with changes in elevation, moisture, and forest type. 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 past land-use history (Swetnam and Baisan 1996). Some of these patterns will be discussed in the next section 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, ponderosa pine forests. 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 Pinaleno Mountains is an example where a relatively high elevation mixed-conifer forest had a fire frequency similar to lower elevation pine forests (Grissino-Mayer and others 1995). We hypothesized that this was due to 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 fire-free interval between fires, considering all fires within sites from 1700 to 1900 (see maximum fire intervals for "all" category in Table 2), was approximately 8 to 23 years. The exceptions were in Upper and Middle Rhyolite Canyon, where an unusually long interval occurred during the early 1800s, possibly due to a flood or debris flow event in these portions of the canyon that interrupted fuel continuity (Swetnam and others 1989, 1992). The minimum interval for the "all" fires category was one year in all sites. In other words, even in the smallest study sites, at least one, 1-year fire interval was detected during the period 1700-1900. Using the 25 percent category for fire dates (i.e., relatively widespread fires within sites) the minimum fire intervals ranged from 1 to 4 years, except in Rhyolite Canyon Middle (Table 2), where the minimum fire interval for fires recorded on 25 percent or more trees was 9 years. Interestingly, the smallest minimum fire interval for the 25 percent category, 1 year, occurred in the Rhyolite Canyon Lower and Rustler Park sites. We hypothesized that relatively high fire frequencies in these two Chiricahua Mountain sites, particularly in the late 1800s, may reflect increased fire occurrence due to Apache-set fires (Seklecki and others this volume, Swetnam and others 1989, 1992). Both areas were probable Apache camp sites or along often-used travel routes. Additional research is needed to test this hypothesis (e.g., by sampling in non-travel route areas, and by testing changes in climate-fire associations).

Several measures of central tendency are listed in Table 2 (mean, median, and Weibull median probability interval, or WMPI). Usually the measures of

Table 2. Summary descriptive statistics for Borderlands fire-scar chronologies, for the period 1700 to 1900 (except Sierra Ajos, 1700-1989).

Site name/ Mountain range	Fire size class	Mean	Median	WMPI	Min. fire interval	Max. fire interval	Stand dev.	Last widespread fire
Rhyolite Lower Chiricahua	all	6.17	6	5.41	1	15	3.80	1886
	10%	8.75	9	8.03	1	17	4.61	
	25%	9.21	10	8.77	1	17	4.35	
Pine Canyon Chiricahua	all	4.20	4	3.97	1	9	2.33	1876
	10%	5.10	4	4.79	1	11	2.80	
	25%	5.96	5	5.90	3	11	2.40	
Rhyolite Middle Chiricahua	all	8.30	7	6.78	1	33	7.28	1886
	10%	15.25	13	14.20	4	50	11.42	
	25%	17.90	14.5	17.08	9	50	11.86	
Sierra Ajos Ridge Sierra Ajos	all	4.26	4	4.01	1	18	2.66	1972
	10%	8.57	7	8.07	2	33	5.67	
	25%	9.60	8	9.12	2	33	6.00	
Sierra Ajos Saddle Sierra Ajos	all	4.04	3	3.79	1	22	3.05	1972
	10%	5.54	4	5.14	2	22	3.91	
	25%	5.88	5	5.47	2	22	4.05	
Rhyolite Upper Chiricahua	all	7.96	6.5	6.66	1	31	6.68	1886
	10%	12.64	12.5	12.22	4	31	6.68	
	25%	13.08	13	12.67	4	31	6.74	
Josephine Saddle Santa Rita	all	6.59	5	6.26	2	18	3.76	1877
	10%	8.24	7	7.94	3	21	4.24	
	25%	9.61	10	9.08	3	30	6.00	
Sawmill Canyon Huachuca	all	4.88	4	4.67	2	13	2.62	1914
	10%	5.93	5	5.57	2	22	3.97	
	25%	7.12	5	6.64	3	22	4.94	
Rose Canyon Santa Catalina	all	5.50	5	5.26	1	15	2.92	1900
	10%	7.33	6	7.01	2	16	3.80	
	25%	7.33	6	7.01	2	16	3.80	
Animas North Animas	all	5.35	4	4.31	1	16	4.39	1879
	10%	14.14	9	11.92	3	36	11.11	
	25%	16.50	12.5	14.65	4	41	11.77	
Animas South Animas	all	7.42	6	6.61	1	21	5.02	1879
	10%	14.33	14	12.66	2	32	9.27	
	25%	24.57	22	22.82	4	46	13.71	
Rustler Park Chiricahua	all	2.91	3	2.71	1	16	2.09	1892
	10%	3.85	3	3.56	1	16	2.51	
	25%	4.59	4	4.36	1	16	2.76	
Mica Mountain Rincon	all	2.95	3	2.67	1	9	1.94	1893
	10%	6.13	6	6.02	2	13	2.67	
	25%	7.32	7	7.13	2	13	3.29	
Pat Scott Peak Huachuca	all	2.96	3	2.84	1	8	1.52	1899
	10%	5.13	4	4.74	1	19	3.31	
	25%	9.75	7.5	8.76	3	29	3.41	
Lemmon Peak Santa Catalina	all	6.60	5.5	6.03	1	17	4.08	1900
	10%	8.61	9	7.94	2	17	4.80	
	25%	10.42	12	9.65	2	23	5.72	
Peter's Flat Pinaleno	all	6.10	4	5.24	1	22	4.69	1893
	10%	9.45	8.5	8.91	3	22	5.30	
	25%	12.60	12	12.35	3	22	5.25	
Camp Point Pinaleno	all	6.82	5	5.75	1	23	5.30	1871
	10%	8.52	8	7.73	2	23	5.60	
	25%	12.67	12	11.45	3	34	8.77	

central tendency were within one to a few years of each other. These measures were useful for generalizing typical fire intervals, however, the higher moments of the fire interval distributions (i.e., variance, range, skewness, kurtosis, etc.) may be of greater ecological importance than the central tendency descriptors. Moreover, distributions with similar means (medians, WMPIs, etc.) can have very different shapes (Fig. 2). In terms of plant responses to different or changing fire regimes, the relatively rare occurrence of long intervals between fires (the right tail of distributions in Fig. 2) may have been particularly important in determining the successful recruitment and survivorship of individuals or cohorts. The essential point here is that it is unwise to focus solely on measures of central tendency over blocks of time (e.g., fire frequency or mean fire intervals) in comparing historical fire regimes, or in attempting to interpret the importance of past fire to communities.

