Fire History in the Gallery Pine-Oak Forests and Adjacent Grasslands of the Chiricahua Mountains of Arizona[1]

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Abstract.—Many authors have speculated about presettlement fire frequencies in semidesert grasslands and the relative importance of fire in the ecology of these systems. Yet, lack of direct evidence (e.g. fire scars) has hampered attempts to reconstruct the role of fire in these areas. Tangible evidence, however, is available from fire-scarred pines in canyon-gallery forests of the Madrean Province that recorded surface fires spreading from adjacent grasslands and savannas. Given the highly dissected topography that typically separates canyons, it is likely that many fires spread primarily into and between canyons from the lower savanna/grasslands, as opposed to originating at higher elevations. Inter-canyon synchrony of fire dates would provide supporting evidence for this hypothesis. Conversely, asynchrony would suggest lack of fire spread between canyons. If true, fire frequencies recorded in these gallery forests should approximate the minimum fire frequencies sustained in the adjacent grasslands.

Fire intervals at the canyon sites range between 3.0 and 4.0 years, while the synchronous intercanyon intervals range between 7.4 and 8.1 years. The range of fire frequency in the semidesert grasslands, given our interpretations, falls approximately between the individual canyon site fire frequency of four years, and the intercanyon fire frequency of eight years.

INTRODUCTION

The Madrean Province is a biome of disjunct mountain islands that connect the Southwest Borderlands of Arizona and New Mexico to the Mexican states of Sonora and Chihuahua (See Fig. 1). A biophysical and sociopolitical corridor linking the Southern Rockies and the Northern Sierra Madres, the Madrean Province is an "archipelago" of conifer-topped mountain islands surrounded by a "shore" of evergreen oak woodlands and a "sea" of semidesert grasslands (Gehlbach 1981; Wilson 1995). In this province, fire is widely regarded as a fundamental ecosystem process, yet, knowledge of past fire regimes in the pine-oak forests, oak woodlands, and semidesert grasslands is relatively limited. For example, many authors have used indirect historical evidence to infer presettlement fire frequencies in woodlands, savannas, and grasslands (e.g., Bahre 1995a, 1985; Baisan 1990; Baisan and Swetnam 1990; