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CLIMATIC AND HUMAN INFLUENCES ON FIRE REGIMES OF THE SOUTHERN SAN JUAN MOUNTAINS, COLORADO, USA

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Abstract. Fire severity, frequency, and extent are expected to change dramatically in coming decades in response to changing climatic conditions, superimposed on the adverse cumulative effects of various human-related disturbances on ecosystems during the past 100 years or more. To better gauge these expected changes, knowledge of climatic and human influences on past fire regimes is essential. We characterized the temporal and spatial properties of fire regimes in ponderosa pine forests of the southern San Juan Mountains of southwestern Colorado by collecting 175 fire-scarred tree samples from nine sites across a wide range of topographic settings. All tree rings and fire scars were dated using standard dendrochronological techniques. Fire-free intervals were statistically modeled using the Weibull distribution to provide quantitative measures that characterized the historical range of variation in pre-EuroAmerican fire regimes.

Fires during our reference period were more frequent in the low elevation ponderosa pine forests (6–10 yr) than in the high elevation, mixed conifer forests (18–28 yr). Fires at lower elevations were predominantly low-severity, isolated fires. Fires during some years (e.g., 1748) were spatially extensive throughout the entire mountain range. Intervals that delimited significantly long fire-free periods ranged from 10–19 yr (low elevation) to 27–50 yr (high elevation). Fire histories were similar between the eastern and western portions of the mountain range, although we found significant evidence of topographic isolation on fire regimes at one site. Pre-1880 fires primarily occurred in the dormant season, and we found no temporal changes in past fire seasonality. We found no compelling evidence that Native Americans influenced fire regimes in our study sites.

We found a hiatus in fire occurrence between 1750 and 1770 that we believe was likely related to weakened El Niño-Southern Oscillation activity, an extended series of cool-phase Pacific Decadal Oscillation events, and weakened monsoonal moisture, all possibly entrained in an invasive air mass typical of locations that are more northerly. In addition, pre-1880 fires occurred during years of severe drought, conditioned by above average moisture conditions in preceding years. The 20th century is characterized by a near complete absence of fires (fire-free interval of >100 yr), suggesting future wildfires may be more widespread and ecologically severe compared to pre-1880 fires.

Key words: climate–fire interactions; dendrochronology; disturbances, human; fire history; fire regimes; mixed conifer; ponderosa pine; San Juan Mountains, Colorado, USA.

INTRODUCTION

Ponderosa pine (*Pinus ponderosa* Dougl. ex Lawson) is widespread throughout much of western North America, extending from the foothills to middle elevations of many mountain ranges and plateaus, and grows within a wide variety of site conditions and climatic regimes (Oliver and Ryker 1990). Recent research has demonstrated that fire regimes in ponderosa pine forests varied substantially through time and across space prior to EuroAmerican settlement in the mid to late 1800s. Most forests of pure ponderosa pine in Arizona and New Mexico were characterized by frequent, low-severity fires that maintained open forests of many size and age classes (Cooper 1960, Swetnam and Baisan 1996, Fulé et al. 1997). Pure ponderosa pine forests in eastern Oregon, Washington, and western Montana had similar fire regimes (Arno 1980, Agee 1993, Everett et al. 1994, Heyerdahl et al. 2001), as did low-elevation ponderosa pine forests near the forest–grassland ecotone in northern Colorado (Veblen et al. 2000) and the Black Hills of South Dakota and Wyoming (Brown and Sieg 1996, 1999). Fire-free intervals also appear to lengthen with increasing elevation within any given region, although many local exceptions to this pattern have been documented (Arno 1980, Swetnam and Baisan 1996, Veblen et al. 2000).

Fire regimes also varied temporally with different patterns in different regions. Many studies have documented a close relationship between changes in ponderosa pine fire regimes and changes in climate. Studies conducted in Arizona, New Mexico, and Colorado, for

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example, show a reduction in the occurrence of widespread fires in the late 1700s to early 1800s, perhaps as a result of reduced El Niño-Southern Oscillation (ENSO) activity (Cleaveland et al. 1992, Swetnam and Betancourt 1998, Grissino-Mayer and Swetnam 2000, Veblen et al. 2000). A similar hiatus in fire occurrence is apparent in more northerly reconstructions of fire from the Black Hills region during 1706–1753 (Brown and Sieg 1996) and at Cheesman Lake in the Front Range of Colorado during 1723–1851 (Brown et al. 1999). Because these regions lie outside the known geographic influence of ENSO activity, some other climate mechanism may be responsible for this conspicuous, and earlier, gap in fire occurrence. Other studies have documented effects on fire regimes associated with Native American practices in western Montana (Barrett and Arno 1982), southern New Mexico (Kaye and Swetnam 1999), and southern Arizona (Seklecki et al. 1996). Fire frequency also increased in a portion of the western Black Hills in the late 1700s, coincident with the arrival of the Sioux people to the region (Fisher et al. 1987). The relative roles of lightning and native peoples on fire regimes in the uplands of the Southwest were recently summarized by Allen (2002).

We reconstructed the temporal and spatial properties of fire regimes in ponderosa pine forests of the southern San Juan Mountains (SJM) in southwestern Colorado for several reasons. First, a large and conspicuous gap exists in southwestern Colorado where no studies have reconstructed past fires, despite a broad network of fire history sites throughout western North America (Heyerdahl et al. 1995, Swetnam and Baisan 1996). The locations of our study sites are important for bridging fire regimes in the Southwest with those found in locations that are more northerly. This contiguous network will facilitate interpretations of possible climatic forcing mechanisms that operated in the past to affect fire regimes across broad spatial scales.

A second goal was to determine whether fire regimes in the SJM were aligned to those found in more northerly or southerly locations. The SJM exist near the northern periphery of the semiarid Southwest. The SJM therefore may experience a shorter fire season than more southerly locations, perhaps contributing to fewer fires throughout the year. Furthermore, the fuel complex in southwestern Colorado consists of forest with understory dominated by shrubs; this is more similar to the ponderosa pine forests in northern Colorado than to the forests with grass-dominated understory of northern Arizona and New Mexico. Thus, it is possible that fire regimes in southwestern Colorado share patterns of fire frequency with northern areas. The continental location, however, would contribute to higher summer temperatures, greater convective activity, a higher frequency and greater intensity of thunderstorms, and perhaps cause more lightning ignitions. Thus, it is also likely that the fire regime of the SJM could be more aligned with that found in Arizona and New Mexico.

Third, a sense of urgency exists because the behavior of future wildfires and reintroduction of fire by management agencies require knowledge of past fire regimes, including fire frequency, spatial extent, seasonality, and response by fire to climatic factors (Swetnam et al. 1999). This knowledge provides a template on fire attributes as they likely existed prior to Euro-American influence, by which investigators can evaluate current and future fire behavior. The evaluation is all the more important because increasing global temperatures and associated changes in precipitation patterns are occurring, primarily from enhanced levels of greenhouse gases caused by human activity. Several studies have clearly demonstrated changes in fire regimes associated with expected changes in future climate, including changes in fire frequency, extent, seasonality, and timing of the fire season (Balling et al. 1992, Wotton and Flannigan 1993, Bergeron and Flannigan 1995). To gauge the influence of these expected changes in climate on future fire regimes, investigators must know the past relationship between climate and fire across many spatiotemporal scales.

We addressed four primary questions with our reconstruction of past fires. (1) How did pre-1880 fires vary temporally within the SJM? We were specifically interested in analyzing fire–climate and fire–human relationships, their variability over time, and whether a hiatus in fires occurred in the late 1700s to early 1800s. (2) How did pre-1880 fires vary spatially within the SJM? We expected to find longer intervals at higher elevations, in sites having topographic barriers to fire spread, and in the generally wetter eastern portion of the SJM. (3) Were pre-1880 fire-free intervals in the SJM similar to the shorter intervals that characterized forests in Arizona and New Mexico or to the longer intervals found in northern Colorado? (4) To what extent did Native American people influence pre-1880 fire regimes? Native Americans may have augmented the natural fire frequency and altered the seasonality of past fires with intentionally set fires.