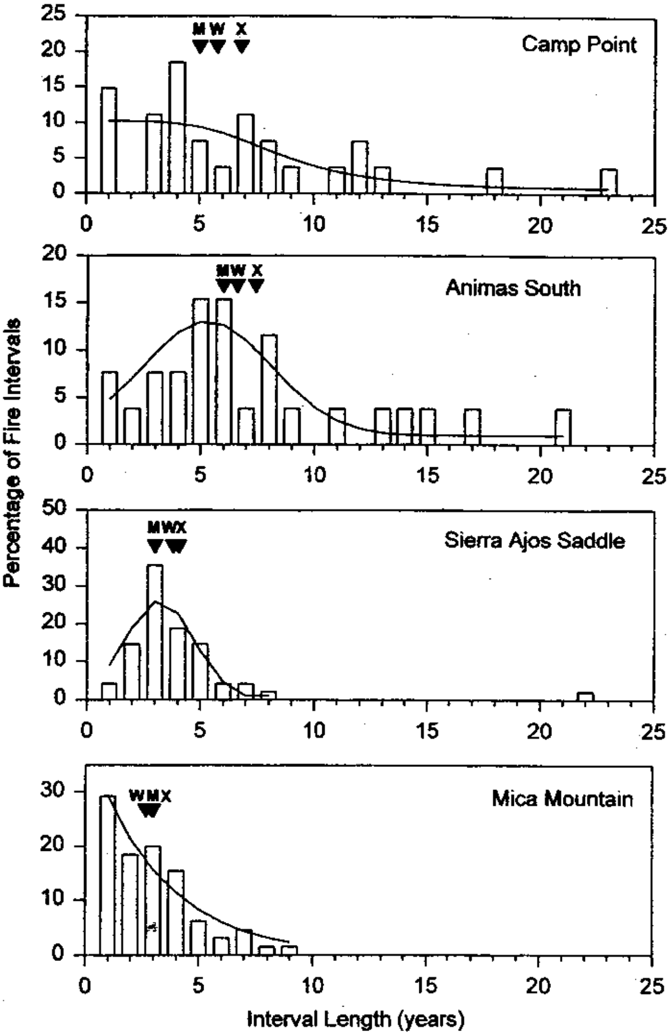

Figure 2. Examples of fire interval distributions from four study sites. The arrowheads show three difference measures of central tendency: M = median, W = Weibull median probability interval, and X = mean.

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 arid fore-summer (Fig. 3). Of a total 3,701 fire scars that were examined, 2,656, or 72%, were successfully classified according to one of the five intra-ring position classes. The remaining 28% could not be classified because of very small rings, decay, etc. The percentages shown (Fig. 3) are for the classified scars only (i.e., the classes sum to 100%). Approximate seasonal timing shown above the classes is based upon our knowledge of cambial phenology of trees in southern Arizona. This knowledge is improving as we continuously gather data from a set of trees monitored with dendrometers and dendrographs in the Chiricahua Mountains (Baisan and Swetnam 1994). At this time, our best estimates of the timing of past fires, based on a splitting of the intra-ring position into five categories, are within windows of about two weeks to one month. These approximate seasonal dates overlap for each succeeding intra-ring position, due to variability in the cambial growth onset dates, rates, and cessation dates in different years, sites, and species. In general, most fires occurred sometime between late April and late June (Fig. 3). This corresponds approximately to the arid foresummer and 20th century lightning fire season (Barrows 1978). There were, however, differences in the seasonal timing of fires during specific years (e.g., Baisan and Swetnam 1990, Swetnam and others 1989), for different time periods (Grissino-Mayer 1995, Grissino-Mayer and Swetnam 1995), and in different sites (Seklecki and others this volume), all of which provide clues about the nature of these fires and fire regimes.

The ecological implications and importance of different fire interval distributions and fire seasons are not well understood. There probably is some predictability to the combination of plant species, age, size, and arrangement found in areas with particular types of historical fire distributions. However, there are no completed studies coupling data on such ecological *patterns* and *process* in the Southwestern U.S. over periods of centuries. (But see Danzer and others this volume, and Villanueva-Diaz and McPherson 1995, and this volume, for on-going stud-

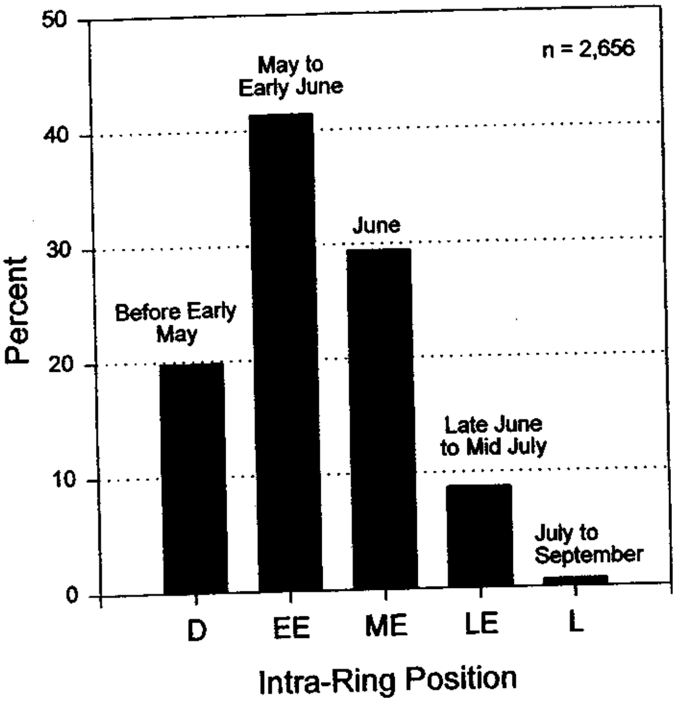

Figure 3. The distribution of intra-ring fire-scar position for the seventeen study sites in the Borderlands. The intra-ring classes are: D = dormant season scar; on ring boundary, EE = early-earlywood scar; within first 1/3 of earlywood, ME = middle-earlywood scar, within second 1/3 of the earlywood, LE = late-earlywood; within third 1/3 of the earlywood, L = latewood; within the latewood. (See text for explanation of seasonal interpretations.)

ies. Also see Barton [1993, 1994] for a very insightful set of observations and experiments relating to fire, micro-climate, and tree biogeography in the Chiricahua Mountains.)

Statistical summaries of fire interval or seasonal distributions (process histories) are useful for comparative purposes (e.g. Table 2, Fig. 2, Fig. 3) and ultimately these data and comparisons will help us develop and test predictive models of fire regime-ecosystem dynamics. For example, Miller (1995) has used fire interval and relative size data from fire history studies in the Sierra Nevada to test a process-based model of forest dynamics (ZELIG). A similar analysis is underway for mixed-conifer forests in the Sacramento Mountains of New Mexico (C. Regan, pers. comm.).

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 at least equally important. This aspect is the fundamentally historical and chronological nature of fire event data. In the following sections we further document and describe Borderlands fire regimes with specific fire chronology examples. These three case histories illustrate both general patterns observed in other Borderlands sites, as well as their own unique, narrative histories that demonstrate the explanatory power of chronology and contingency. 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 two forest stands in the Santa Catalina Mountains exemplify a typical pattern of abrupt cessation of widespread, low intensity, surface fires at about the time intensive livestock grazing began in the Borderlands (Fig. 4). This pattern is most clearly seen in the Palisades/Rose Canyon chronology (lower graph), where the last widespread fire occurred in 1900. Shorter fire intervals are also evident in this chronology from a relatively dry pine forest as compared with the higher elevation, wetter, mixed-conifer site on Mt. Lemmon (upper graph).

The last dates of widespread surface fires consistently recorded by fire scars in the Southwestern U.S. (Arizona and New Mexico) were from the late 1870s to early 1900s (Swetnam 1990, Swetnam and Baisan 1996, Table 2). Comparison of these dates in different mountain ranges with land-use histories indicates that at least two contingent historical factors were associated with the decline of surface fire regimes: (1) cessation of hostilities with Native Americans (e.g., Apaches in the Borderlands), and (2) the rise of the livestock industry. The second factor was at least in part dependent on the first, but it was also a function of larger-scale economic forces, particularly access to emerging markets and railroads (Wagoner 1961).

The negative effects of livestock grazing on surface fire regimes was due to the removal of fine fuels (grasses and forbs) essential for carrying frequent surface fires (1 or more fires per decade). Total removal of grasses was probably not necessary in many arid and semi-arid landscapes; surface fires may no longer have effectively spread across landscapes where already sparse surface fuels were fur-

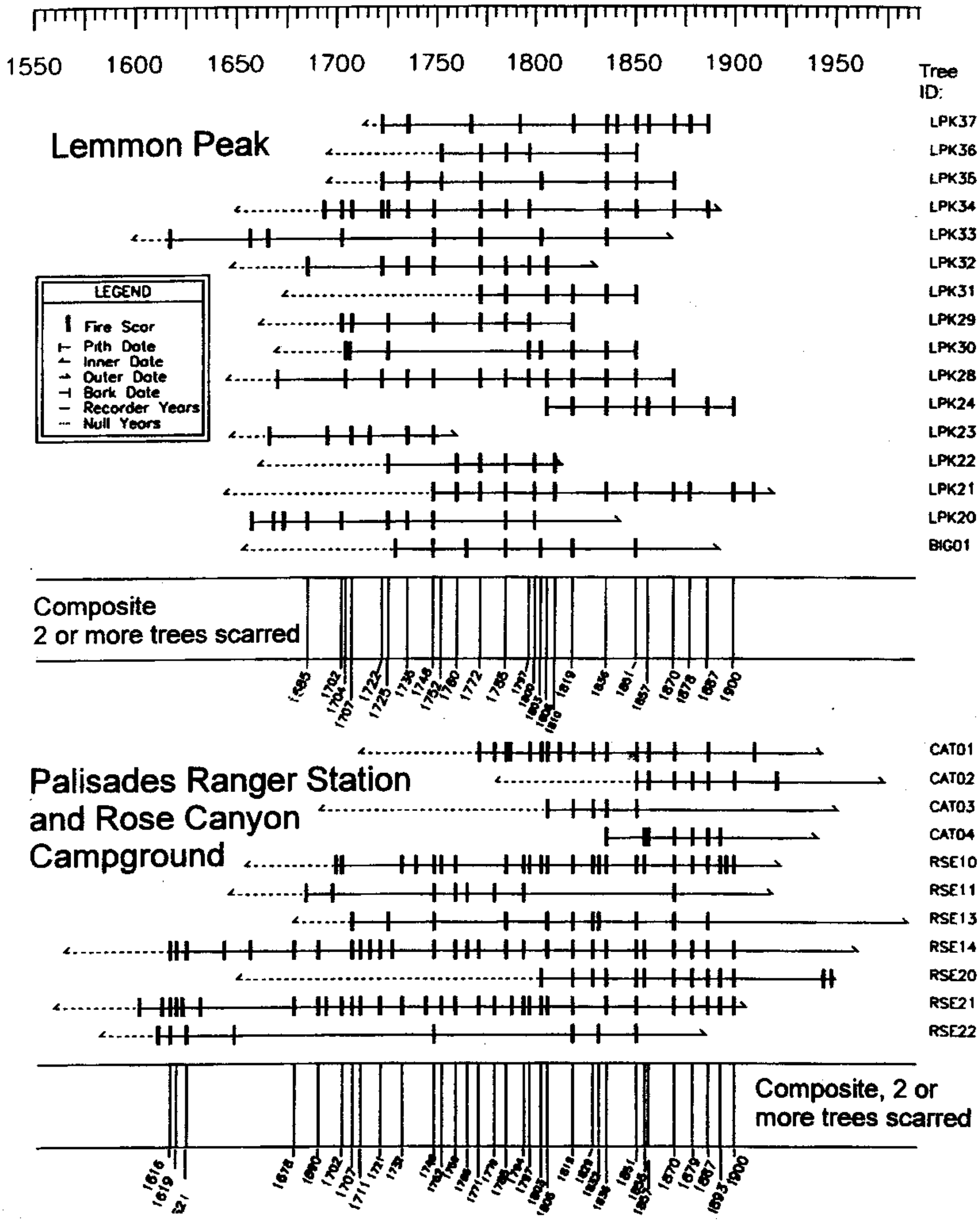

Figure 4. Master fire chronology charts for two sites in the Santa Catalina Mountains, Arizona. The horizontal lines are fire-scar records from individual trees and the vertical tick marks are fire-scar dates recorded on those trees. The composite graphs (long vertical lines at the base of each chart) show fire dates recorded by two or more fire-scarred trees. These chronologies are quite typical of pine and mixed-conifer fire chronologies in the Southwest, with widespread fire events within the sites indicated by synchronous fire dates among sampled trees, and a near cessation of such fires around the turn of the century.

ther reduced by grazing. New trails, fences, and roads associated with intensive grazing practices also disrupted fuel continuity, and hence the ability of fires to spread over large areas. Since site productivity is highly variable, and topography is also very important for fire spread, we would expect that different grazing intensities would have had variable effects on fire regime changes in different landscape situations.