STUDY AREA

The San Juan National Forest covers 757 000 ha in the southern and western portions of the massive San Juan Mountain Range in southwestern Colorado, USA (Fig. 1). Elevations range from 1800 m to >4200 m, and a wide variety of geologic substrates and topography are present. Ponderosa pine and mixed conifer forests cover extensive areas at the lower to middle elevations (2100–2900 m) of the San Juan Mountains, and exhibit a complex mixture of species compositions, disturbance regimes, and local histories (DeVelice et al. 1986, Romme et al. 1992). Ponderosa pine is the major canopy species in all of the forests within this vegetational zone, but associated species vary with elevation and aspect (Floyd-Hanna et al. 1996). At lower

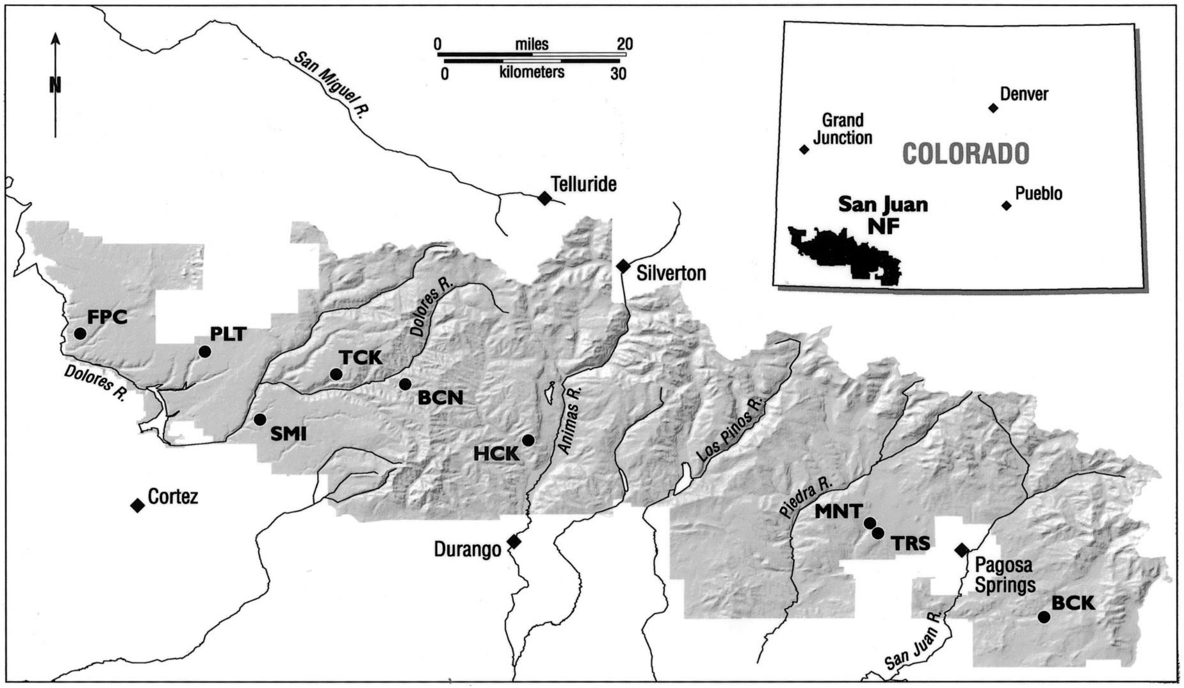

FIG. 1. The San Juan National Forest of southwestern Colorado, showing site locations. See Table 1 for codes and full site names.

elevations and on xeric aspects, ponderosa pine forms pure stands in the overstory. Six of our sites were located in such stands (Table 1). At higher elevations and on mesic aspects, the understory is dominated by shrubs, especially Gambel oak (*Quercus gambelii* Nutt.). Additionally, we sampled three stands in mixed conifer forests (Table 1), representing the warm, dry, mixed conifer forests growing at lower elevations adjacent to pure stands of ponderosa pine. The cool, wet, mixed conifer forests found at higher elevations and lacking ponderosa pine were not considered here.

Prior to EuroAmerican settlement, the major inhabitants of the San Juan Mountain region were the Ute people (Callaway et al. 1986, Ellis 1996). Little is known about the prehistory of the Utes, and it is not certain when they moved into the region (Duke 1995). Available evidence suggests that they were relatively few in number and were scattered over an enormous area (Bolton 1950). Oral histories indicate that the Utes set fires on occasion (M. Colyer, *personal communication*), but almost nothing is documented about specific Ute fire practices. We therefore know little about the kinds or magnitudes of impacts that the Utes may have had on local ecosystems during the period of indigenous settlement.

The first permanent EuroAmerican settlers in the San Juan Mountains were miners who arrived in the 1860s (Smith 1996), followed by cattlemen in the 1870s, and sheep herders soon after (Dishman 1982). Livestock grazing was unregulated and apparently heavy in many areas. As early as the 1890s, widespread range deterioration was already reported (DuBois 1903, Dishman 1982, Dahms and Geils 1997:32). This early heavy grazing probably reduced biomass and changed community composition in the herbaceous strata of the forests (Arnold 1950, Madany and West 1983, Fleischner 1994). Logging of ponderosa pine forests began in the late 1800s, accelerated during the 1920s, and by the mid-20th century, nearly every accessible stand had been affected (Dishman 1982, Smith 1982; J. S. Redders, *personal communication*). Most logging emphasized selective removal of the large, high quality trees.

METHODS

Site selection

We selected nine study sites representing the range of elevation, topography, and habitat types within the ponderosa pine and warm, dry, mixed conifer zones of the San Juan Mountains (Fig. 1, Table 1). These sites ensured that a comprehensive east-west gradient was represented. Candidate sites were first inspected to ensure that each had visible evidence of fire (i.e., trees with multiple scars). Site SMI is located near the end of a long narrow ridge, with steep barren slopes on the west and south that potentially serve as barriers to fire spread. None of the other sites has any topographic features that would likely limit fire spread into or out of the site. Site TRS is adjacent to an archaeological site representing a Ute camping area of the 18th and 19th century (Duke 1995). Although Native American people traveled throughout the San Juan Mountain area,

TABLE 1. Characteristics of sites where fire history was reconstructed in the San Juan Mountains, Colorado, USA, arranged from highest elevation to lowest elevation.

						No. tree-ring samples‡		
Study site and code	Location	Elevation (m)	Area (ha)	Topography	Vegetation†	Live	Dead or remnant	Total
Burnette Canyon (BCN)	37°35′ N, 108°08′ W	2740–2840	50	narrow ridge and adjacent slopes	MC with PIPO	5	3	8
Taylor Creek (TCK)	37°36′ N, 108°13′ W	2530–2650	100	steep slopes and deep ravines	MC with PIPO	9	7	16
Monument (MNT)	37°19′ N, 107°12′ W	2470–2560	200	moderate slopes and ravines	MC with PIPO	3	15	18
Smoothing Iron (SMI)	37°32′ N, 108°21′ W	2470–2560	200	broad isolated ridge top	PIPO with QUGA	9	14	23
Benson Creek (BCK)	37°08′ N, 106°52′ W	2440–2560	200	moderate slopes and ravines	PIPO with QUGA	9	14	23
Hermosa Creek (HCK)	37°28′ N, 107°50′ W	2410–2560	50	steep slopes and deep ravines	PIPO/QUGA with some PSME	21	2	23
Turkey Springs (TRS)	37°18′ N, 107°10′ W	2440–2470	200	gentle slopes, nearly flat	pure PIPO	4	24	28
Plateau Creek (PLT)	37°38′ N, 108°28′ W	2410–2440	150	gentle slopes, nearly flat	pure PIPO	1	20	21
Five Pine Canyon (FPC)	37°41′ N, 108°41′ W	2250–2375	200	gentle slopes and shallow ravines	PIPO/QUGA with PJ	5	10	15

† MC = mixed conifer; PSME = *Pseudotsuga menziesii* (Douglas-fir); PIPO = *Pinus ponderosa* (ponderosa pine); QUGA = *Quercus gambelii* (Gambel oak); PJ = pinyon juniper.

‡ Total number of tree-ring samples analyzed from all sites = 175; these include 66 from living trees and 109 from dead trees or remnants of trees.

we are unaware of similar intensive use in the vicinity of our other study sites.

Field methods

At each site, we collected between 10 and 30 samples, targeting logs, snags (standing dead trees), remnants (portions of eroded logs), stumps, and living trees that displayed visible sequences of multiple fire scars on the basal portion of the tree bole. We used a chain saw to extract complete cross sections from the bole through the fire-scarred surface. Because fire-scarred living trees provide information on 20th century fire regimes, small partial sections were cut from selected living trees (Arno and Sneck 1977, Baisan and Swetnam 1990). We also recorded information about each tree (e.g., diameter at breast height, crown condition, and signs of injury or damage) that would aid the tree-ring dating process. Areas sampled ranged from 50 ha to 200 ha.