The decline of widespread surface fire regimes in the Southwest was coincident with the boom in the livestock industry around the turn of the century (Bahre 1991, Denevan 1967, Wagoner 1952, 1961, Wilson 1995). We do not have good documentation of land-use histories for all of the different Borderlands mountain ranges, but there does seem to be some consistency in the historical comparisons where we have information. For example, because of the ruggedness of the mountain ranges, and the Apache threat, upper elevation forests of the Santa Catalina and Rincon mountains were probably not used for summer pastures until after about 1886 (Baisan 1990), when Geronimo surrendered to General Crook. The last widespread surface fires in study sites within these ranges were in 1900 and 1893, respectively (Table 1). In comparison, the Huachuca and Santa Rita Mountains (and especially the grasslands and woodlands at their bases) were heavy exploited for livestock grazing beginning in the 1870s because of the establishment of Fort Huachuca at the base of the Huachucas, and large ranching operations (Empire and Cienega Ranches) adjacent to the Santa Ritas (Wagoner 1961, Wilson 1995). The last widespread fire occurred in 1877 in the Josephine Saddle area of the Santa Ritas, and although a few widespread fires occurred after the late 1870s in the Huachuca sites, fire frequency clearly decreased ca. 1880 (Danzer and others, this volume).

This decline in widespread surface fires occurred even within areas where hostilities with Native Americans had already ceased some decades before, but widespread fires had continued to occur (e.g., parts of northern New Mexico). This argues that intensive livestock grazing was the primary and most common factor causing the end of frequent surface fire regimes, rather than lack of fire ignitions by Native Americans. The decadal-scale differences in timing of the last widespread fire in the different mountain ranges of the Southwest are even more convincing on this point. For example, widespread fire cessation dates in the early to mid-1800s, or earlier, have been documented in several areas of northern Arizona and New Mexico where herds of sheep, goats, cows, and horses were introduced by Spanish colonists, and later the Navajos (e.g., Baisan and Swetnam in prep., Savage and Swetnam 1990, Touchan and others 1995).

Fire suppression by government agencies did not begin in most places until after ca. 1910-1915, and arguably would not have been important in ending surface fire regimes without the collateral effects of livestock grazing (Leopold 1924). More effective fire suppression began after the 1930s when manpower increased (e.g., the Civilian Conservation Corps during the Great Depression) and many trails, guard stations, and lookout towers were built. Fire detection and fire fighting effectiveness increased again after World War II when surplus aircraft became available (Pyne 1982).

Climate change is an unlikely explanation for the abrupt surface fire cessation observed in Southwestern forests. If climate change was important in causing the extreme fire regime changes observed in so many locations we would expect regional climatic records (e.g., rainfall or temperature) to also show a major shift at this time. In general, they do not. A severe drought gripped the Southwest for a few years in the early 1890s and an extreme wet period occurred during the late 1910s and early 1920s (Fritts 1991, Sellers and others 1987), but fire regime changes in most sites were not consistently or closely synchronous with either of these two climatic events. In contrast, as will be discussed below, the ending dates of widespread surface fires corresponded more consistently and closely with the rise of intensive livestock grazing in each area. Moreover, surface fire regimes continued unaltered in mountains on the Mexican side of the border, and more-or-less unaltered in some remote areas on the U.S. side where intensive livestock grazing and/or effective fire suppression never occurred (e.g., isolated forest stands on "kipukas" in lava fields [Grissino-Mayer 1995]), but where similar regional climatic patterns prevailed.

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

Fire-scar specimens have been collected in only a couple of mountain areas in northern Mexico. Research in the Sierra de los Ajos (Dieterich 1983, Baisan and Swetnam 1995) shows that surface fires have occurred on this mountain 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 throughout the 20th century (Fig. 5). Fule and Covington (1995) report a similar continuation of widespread surface fires in pine forests in the state of Durango, although they note a shift to somewhat lower fire frequencies after ca. 1950. Other, recent fire-scar collections and observations in Mexican Borderlands mountain ranges (i.e., Sierra San Luis, Sierra del Tigre, Sierra Bocadehuachi, and in lower elevations of the Sierra de los Ajos) indicate that continuous, twentieth century surface fire regimes are not uncommon (Kaib, pers. obs.).

We sampled two sites in the Sierra de los Ajos. One was located in a single large forest stand on a saddle to the southwest of the highest peak in the mountains (Las Flores, 2620 m), and the other was in three adjacent forest stands along a ridge to the northeast of this peak. The two sites were about 4 kilometers apart. The saddle site had a somewhat higher fire frequency than the ridge site (Table 2, Fig. 5). We conjecture that this difference was related to landscape connectivity; the saddle site was subject to spreading fires from both sides of the main divide in this range, while the ridge site was subject to spreading fire from only one side.

The uninterrupted surface fire regimes in the Sierra de los Ajos have several important implications for our understanding of fire history in this region. First, continued, frequent surface fires suggest that