Laboratory methods

All cross sections were reassembled and mounted on plyboard if necessary, then sanded using progressively finer sandpaper to produce high quality, polished transverse surfaces on which the cellular structure of the tree rings could be readily identified under standard 7–10× magnification. All tree rings were crossdated, using reference chronologies previously developed for the northern Rio Grande area and Mesa Verde National Park (Dean and Robinson 1978). In addition to the year of scar formation, we also recorded possible fire-induced zones of growth releases or growth suppressions and whether resin ducts were present. Growth suppression can be caused by physical damage to foliage and to roots, a growth release can be caused by fire-induced nutrient enhancement and/or reduction of neighboring competitors, while resin duct formation is a common response by conifers to physical trauma (i.e., resinosis; Brown et al. 1992, Brown and Swetnam 1994, Wimmer 2002).

Trees with multiple scars occasionally have discontinuous tree-ring records due to repeated burning and removal of the outermost tree rings and perhaps any embedded fire scars. This removal would affect calculations of percentage of trees scarred when assessing how widespread any particular fire was within any site. To ensure valid results from the statistical analyses that assessed fire extent, we documented whether tree rings were ‘‘recorder years’’ or ‘‘non-recorder years’’ (Grissino-Mayer 1999). ‘‘Recorder years’’ are those tree rings found on intact, noneroded sections that formed after the initial scarring event, and contain a fire scar or could have contained one had a fire occurred. ‘‘Non-recorder years’’ are those tree rings that preceded the initial scarring event, or were too eroded, decayed, or burned to provide fire history information. All statistical analyses were conducted over segments of recorder years only.

Fire seasonality

The dominant season of past fire occurrence was evaluated by recording the intraannual position of the fire scar within the tree ring (Dieterich and Swetnam 1984, Baisan and Swetnam 1990). If the position of the scar could not be determined with accuracy, it was not included in the analysis. We assigned calendar months to these intraannual positions based on previous studies that investigated the cambial phenology of Southwestern tree species growing near Mesa Verde National Park (Fritts et al. 1965), and from a pilot study initiated in 1995 at our Hermosa Creek site (W. H. Romme, *unpublished data*):

1) EE: a scar located in the first third portion of the earlywood (mid-June to early July).
2) ME: a scar located in the second third portion of the earlywood (early July to mid-July).
3) LE: a scar located in the latter third portion of the earlywood (mid-July to late July).
4) L: a scar located in the latewood (late July to August).

A dormant season fire scar (D) positioned between tree rings could have occurred either in early spring (April to mid-June) or late summer/fall (August and September); winter snowfall makes it unlikely fires occurred during other months. Because no physiological evidence allowed us to determine in which of these two seasons the fire occurred, a dormant season fire scar was interpreted as a spring fire. Assigning a calendar year to a dormant season scar, however, was occasionally assisted by observing the fire scar positions for the same year on other nearby samples. For example, if some samples from the same site had a few scars in the latewood portion of the tree ring, then any dormant season scars on other samples from the same site could be assigned to the late summer/fall season for the same year.

Examining fire-free intervals

For each sample, we recorded fire years, scar position, any injuries or anomalous ring features, inner/outer ring dates, and whether the rings were recorder or non-recorder years. This information was then entered into an FHX2 database (Grissino-Mayer 2001). For each site, we created graphs that depicted the temporal and spatial patterns of past fires (Dieterich 1980). The beginning year for statistical analyses at each site was that year when at least two samples recorded a fire (which ranged from 1654 to 1748; Swetnam and Baisan 1996, Grissino-Mayer 1999). The year 1880 was chosen as the ending year because human-related disturbances that altered fire regimes became pervasive beginning in the 1880s throughout much of the American West.

A key objective in the analysis of fire-free intervals is to assess how frequently fires occurred historically. We composited (i.e., fire dates from all samples composited to a single time series) then modeled fire-free interval data using the Weibull distribution, which has been shown to be an effective model of Southwestern fire regimes (Swetnam and Baisan 1996, Grissino-Mayer 1999). Goodness-of-fit of the Weibull distribution to the fire-free interval data was measured using the Kolmogorov-Smirnov goodness-of-fit test (Grissino-Mayer 1999), which in all instances indicated superior fits of the Weibull distribution compared to the assumed normal distribution. We assessed central tendency in the distribution of fire-free intervals using two measures. The Weibull Median Interval (MEI) is the interval associated with the 50th percentile of the distribution, while the Weibull Modal Interval (MOI) is the interval associated with the maximum area under the probability density function. The range of historical variability was delimited by calculating the Lower and Upper Exceedance Intervals (LEI and UEI; see Grissino-Mayer 1999). Variance in fire-free intervals was assessed using the coefficient of variation.

To assess the ability of fire to spread within each study site, we additionally computed statistics for fires that scarred at least 25% of the recorder trees within the area and compared these to statistics based on all fires, regardless of the number of trees that recorded fires. Percentage scarred classes have been used extensively in previous studies to indicate fires that were perhaps more widespread within individual sites (Swetnam 1990, Swetnam and Baisan 1996, Fulé and Covington 1997, Veblen et al. 2000).

To assess temporal changes in fire regimes, we divided the period of analysis for the entire composited San Juan data set into two independent periods based on apparent changes in fire-free intervals as seen in the composite graphs. The difference in mean intervals between periods was statistically evaluated using a Student's t test on interval data that were first normal transformed to reduce effects of skewness, and then converted to standard normal distributions. In addition, post-1880 fire regimes were compared to pre-1880 fire regimes using critical threshold descriptive statistics (the UEI and maximum interval) to assess the degree of hazard that currently exists in the forests of the San Juan Mountains (Grissino-Mayer 1999).

Evaluating the fire–climate association

To identify climate conditions that acted as precursors to fire occurrence, we used superposed epoch analysis (Swetnam and Betancourt 1992, Swetnam and Baisan 1996), which evaluates climate conditions prior to and during fire years. Average climate conditions are calculated for each year prior to (up to $t - 5$), during ($t = 0$), and after (to $t + 2$) the year of fire. Confidence intervals for assessing statistical significance were calculated using bootstrapping techniques on events randomly drawn from the population of observations.

Because instrumental weather records are too brief to assess pre-1880 fire regimes, we used a limber pine tree-ring chronology as a proxy for precipitation. These trees were collected from a site in the southern portion of the San Juan Mountains (R. Adams, L. Baxter, and J. Fairchild, *unpublished data*). Correlation analysis between this chronology and precipitation for Durango, Colorado (1900–1990, available from the Western Regional Climate Center, Reno, Nevada) revealed these