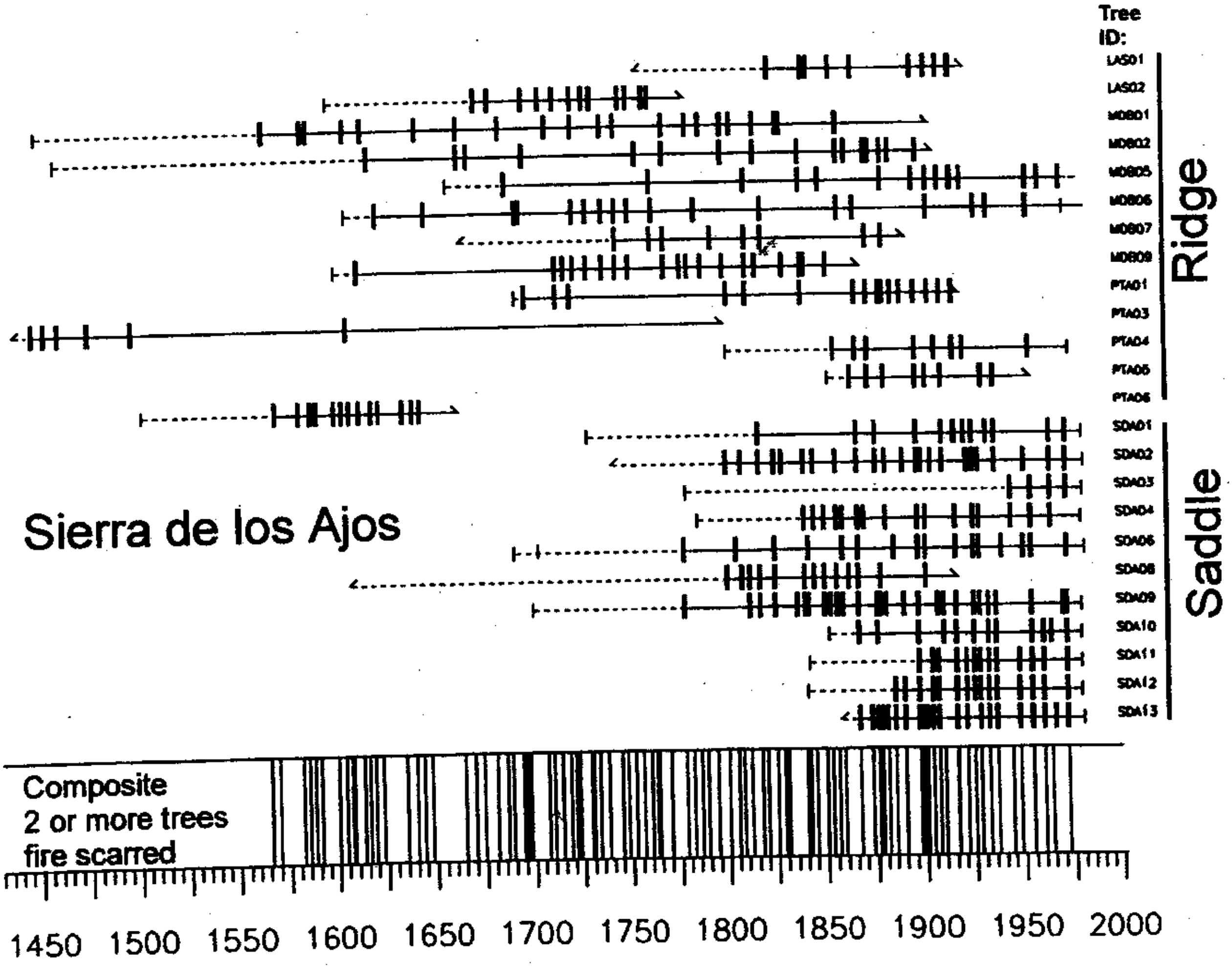

Figure 5. Master fire chronology charts for two sites in the Sierra de los Ajos, Sonora, Mexico. See caption and legend for Fig. 4. These chronologies document a continuous surface fire regime into the 20th century, a pattern observed in only a few isolated locations in the United States.

the final removal of the Apaches from the Borderlands in 1886 had no obvious effects on fire frequency in these mountains because human-set fires were not a primary, or limiting source of fire in these areas. Lightning fire ignitions were sufficiently frequent so that removal of Apache sources of fire had no distinguishable effect on fire frequency. Alternatively, Mexicans may have assumed the role of igniting fires on this range, as may have been previously carried out by Apaches. However, we doubt that either Mexicans, or Apaches before them, significantly influenced the fire regime. Today, these are remote mountains with no permanent settlements. The frequency of use of these mountains by Apaches is unknown. The area is 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 (Fig. 5). Apachean movement and use of different Southwestern mountain ranges was probably sporadic, and partly dependent on changing political conditions (e.g., warfare). (See Morino [1995] for example, where temporal changes in fire frequency in the Organ Mountains, New Mexico were coincident with political change, and this was argued to be evidence of Apachean influence on past fire regimes.) If Mexicans assumed a hypothetical role of frequent landscape burning after the removal of Apaches they would have had to do this almost immediately after the Apaches were removed in the late 1800s, because no obvious shifts are observed at that time (Fig. 5). We would also expect that changes in climate affecting livestock production, politics (revolutions!), and economic fluctuations would have led to variable grazing activity through the 20th century, and the level of people's presence and burning activities within the mountain. The fire chronologies, however, do not show obvious changes that might be related to such human-related factors (Fig. 5). Finally, it is also evident from lightning detection records (e.g., Gosz and others 1995) that a sufficient number of lightning strikes occur in most areas of Southwestern and Borderlands mountain ranges to account for even the highest possible fire frequencies we can determine with fire scars (i.e., one fire per year).

A second finding derived from these fire chronologies is that grazing by cattle within these forests, at some level of intensity, seems to have had no obvious effect on the highly frequent, spreading surface fires. The important historical differences between the late 19th century effects of livestock grazing on fire regimes on the U.S. versus the Mexican side of the border were probably the numbers and types of animals that grazed these landscapes. We know very little about the grazing history or current number of animals in the Ajos, but we did observe small numbers of cattle grazing near and within our sampled sites when we collected our specimens in the early 1980s and again in the 1990s. We were quite impressed with the "open" character of the forests, the abundance of grasses, and evidence of recent surface fires. These conditions were reminiscent of Leopold's (1937) and Marshall's (1963) descriptions of northern Mexico forests when they visited there in the 1930s and 1950s. In contrast, some of the grasslands and savanna areas around the base of the Ajos appear to have been very overgrazed and eroded.

On the U.S. side of the border, there is abundant historical evidence that during the late 1800s livestock numbers were many times higher than today in almost all Southwestern mountain ranges and valleys, resulting in severe overgrazing. Southern Arizona was no exception in this regard (Bahre 1991, 1995, Leopold 1924, Wagoner 1961, Wilson 1995). In addition to cattle, large sheep and goat herds were also grazed in some areas of Southern Arizona (Bahre 1995, Hadley and others 1991, Wilson 1995). Open range, access to railheads, and a shift in ranching strategy from steer operations to cow-calf operations, may have been keys to the development of huge ranching operations on the U.S. side. The passage of mandatory range leasing laws in Texas in 1879 and 1883 created discontent and led to movement of ranchers and massive numbers of cattle to the unrestricted ranges of Arizona (Wagoner 1961). It is unlikely that these political and economic forces had much if any effect on Mexican ranges.

In summary, our explanation for the continued, frequent surface fires in the Sierra de los Ajos, and probably also for other Mexican Borderlands mountain ranges, was (1) the lack of intensive grazing by large numbers of cows, sheep, or goats in the higher elevations, and (2) a lack of effective fire suppression by the Mexican government. 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. The continued, frequent surface fires since 1886, when almost all Apaches were removed from the Borderlands, suggests that Apaches probably did not significantly increase fire frequencies in these areas above the fire frequencies that would have occurred anyway as a function of lightning ignitions and fuel dynamics.

Mixed Surface Fire and Crown Fires in Rugged Topography

The Animas Mountains fire chronologies provide an interesting contrast to the more typical frequent, widespread surface fire regimes reconstructed in most other Southwestern pine-dominant forests (Fig. 6). This complex history shows a pattern of "mixed" fire regimes, characterized by moderate frequency surface fires (about 3 to 15 year intervals) within individual forest stands, and widespread, higher intensity burns, including some stand-replacing fires, occurring at relatively lower frequency (about 20 to 50 year intervals) (Fig. 6).

The Animas Mountains fire-scar collection is one the largest from the Borderlands, both in terms of the numbers of trees sampled and in their broad spatial distribution. The master fire chronology (Fig. 6) is aggregated into clusters of 3 to 10 fire-scarred trees sampled within forest stands widely distributed over and around the highest peaks of the range (Fig. 7). This collection is comparable in extent to another mountain range-scale fire chronology from the Rincon Mountains (Baisan 1990, Baisan and Swetnam 1990). The Rincon Mountain fire chronology shows consistent, widespread fires (highly synchronous among trees and stands) at intervals of about 3 to 8 years. Little evidence for high intensity, long interval fires in the presettlement era was present in the Rincons. In contrast, the Animas chronology shows considerably less synchrony of surface fire dates among dispersed stands than the Rincon chronology, but other evidence points to occasional, mountain-wide (synchronized), high intensity burns.

The 1989 wildfire in the Animas range may have been an analog for the earlier synchronous moun-

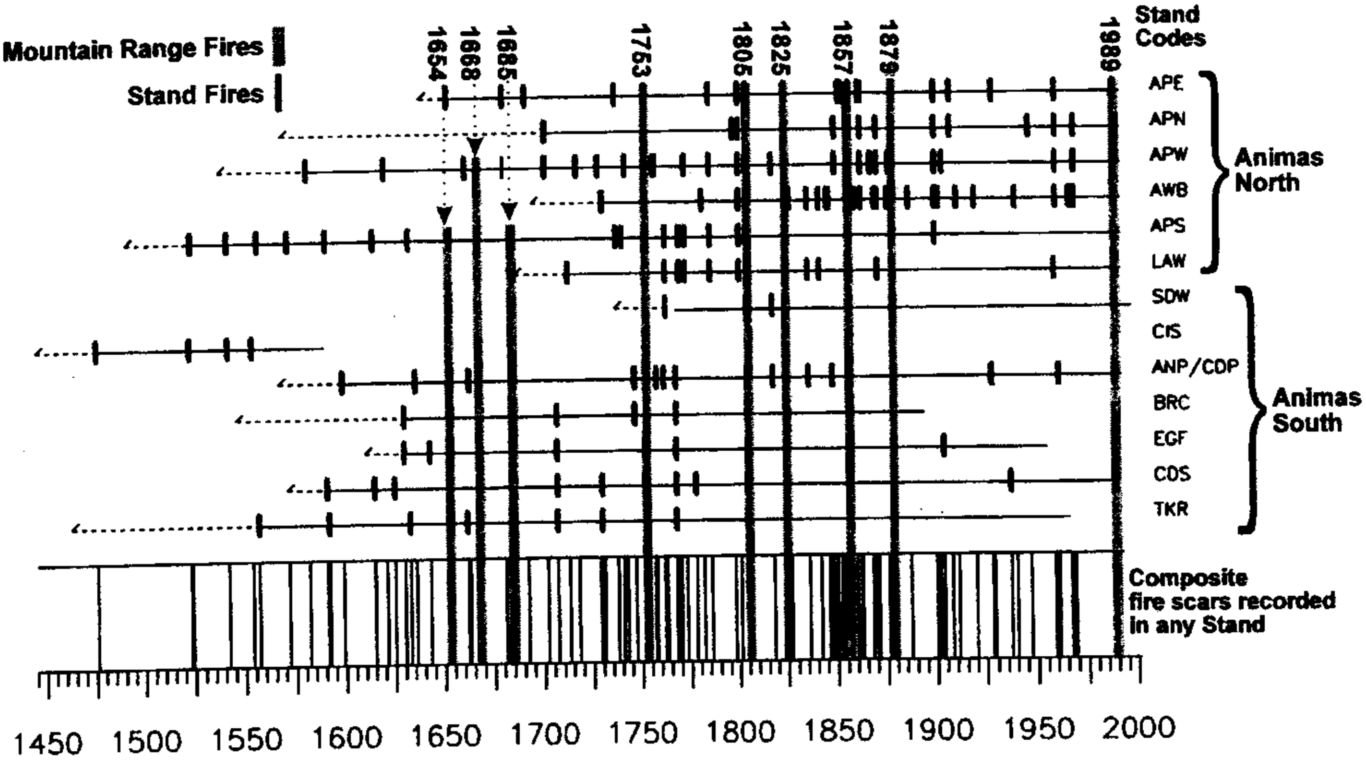

Figure 6. Master fire chronology chart for the Animas Mountains, New Mexico. See caption and legend for Fig. 4. The horizontal lines in this case are composite fire-scar records from groups of fire-scarred trees (three to 10 trees) from small stands distributed around the top of this range. The long vertical gray lines show years in which fires swept through most or all stands. See Fig. 7 for a map showing the spatial distributions of sampled stands.