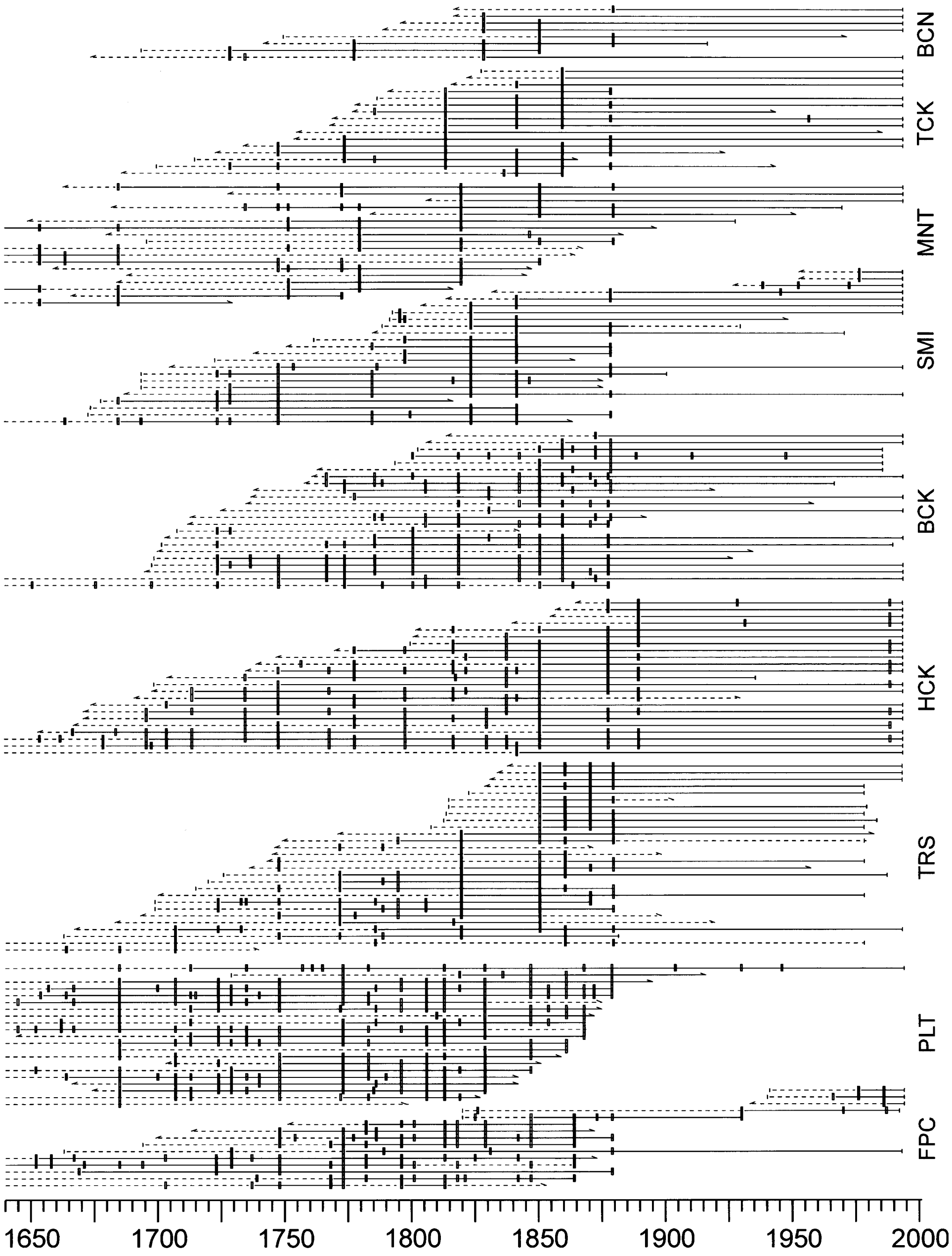

FIG. 2. Master fire chronologies for all nine study sites in the San Juan Mountains from 1650 to 1994, arranged from highest elevation (BCN) to lowest elevation (FPC). Horizontal lines represent the time span for individual trees; solid lines indicate recorder years; dashed lines indicate non-recorder years (see *Methods: Laboratory methods*). Short vertical bars depict dated fire scars.

trees respond predominantly to February–July total rainfall ($r = 0.62$, $P < 0.0001$), with June precipitation having the greatest single-month relationship ($r = 0.53$, $P < 0.0001$). Therefore, tree-ring indices used in the superposed epoch analysis can be used to infer spring/summer rainfall conditions (i.e., values above/below 1.0 represent wetter/drier spring/summer conditions).

RESULTS

Temporal patterns in past fire

Fires were relatively frequent between 1680 and 1880 for ponderosa pine forests in the San Juan Mountains as a whole (Fig. 2). Fire frequency dropped dramatically after 1880 (at all sites with sufficient numbers of samples), coinciding with the onset of heavy grazing, although one site (HCK) recorded a widespread fire in 1890. The paucity of fires during the 20th century is remarkable. Six sites (BCN, TCK, and MNT at high elevation, SMI and BCK at mid elevation, and TRS at low elevation) had no widespread fire after 1880, a fire-free interval of at least 114 years (1881–1994). The HCK site had an unprecedented (within its 300-yr record) fire-free interval of 100 years (1890–1989). At the two remaining sites (PLT and FPC), sample sizes were too low during the 20th century to assess fire frequency.

Several key patterns emerged among the measures of central tendency. The median fire-free interval was, without exception, either equal to or shorter than the mean fire-free interval because the median observation in a data set is generally more resistant to ''outlier drag.'' In addition, the two central measures based on the Weibull distribution were generally shorter than the mean fire-free interval, with the Weibull Modal Interval (MOI) generally shorter than the Weibull Median Interval (MEI). There was little difference between the median fire-free interval and the Weibull Median Interval except for the higher elevation sites, which were characterized by longer intervals. At the SMI site, the MOI was much lower than the MEI, reflecting the effects of a higher number of shorter intervals (Fig. 3). These four measures clearly formed a regular pattern, with few exceptions: mean fire-free interval $>$ median fire-free interval $\geq$ Weibull Median Interval $>$ Weibull Modal Interval. Of these four measures, the Weibull Median Interval appeared less influenced by clusters of short or long intervals in the distributions, and we therefore recommend this as a preferred measure of central tendency in fire-free interval analyses.

Similar patterns emerged among the statistics that describe the range in fire-free intervals among the sites. The minimum and maximum fire-free intervals and the Lower and Upper Exceedance Intervals all decreased with decreasing elevation (Table 2). The minimum fire-free interval ranged from 1 yr at low to mid-elevation sites to 5–6 yr at higher elevation sites. The LEI ranged from just 2 yr at low elevations to as high as 12 yr at higher elevations. Maximum fire-free intervals ranged from 18–19 yr in low to mid-elevation sites to 50–51 yr at higher elevation sites. The UEI ranged from 10–12 yr at lower elevations to as high as 38–50 yr at upper elevation sites.

The variability in fire-free intervals is itself a function of both the range between the minimum and maximum intervals and the regularity of years between successive fires. No clear elevational pattern, however, was evident in the variability of fire-free intervals. High-elevation sites had both high variability (CV $=$ 0.73 at MNT) and low variability (CV $=$ 0.43 at TCK), similar to the range of values at low-elevation sites. Variability was highest at site SMI (CV $=$ 0.84), consistent with the wide range in its measures of central tendency (MOI $=$ 3 yr while MEI $=$ 13 yr).

Few of our sites showed unambiguous evidence of a hiatus in fire occurrence in the late 1700s to early 1800s (Fig. 2) as documented at numerous other sites in the Southwest (Swetnam 1990, Swetnam and Baisan 1996, Grissino-Mayer and Swetnam 2000). Instead, we observed a clear hiatus from about 1750 to about 1770 in the composite graphs for all sites (the horizontal lines in Fig. 4A), especially when filtered to show the widespread fires (Fig. 4B). To determine whether a change in fire frequency had occurred after the hiatus, we divided the entire reference period into two shorter sub periods, 1680–1752 and 1767–1880. The (normal transformed) mean fire-free interval for the 1680–1752 period was significantly longer than the mean interval for the 1767–1880 period for all fires ($P = 0.04$) and for the more widespread fires ($P = 0.03$; Table 3).

Spatial patterns in past fire

A clear elevational gradient in fire occurrence is apparent (Fig. 2). As expected, fires were not as common in the higher elevation mixed conifer stands (BCN and TCK) as they were in drier, pure ponderosa pine stands at lower elevations (PLT and FPC), while mid-elevation sites with mixed pine and Douglas-fir (HCK and SMI) had intermediate values (Table 2). Many fires were widespread within individual sites (i.e., they scarred a large percentage of sampled recorder trees for that year), but were likely low-severity fires for so many trees to have survived. Two of the pure pine sites were anomalous, however. Statistics for the low-elevation TRS site are more like those of the higher elevation, ponderosa pine–Douglas-fir sites, while the BCK site, at a relatively high elevation, has fire-free interval statistics similar to lower elevation sites.

In the lower and middle elevation sites, MEI values for fires that scarred $\geq$25% of recorder trees were about twice as long as values computed for all recorded fires, ranging from 29% to 130% increases in the fire-free intervals (Table 4). This suggests that many fires in the low elevation sites were small and localized. In contrast, MEI values for the three high elevation sites showed lower differences between all fires and widespread fires (between 22% and 36% increases), suggesting that most fires in these mixed conifer stands burned through most of the stand. This observation is clearly seen in the composite graphs (Fig. 2). Many more, isolated, local fires occurred in the lower elevation pure ponderosa pine stands than occurred in the high elevation stands.