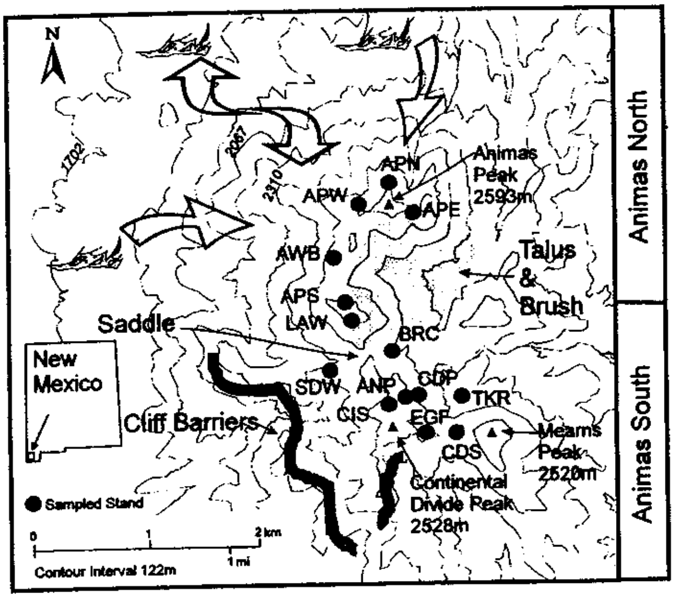

Figure 7. Topographic map of the Animas Mountains. Contour intervals are about 120 meters. Three letter codes show stand locations (corresponding to stand composites in Fig. 4). The northern stand group on Animas Peak was subject to spreading fires across the elevation gradient on the north side of the range. The southern stand group was more isolated from fires spreading from the grasslands to the west by cliffs.

tain-wide fires evident in the chronology (Fig. 6). 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 after the fire had spread over at least 10,000 hectares 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. We do not have precise measurements of the sizes of the high intensity burn patches, but some appeared to be on the order of about 200 to 500 hectares in size. Our evidence for the 1989 analog conjecture 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, and
3. Dates of tree recruitment following some of these fires (Baisan and Swetnam 1995).

Villanueva-Diaz and McPherson's data (1995, this volume) on tree age structure from several stands in the Animas also suggest that tree recruitment tended to follow large fires, particularly the 1879 burn. This is the pattern we would expect if stand structures were opened by relatively high intensity burns.

Other spatio-temporal patterns in the chronology point to the importance of landscape connectivity and land-use history. It is evident, for example, that surface fires were more frequent in some of the Animas Peak stands (upper 4 stands in Figs. 6 and 7) than in the stands located further to the south. This pattern was probably due to the continuous, unbroken topography and fuels leading from grasslands and woodlands on bajadas at the base of the mountains up to the summit of Animas Peak on this north side. Fires could spread (and did in 1989) unhindered by topography from any ignition point along this long elevation 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. In contrast, other stands south of Animas Peak (Fig. 7) are more isolated from 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. Higher elevation north-facing stands in this southern area tend to be closed-canopy mixed-conifer. Other areas along the east and south sides, and in some cases located between our sampled stands, currently sustain only scattered oak-brush fields inter-mixed with talus slopes. Hence, southerly located stands in the range are more isolated from spreading fires than stands on the northern end of the range (Fig. 7).

Differences in 20th century fire occurrence patterns between the north and south stands reveals the importance of both land-use history and landscape/fuel connectivity. The first significant ranching in the Animas Valley and Range probably began in the late 1880s. The last widespread fire before 1989 in the southerly stands was in 1879. However, some fires continued to occur in the northern stands (Fig 6). Again, we ascribe this pattern to the continuity of topography and fuels on this side of the mountain. Despite the effects of an unknown, but probably low level of livestock grazing, these areas still had sufficient fuels to carry fire within and between open grassy forests on these slopes. Fires may have come from, or burned down into, the lower elevation woodlands and grasslands on this side. In comparison, fire regimes in the more isolated, southerly stands seem to have been impacted immediately by the onset of livestock grazing in the 1880s, with a cessation of widespread fires, and the occurrence of only a few fires within stands during the 20th century (Fig. 6).

A spring in the relatively flat and grassy saddle between the north and south stands, and another spring just over the saddle on the east side, may have been the main impetus for moving livestock onto and through this part of the mountain seasonally. The livestock grazing (and trails, etc.) may have had such a pronounced effect here, but not in the northern stands, because of already sparse and disconnected fuels within and between the southerly stands. In other words, prior to the livestock grazing era there was probably sufficient fuel to sustain some spreading fires within and between the southern stands, albeit at a somewhat lower frequency than the northern stands (Fig. 6). After livestock grazing began, fuel amounts (grasses and forbs) and connectivity were reduced below a threshold necessary for sustaining surface fire regimes in these relatively isolated stands.

From the early 1910s to the 1950s the Animas range was under U. S. Forest Service jurisdiction. A primitive fire lookout was set up on one of the peaks in the early years but was probably manned only during some periods. The less frequent and synchronous fires between ca. 1910 to the 1950s in the Animas Peak stands may reflect effects of these minimal fire suppression efforts. The Animas range and surrounding lands were transferred to private hands in the late 1950s. After that time, limited fire suppression assistance came from state and federal agencies, but some fires probably reached large sizes on the northern side, and other areas within and around the mountain before much attention was paid to them in this remote corner of New Mexico.

Finally, we are left with one more piece to this complex puzzle of past fire regime patterns in the Animas Mountains. How is it that, during certain years, at relatively long intervals, fires seem to have swept over most or all of the stands, even though the southern stands were relatively isolated? Our explanation is that fuel connectivity (continuity and amount) between stands built up relatively slowly, so that at intervals of about 20 to 50 years conditions were primed for widespread, mountain-wide fires. Climatic conditions (daily to seasonal to interannual contingent events) conducive to fire ignition and spread promoted these mountain-wide events. A comparison with regional, tree-ring based drought reconstructions (Meko and others 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 1996). The 110-year hiatus between the 1879 and 1989 fires was probably due to the combination of livestock grazing on the mountain preventing or slowing the within and inter-stand fuel build up, and the limited fire suppression efforts.

DISCUSSION

While ecosystem patterns and processes have certainly changed, as they always have, we would ignore their history at our own peril. Indeed, dismissal of the past as "irrelevant to current situations" early in this century by some forest scientists and managers 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 we face today. Similarly, we feel 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 indeed 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 given landscape is dependent on the scale of our perspectives. Generally, longer temporal and larger spatial scale perspectives 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. In fact, such identification and recognition are often impossible without historical-ecological data and perspectives.

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 fire suppression and subsequent accumulation of live and dead fuels. The historically and ecologically anomalous nature of these changes are indicated by documentary and ecological studies (e.g., Cooper 1960, Weaver 1951), and by numerous fire history studies in Southwestern ponderosa pine forests (Swetnam and Baisan 1996). These patterns are especially evident as presettlement histories are contrasted with stand-replacement fire regimes occurring with increasing frequency in the 20th century in the same forests.

The main point of this example is that historical reconstructions and perspectives provide hard evidence for the reality of current extreme, unsustainable changes, as well as powerful explanations for their probable historical roots. These perspectives and explanations can provide direct scientific support to management decisions aimed toward restoring ecosystem processes and structures to more desirable and ecologically appropriate states.