Fire-free intervals at SMI, which has potential barriers to fires spreading into the area, were generally longer than at the other low and mid-elevation sites that had similar vegetation but no topographic barriers. Most measures of central tendency in fire-free intervals at this site are considerably longer than the other low-elevation ponderosa pine sites (Table 2), while the MEI

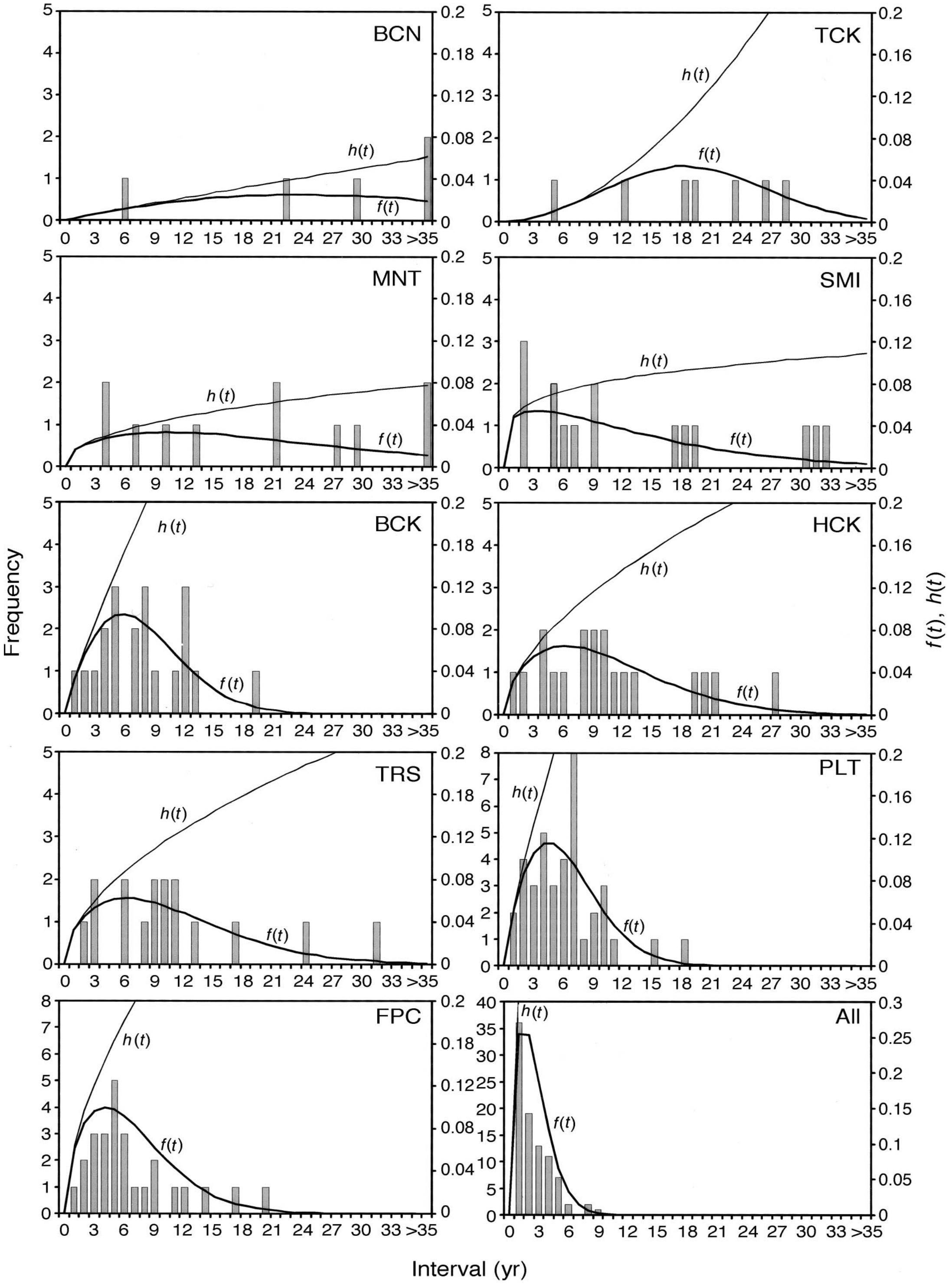

FIG. 3. Distributions of the fire-free intervals for all nine study sites during the reference period, and for all nine sites combined (All). The probability density function, $f(t)$, models the fire-free interval data based on the Weibull distribution, and can be used to assess the goodness of fit. The hazard rate is represented by $h(t)$. Steep slopes indicate sites with shorter fire-free intervals and greater degree of fire hazard.

TABLE 2. Descriptive statistics for fire-free interval analyses for nine study sites in the San Juan Mountains, arranged in order of decreasing elevation (from left to right).

Statistic†	BCN	TCK	MNT	SMI	BCK	HCK	TRS	PLT	FPC	All‡
Begin year§	1729	1748	1654	1685	1729	1679	1707	1645	1703	1650
Total no. intervals	5	7	11	15	20	19	16	38	26	91
Mean fire interval (yr)	30	19	21	13	8	11	11	6	7	3
Median interval (yr)	29	19	21	9	8	9	9	6	5	2
MEI (yr)	28	18	18	10	7	9	10	6	6	2
MOI (yr)	23	18	10	3	6	6	6	4	4	2
Minimum interval (yr)	6	5	4	2	1	1	2	1	1	1
Maximum interval (yr)	51	28	50	32	19	27	31	18	20	9
LEI (yr)	12	10	6	3	3	3	3	2	2	1
UEI (yr)	50	27	38	25	13	19	19	10	12	5
CV	0.59	0.43	0.73	0.84	0.57	0.66	0.71	0.59	0.69	0.71
Skewness	−0.16	−0.51	0.61	0.70	0.64	0.81	1.30	1.11	1.29	1.39

† Abbreviations: MEI = Weibull Median Interval; MOI = Weibull Modal Interval; LEI = Lower Exceedance Interval; UEI = Upper Exceedance Interval; CV = coefficient of variation.

‡ All sites combined.

§ The beginning year for analysis was the first year with a minimum of two trees scarred. The ending year of analysis for all sites was 1880.

for more widespread fires is over twice that found at the other ponderosa pine sites (Table 4). These results suggest that topographic barriers have a considerable effect on fire frequency and likely influence local vegetation communities.

Fire seasonality

For all nine sites combined, 57% of all fires prior to 1880 occurred during the spring dormant season (April to mid-June; see Table 5). Fires were less frequent between mid-June and mid-July (only 12% of all fires), the period that corresponds to the height of the current summer monsoon season. These fires likely occurred in years when monsoon rainfall either was diminished, or delayed, or failed altogether. Another peak in fire activity occurs in the late portion in the growing season (mid-July and after, 31% of all fires). The relative proportions of dormant and growing season scars fluctuated somewhat over time, but we found no apparent temporal trends that might indicate changing seasonality of fires. In addition, no trends were apparent along the range of elevations represented by our sites. We did uncover, however, striking differences among study sites. For example, most fires at the PLT site occurred during the dormant season (82%), whereas summer burns (mid-June through August) predominated at TRS (64%). We also observed that fires during certain years occurred prior to and throughout the growing season (Fig. 5). Similar findings were observed for other locations in the Southwest (Baisan and Swetnam 1990). These multiple seasonal estimates for a single year indicate either (1) single-ignition fires that were persistent throughout the growing season within individual stands, (2) multiple-ignition fires that occurred during different periods within and/or among the sampled stands, (3) differences in cambial phenology among trees, or (4) our within-ring estimation process of fire-scar position is too coarse for accurate determination of past fire seasons.

Fire–climate associations

Fires occurred more often during drought years. This statistically significant ($P < 0.001$) trend was evident based on all fires regardless of extent (Fig. 6A, Year 0) as well as on widespread fires (recorded on 25% of all recorder trees; Fig. 6B). Above-average rainfall in years $t - 3$ and $t - 2$ prior to the fire year may have facilitated fire occurrence as indicated by indices that approached the $+0.95$ confidence level. Although most of these indices were not statistically significant, their overall pattern and potential influence on fire occurrence should not be overlooked. A statistically significant ($P < 0.01$) relationship was observed, however, between rainfall in year $t - 2$ and fire occurrence based on fires that scarred at least 25% of the sampled trees (Fig. 6B). This suggests that fires that are more widespread are additionally influenced by abundant moisture in previous years, thus increasing fine fuel loadings and contributing to more homogeneous fuel coverage across the landscape in years preceding fire occurrence. Finally, we conducted separate superposed epoch analyses (not shown) on the 1680–1752 and 1767–1880 sub periods to determine whether the relationship between fire and climate had changed temporally between periods. The two sets of results were very similar to the previous analysis, indicating no change in the response by fire to climate between periods.