Although we have learned something about high intensity fires, we do not yet have a clear understanding of the long-term role of these types of fire regimes in Borderlands mountain ranges, particularly the sizes of vegetation patches burned by such fires. We suspect that the 1989-type burn that occurred in the Animas may not have been historically or ecologically anomalous in this range, but we have doubts that this is true for the 1994 Rattlesnake burn in the Chiricahua Mountains or some other high intensity crown fires in southern Arizona ranges in the past decade. This is based on two observations. First, we lack evidence for fires burning at the intensities and patch sizes of the Rattlesnake and other fires within these ranges in the past (i.e., before ca. 1910). Such evidence would be recovering vegetation patches of these sizes (thousands of hectares), such as aspen stands, or conifer forests in varying seral, successional states, with at least fragmentary remnants (charred, snags, logs, or stumps) of the old, burned forest still present. Granted, as the old saying goes, "absence of evidence is not evidence of absence." However, within the limits of the preservation of fire-killed tree boles, and the time it would take for overstory trees to grow up into a structure that would hide the signs of a previous stand-replacing fire (perhaps 200 to 300 years or longer), we can be reasonably confident that canopy gaps the size of some created by the Rattlesnake fire, were rare to non-existent in the past few centuries. Second, we have fire-scarred specimens from a few locations (i.e., in the Rincons and Chiricahuas) where, clearly, only low intensity surface fire regimes persisted for the past three to five centuries. These stands, including the fire-scarred trees we sampled, were totally incinerated by recent crown fires.

We believe these facts constitute a "wake-up" call to managers, scientists, and the public. Some may argue that such extreme, historical-ecological changes should not necessarily concern us. Is a brush field slowly succeeding back to a conifer forest after a crown fire inherently less valuable or desirable than the conifer forest that burned? Some also argue that we should now just step back, and let nature take its course. However, heat damage to soils (e.g., loss of nutrients) probably occurred during the recent high intensity fires, and considerable soil erosion is occurring in some locations. This may cause threshold changes that will prevent these ecosystems from returning to forest or woodlands for many centuries, or millennia. The Earth has witnessed all manner of ecosystem changes, but heretofore, changes of these magnitudes and extent had their origin in non-human forces (e.g., climate change). Now, we humans may be the chief causes of these changes. This situation puts the responsibility squarely on our collective shoulders as land stewards to (1) learn whether these changes are truly, historically or ecologically anomalous, unsustainable, or undesirable (and these are not mutually exclusive conditions), and (2) to restore or maintain processes and structures in these biotic communities that will preserve their ecological legacy and integrity for future generations.

SUMMARY

1. Before 1900, surface fires occurred frequently (at least one fire per decade) in nearly all Borderland 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 are, in part, 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 dominant forests (Swetnam and Baisan 1996). High variability in fire history between sites was partly due to unique historical patterns (contingencies), such as time periods with unusually long or short fire intervals,

possibly due to 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). Fire regimes are a result of continuous, repeatable processes that are at least partially generalizable and predictable, and unique, contingent events that are not strictly generalizable, or predictable.

2. Fire regimes in most Borderlands mountain ranges on the U.S. side changed drastically around the turn of the century. Frequent, widespread surface fires in most pine and mixed-conifer forests effectively ceased to occur between ca. 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, although the possibility remains that it contributed to the continued absence of fires in the late 1910s and 20s, when conditions were generally wet, and effective fire suppression infrastructure was not yet in place.
3. Frequent, widespread surface fire regimes persisted in the twentieth century in Borderlands mountain ranges on the Mexican side. These continued surface fire regimes were probably due to a lack of high intensity livestock grazing in pine forests, and a lack of effective fire suppression by Mexican government agencies. Persistent fire regimes in areas currently grazed by cattle also indicate that, under some livestock production systems, surface fires can consistently ignite and spread over the landscape. The continuous surface fire regimes after 1886 also suggest that Apaches were not a necessary source of fire in these or other mountain ranges to maintain high fire frequencies. Apaches may have increased fire frequencies in certain places and times above what they would have been with lightning ignitions alone, but more site-specific research and evidence are needed to identify those places and times.
4. Rugged, dissected Borderlands mountain ranges, such as the Animas Mountains, can sustain mixed fire regimes composed of 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 patches. These patches were embedded in a much larger matrix of lower intensity surface fire. We hypothesize that this pattern may also have been sustained before 1900 in the Animas and in other, similar mountain ranges in the Borderlands. One implication of this type of fire regime is that fires burning at high intensity (crown fires) in patches, of some unknown size, may not be historically anomalous in some Borderlands mountain ranges.

Research Needs

Ultimately our decisions as land stewards will hinge, at least partly, on a better understanding of the past, which can guide us in understanding the consequences of our future actions. There are many things we need to learn more about.

1. We need to know more about the biotic consequences of different fire regimes. Specifically, what are the densities, age structures, distributions, and dynamics of plants and animals that are both a consequence and cause of different fire regimes in the Borderlands?
2. More knowledge is needed of fire history and fire effects in the highest and lowest elevation biotic communities, such as spruce-fir, upper elevation mixed-conifer, riparian zones, woodlands, savannas, and grasslands.
3. We need a better understanding of the historical and ecological role of high intensity, crown fires in mixed-conifer and spruce-fir, particularly the size distribution of landscape patches created by past high intensity fires.
4. We need to develop long-range (interseasonal and interannual) fire hazard forecasting models. A basis for these models may be the relation between the El Nino-Southern Oscillation, climate, and fire in the Southwest (Swetnam and Betancourt 1990, 1992) and the importance of interannual, lagging climate-fuel-fire relations (Swetnam and Baisan 1996). Such forecasting tools would be extremely valuable in fire management planning for extreme fire seasons, and for anticipating appropriate seasons and years for increased use of prescribed fire.
5. We need to apply the powerful new tools of remote sensing, geographic information systems, and dynamic, mechanistic simulation models to

improve our methods for reconstructing and interpreting past landscape history, and for gaining knowledge and understanding of current landscapes, fuels, and fire regimes.

ACKNOWLEDGMENTS

We thank Rena Ann Abolt, Peter Brown, Henri Grissino-Mayer, and Mark Kaib for commenting on a draft of this paper and suggesting improvements. Various data sets used in this paper were obtained with support from USDA Forest Service (especially Cooperative Agreements with the Rocky Mountain Forest & Range Experiment Station), USDI National Park Service (Chiricahua National Monument), Southwest Parks and Monuments Association, The Nature Conservancy, and The University of Arizona.

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