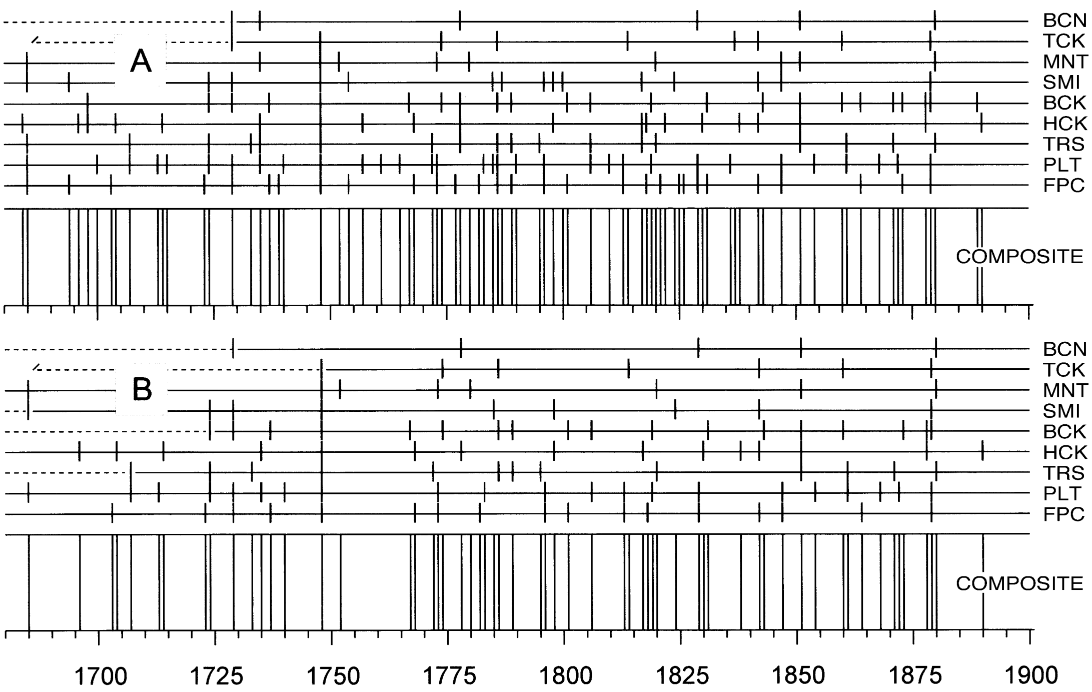

FIG. 4. Fire chronologies for each of nine sites representing (A) all fires and (B) fires that scarred ≥25% of the sampled trees (i.e., widespread fires). A hiatus in fire occurrence is indicated between ~1750 and 1770; this is especially obvious in the lower graph. The Composite axis represents information from all sites.

DISCUSSION

How did pre-1880 fires vary temporally within the San Juan Mountains?

We found a clear hiatus in fire occurrence between ~1750 and 1770, a few decades earlier than reported for other sites throughout the American Southwest. Several studies have noted a reduced amplitude of El Niño-Southern Oscillation (ENSO) variation in the late 1700s to early 1800s (Cleaveland et al. 1992, Swetnam and Betancourt 1998, Veblen et al. 2000). A decrease in ENSO activity would diminish winter/spring rainfall in the Southwest, reducing fine fuels necessary for successful fire ignition and spread. In addition, a recent study (Grissino-Mayer et al. 2002) demonstrated a significant, direct relationship between precipitation in the Southwest and the Pacific Decadal Oscillation (PDO; see Mantua et al. 1997). An extended series of cool-phase PDO events (i.e., a southerly flow of cold ocean waters off the western North American coast) could reduce fire occurrence due to lower overall temperatures that would facilitate high pressure dominance, thus inhibiting convectional uplift and minimizing lightning activity. These cooler climatic characteristics could also lower evaporation rates, thus allowing fuels to retain moisture longer and reducing the probability of successful fire ignitions. Finally, summer rainfall and thunderstorm activity may have been diminished

TABLE 3. Differences in mean fire-free intervals between the 1680–1752 and the 1767–1880 periods for all fire years as well as for years when ≥25% of the sampled trees were scarred per site, with a minimum of two fire scars per year to indicate more widespread fires.

Fire type and period	No. intervals	Mean interval†	df	*t*	*P*
All fires					
1680–1752	21	3.2	72	2.03	0.04
1767–1880	53	2.1			
Widespread fires					
1680–1752	15	4.5	55	2.16	0.03
1767–1880	42	2.7			

† Data have been normal transformed.

TABLE 4. Comparison of Weibull Median Interval (MEI) for all fires and for fires that scarred ≥25% of the recorder trees (a minimum of two trees scarred) at each of our nine study sites in the San Juan Mountains, arranged from high elevation to low elevation.

Study site	MEI (yr) All	MEI (yr) ≥25%	Increase (%)
BCN	28	38	36
TCK	18	22	22
MNT	18	22	22
SMI	10	23	130
BCK	7	9	29
HCK	9	14	56
TRS	10	13	30
PLT	6	9	50
FPC	6	11	83

TABLE 5. Fire scar formation during different portions of the growing season during the pre-1880 reference period, in nine study sites.

Time of year†	No. fire scars (% of total for season)									
	BCN	TCK	MNT	SMI	BCK	HCK	TRS	PLT	FPC	All sites
D: April to mid June	7 (50)	29 (72)	16 (31)	26 (42)	61 (62)	53 (47)	31 (36)	142 (82)	31 (52)	396 (57)
EE: mid June to early July	0 (0)	3 (8)	2 (4)	4 (6)	4 (4)	5 (4)	6 (7)	5 (3)	7 (12)	36 (5)
ME: early July to mid-July	0 (0)	0 (0)	4 (8)	1 (2)	15 (15)	18 (16)	6 (7)	0 (0)	7 (12)	51 (7)
LE: mid July to late July	6 (43)	6 (15)	16 (31)	10 (16)	15 (15)	26 (23)	35 (40)	9 (5)	7 (12)	130 (19)
L: late July and August	1 (7)	2 (5)	13 (26)	21 (34)	3 (3)	10 (9)	9 (10)	18 (10)	7 (12)	84 (12)

† See *Methods: Fire seasonality* for detailed explanation.

if the mechanism that affected ENSO/PDO-driven precipitation also affected summer monsoon activity. Grissino-Mayer and Swetnam (2000) hypothesized that summer monsoon rainfall increased significantly after the hiatus as shown by the changing seasonality of fires in northwestern New Mexico. Any one or a combination of these mechanisms could have caused a hiatus in fire occurrence.

We further propose a possible fourth mechanism. Changes in air mass boundaries may have affected the general climate characteristics of the region and therefore affected fire occurrence. This hypothesis is supported by the temporal variation in the onset of this gap in fire occurrence at various locations throughout the western United States. This suggests a possible north-south spatial pattern. Veblen et al. (2000) reported a gap from 1653 to 1779 in northern Colorado; Brown et al. (1999) found a gap between 1723 and 1851 in central Colorado; and here we report a gap between 1750 and 1770 in the southern San Juan Mountains. Grissino-Mayer and Swetnam (2000) reported a gap from 1780 to 1800 in northwestern New Mexico; and sites in the central and southern Southwest showed a gap from 1800 to ~1850 (Swetnam and Baisan 1996). There is no reason to assume that the climatic factor(s) responsible for creating this long gap began at exactly the same time and had a similar duration and effect at all locations. The responsible climate factor(s) may have been present in the northern portion of the Southwest (including Colorado) earlier than in locations that are more southerly. This suggests an expansion of a dominant air mass from a more northerly location and/or strengthened influences of regional-scale climatic phenomena down into the San Juan Mountains and eventually farther south.

Particularly relevant is the winter air mass boundary that affects the Pacific Northwest, which has its southern boundary along the northern Colorado–Utah–Nevada border (Mitchell 1976). Based on tree-ring data from the Great Basin region, Woodhouse and Kay (1990) determined that a meridional flow pattern (i.e., north to south) likely dominated during the 1600s, early 1700s, and in the 1900s, while a zonal flow orientation (i.e., east to west) dominated during the late 1700s and 1800s. A reconstruction of climate based on a network of tree-ring sites (Fritts et al. 1979) revealed that anomalously strong high pressure existed over the eastern Pacific near British Columbia during the 1600s, early 1700s, and 1900s. This blocking ridge would facilitate meridional circulation patterns in the interior western United States by deflecting zonal flow from the Pacific to the north and/or south. This high pressure region is consistent with cold ocean waters located in the eastern Pacific that could have resulted from an anomalously strong series of cool-phase PDO events. Furthermore, the long gap in fire occurrence is more suggestive of an influence by the PDO, which operates on decadal time scales, compared to the frequency of 3–5 yr for ENSO activity. Such changes would alter the intraannual distribution of frontal and convectional precipitation and the probability of successful lightning ignitions, thus altering fire regimes. The initial influx of this new cooler wintertime air mass could have been a severe change to more southerly ecosystems, enough perhaps to cause a near complete hiatus in fires, after which fires would resume, but with different properties due to the climatically altered fire regime.

Widespread fires in the San Juan Mountains coincide with large fires elsewhere in the Southwest, which further supports the hypothesis that fire occurrence in the San Juan Mountains was influenced by changes in climate. Eight of the 11 years in which three or more of our nine sites recorded widespread fires (≥25% of recorder trees scarred) were also among the top 20 fire years in New Mexico and Arizona (i.e., 1685, 1724, 1729, 1748, 1842, 1851, 1879, and 1880; Swetnam and Baisan 1996). Two of the major fire years in the San Juan Mountains (1786 and 1851) were also major fire years in northern Colorado (Brown et al. 1999, Veblen et al. 2000).

The shift in fire regimes in the San Juan Mountains following the 1750–1770 hiatus is strongly indicated by changes in fire-free intervals. Prior to 1750, fire occurrence was generally low, but was higher after 1770. The effect of the 1748 fire must also be considered a contributing factor. Because the 1748 fire was particularly widespread, occurring in eight of our nine study sites, it may have created a landscape in the San Juan Mountains with more homogeneous fuel characteristics. Fires that occurred after the long hiatus would therefore be expected to be widespread fires, and this is indeed the case. A period after the hiatus (1767–

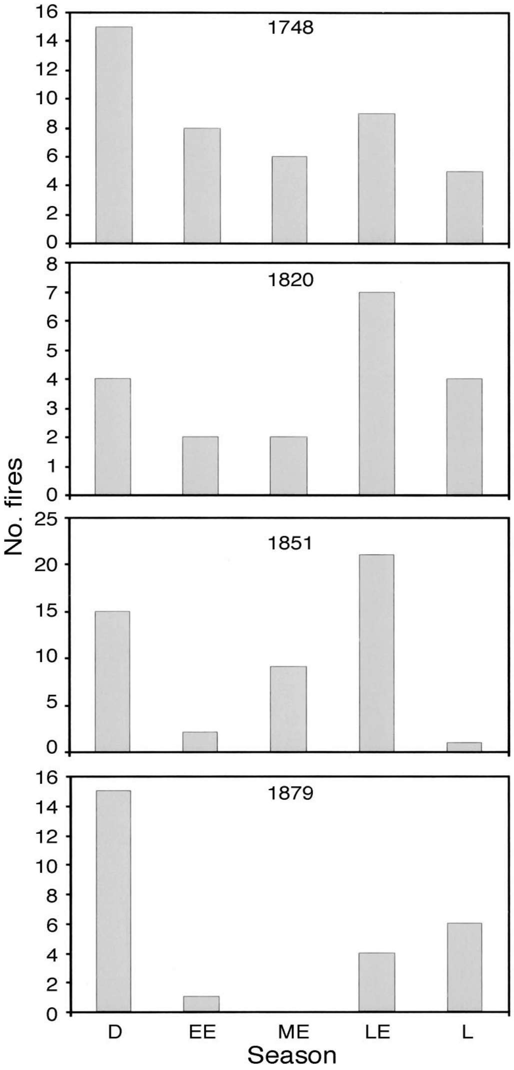

FIG. 5. Fire seasonality during four fire years within the San Juan Mountains. While dormant-season fires predominated, the range of seasons indicates that fires during these years probably occurred throughout the growing season. See *Methods: Fire seasonality* for explanations of seasonal designations.

1880) had a higher percentage of fires at two or more sites. Specifically, there were multi-site fires in 32 of 59 fire years (54%) in this period compared to multi-site fires in 14 of 33 fire years (42%) in an earlier period from 1650 to 1750. Thus, the post-hiatus fire regime was characterized by fires that were more frequent and were generally more widespread.

Fire occurrence is also driven by climate on shorter monthly time scales, primarily by rainfall during July. Summer monsoon rainfall begins at or near the beginning of July, and onset, failure, or possible delay is especially pivotal for fire occurrence. Below average rainfall during July (i.e., a failure or delay) would lower fuel moisture levels and aid successful fire ignition and spread, or enhance the severity of any fires that had occurred earlier by allowing them to become more widespread. Further, our results indicate widespread fire occurrence is likely in years when (1) spring/summer rainfall amounts are well below average, (2) rainfall during preceding years was above average, and (3) spring/summer rainfall two years prior was exceptionally heavy. This scenario is enhanced if a particularly wet El Niño event is succeeded by a particularly dry La Niña event in months leading up to the fire event.

We found few fire events between 1890 and 1989, all of which were very limited in extent (generally a single fire scar in a single stand), a pattern that is consistent with findings throughout the western United States. Between ~1890 and 1930, only two fire scars (1904 and 1911) were found on two of the 94 recorder trees for that period. Fires were simply unable to spread over large areas because of changes in understory fuel conditions (initially by grazing livestock) and active fire suppression (Covington and Moore 1994). This near absence of fires is particularly troubling because these long fire-free intervals far exceed both the maximum fire-free intervals and the Upper Exceedance Intervals based on pre-1880 fire regimes. The situation is more problematic in the pure ponderosa pine stands at low elevations where pre-1880 maximum intervals and Upper Exceedance Interval values were much shorter. Given that over 100 years of fuels have built up in most locations within the San Juan Mountains, any future wildfire will likely have a greater intensity (i.e., heat output) than pre-1880 fires, have greater effects on ecosystems within the San Juan Mountains across all elevational and longitudinal gradients, and be more widespread due to the increased contiguity of fuels across the landscape. This suggestion was recently supported by the spatially extensive Missionary Ridge fire in June and July 2002, 17 km northeast of Durango, Colorado, which burned >29 500 ha in ponderosa pine and mixed conifer forests.

How did pre-1880 fires vary spatially within the San Juan Mountains?

Each of the nine sites had a more-or-less unique fire history (i.e., different fire years) indicating that most fires were relatively localized to one geographic area in the San Juan Mountains (although they may have burned most of an individual stand). Widespread fires, however, occurred during 11 years between 1680 and 1880 when fires were recorded in three or more of our study sites. These must have been severe fire years, when much of the mountain range was ablaze. For example, a major widespread fire occurred in 1748 at eight of our nine study sites, indicating a fire that likely occurred throughout the entire mountain range because BCK is our easternmost site while FPC is our westernmost site, a distance of ~180 km. Given the spatial extent of these fires, both within the San Juan Mountains and throughout the Southwest, it is unlikely such widespread fires were set by Native Americans.

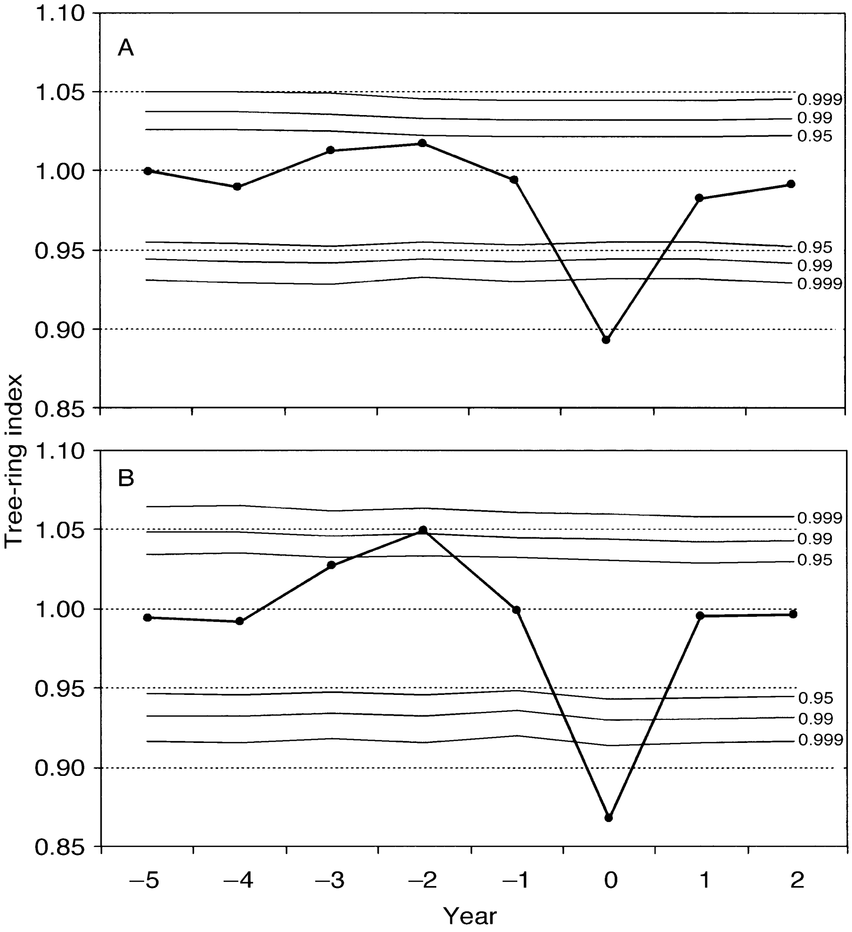

FIG. 6. Results from the superposed epoch analysis, comparing fire occurrence based on (A) all fire scars and (B) only those that scarred ≥25% of the sampled recorder trees. Year 0 is the year of fire. The tree-ring index (mean = 1.0) is a surrogate for spring rainfall. The period analyzed extends from 1654 to 1880. Total fire years = 80; widespread fires = 59. Confidence intervals are represented by 0.95, 0.99, and 0.999.

Fire-free intervals generally were longer at higher elevations. With the exception of one anomalous site where topography played a key role (SMI), Weibull Median Interval values for widespread fires (≥25% of recorder trees scarred) in the pure ponderosa pine stands at lower elevations were 9–14 yr, compared with 22–38 yr for ponderosa pine–mixed conifer sites at higher elevations. The longer fire-free intervals at higher elevations likely reflect the generally mesic conditions that occur at higher elevations caused by lower temperatures that inhibit evapotranspiration, enhanced precipitation from orographic uplift, and greater snow pack and increased runoff from snowmelt. These effects are more pronounced on north-facing high-elevation slopes where evapotranspiration rates are lower and fuel moisture levels are generally higher.

Variability in fire-free intervals is as important as central tendency for interpreting functional implications of the fire regime, such as establishment of ponderosa pine seedlings. At all nine sites in the San Juan Mountains, the range of intervals (i.e., the difference between the Lower and Upper Exceedance Intervals) was 8–16 yr in pure ponderosa pine stands at lower elevations (excluding the anomalous SMI site), and 17–38 yr in ponderosa pine–mixed conifer stands at higher elevations. Fires at the shorter intervals, especially if they occurred during the growing season, would create patches of mineral soil and reduce the density of competing shrubs such as Gambel oak (Harrington 1985, 1987), thus enhancing the germination environment for pine seedlings. Fires at short intervals, however, would also kill young pine seedlings, thus requiring occasional long fire-free intervals to allow the seedlings to grow large enough to survive fire (Pearson 1950, White 1985). Fire-free intervals in the lower elevation ponderosa pine forests were generally longer for widespread fires (≥25% trees scarred) than for fires of any size. This indicates that many of the lower elevation fires were small and localized. Therefore, patches would be present that escaped fire long enough for new pine saplings to become established, even though the stand as a whole was burning frequently. At the higher

TABLE 6. Comparison of fire history statistics (in years) among ponderosa pine forests in Arizona, New Mexico, northern Colorado, and the San Juan Mountains, Colorado.

Statistic	Central, southern Arizona†	Jemez Mountains, New Mexico‡	San Juan Mountains, Colorado§	Northern Front Range, Colorado‖
Median fire interval, all fires, all stands	1–8	3–16	5–29	···
Median fire interval for ≥10% scarred, all stands	3–12	6–23	7–39	···
MEI for ≥10% scarred, low elevation stands	3–14¶	6–20#	8–13††	12
MEI for ≥10% scarred, high elevation stands	3–9¶	7–24#	21–38	16–31

Note: MEI = Weibull Median Interval.
† Swetnam and Baisan (1996:21–22), 24 sites total.
‡ Touchan et al. (1996:39) and Swetnam and Baisan (1996:21–22).
§ This study.
‖ Veblen et al. (2000).
¶ Low elevation = 13 sites; high elevation = 11 sites.
# Low elevation = 8 sites; high elevation = 7 sites.
†† Excludes the anomalous SMI stand (see *Methods: Site selection*).

elevations, fire-free intervals were generally longer than at lower elevations, and most fires at higher elevation were extensive.

Our results also indicate longer fire-free intervals occur in sites having topographic barriers to fire spread, although our conclusions are tentative because we could only assess this for one site (SMI). The Weibull Median Interval value for extensive fires (≥25% of recorders scarred) in the lower elevation SMI site was 23 yr, compared with MEI values of 9–14 yr in all other lower elevation sites. Fire-scarred trees are often rare on steep slopes above cliffs and in other locations that appear to be somewhat protected from fire. Madany and West (1983) also documented very long fire-free intervals in a ponderosa pine forest located on a small, isolated mesa top in southern Utah. Additional research is required, however, on spatial patterns of individual fire events and the effects of local topographic variation on fire history in mountainous areas.

We found no compelling evidence of longer fire-free intervals in the generally wetter eastern portion of the San Juan Mountains. Of the lower elevation sites, MEI values for extensive fires (≥25% of recorder trees scarred) were 9 yr and 11 yr in the two western sites compared with 9 yr and 13 yr in the two eastern sites. For higher elevation sites, MEI values were 22 yr and 38 yr in two western sites compared with 22 yr in one eastern site. Conclusive evidence of a longitudinal gradient in fire regimes would require additional fire history sites peripherally located in the San Juan Mountains.

With which region is the San Juan Mountains fire regime more aligned?

Direct comparisons of fire history statistics from different studies are somewhat difficult because of differences in the statistics used, sampling intensity, and sizes of the study areas. Three recent compilations of fire history statistics from southern/central Arizona, northern New Mexico, and northern Colorado, however, allow cautious comparisons with the San Juan Mountains (Table 6). The statistics share similar characteristics with those from both northern Colorado and northern New Mexico. Median fire-free intervals from the Jemez Mountains of northwestern New Mexico, ~100 km to the south of our study area, are generally shorter except for the comparable range of values for the low elevation stands. MEI values from the northern Front Range for both lower and higher elevation sites correspond closely with our values from pure ponderosa pine and ponderosa pine–mixed conifer stands, respectively.

Fire-free intervals in the San Juan Mountains, therefore, are intermediate between those reported from Arizona and New Mexico and from northern Colorado. The reason for any differences is perhaps related to the different fuel complexes in the different areas. Most of the Arizona and New Mexico sites have understory dominated by grasses, which dry quickly and carry surface fire readily (predominantly the *Pinus ponderosa–Bouteloua gracilis* or *P. ponderosa–Festuca arizonica* habitat types; Alexander 1985). In contrast, shrubs are generally more important than grasses in the understory of pine forests in southwestern Colorado (the *Pinus ponderosa–Quercus gambelii* habitat type; Alexander 1985, Floyd-Hanna et al. 1996). The shrubs dry more slowly than do the grasses, and may generally support a slower rate of fire spread.

Did Native Americans influence pre-1880 fire regimes?

The TRS site is a well-documented prehistoric Ute encampment settlement where Native Americans may have augmented the natural fire frequency and altered the seasonality of past fires with intentionally set fires. However, measures of central tendency were all longer (6–11 yr) than at any of the other lower elevation ponderosa pine sites (4–8 yr) except the anomalous SMI site. This finding does not support the hypothesis that fire-free intervals would be shorter in an area where fire ignition was likely to be augmented by Native Americans. The TRS site, however, has both a lower proportion of dormant season fires (36%) and a higher percentage of late season fires (50%) than any of the other lower elevation sites. Augmentation of late season fires by Native American burning could result in fewer dormant season fires. Nonetheless, this result alone does not provide convincing evidence that Native American people were augmenting fire ignitions in the vicinity of their encampment at Turkey Springs. Our results, though limited to a single site, support the view that human ignitions were relatively unimportant in controlling fire history in the San Juan Mountains as a whole.

Conclusions

The fire regime of ponderosa pine forests in the southern San Juan Mountains currently exists outside its historical range of variability for fire frequency and extent. This suggests that future fires will be larger and more severe than previous fires because of the fuel that has accumulated during the anomalously long current fire-free interval. The pre-1880 fire regime exhibited substantial spatial and temporal variability. For example, stands at higher elevations and in proximity to topographic barriers to fire spread have had generally longer fire intervals, and fire intervals within individual stands varied from <5 yr to >30 yr. Very extensive fires occurred in past years and should be expected in the future. Past years of extensive fire generally were very dry years that followed two to three years of generally wetter conditions. Fires in the San Juan Mountains (and perhaps throughout much of the western United States) may have been directly impacted by significant changes in past climate on interdecadal time scales. We believe these changes were related to weakened El Niño-Southern Oscillation activity, an extended series of cool-phase Pacific Decadal Oscillation events, and weakened monsoonal moisture, all possibly entrained in an invasive air mass typical of locations that are more northerly. Many studies have firmly established that the climate of the 20th and 21st centuries is not comparable to climate during the 18th and 19th centuries due to human alterations of the atmosphere. Wildfires may not function or behave during the present and future as they did under pre-EuroAmerican environmental conditions due to the altered climate regimes. Finally, although Native American people undoubtedly ignited fires during the centuries before 1880, they apparently had a limited impact on the overall fire regime of the San Juan Mountains. Our findings indicate that fire frequency and extent prior to 1880 were controlled primarily by climatic influences.

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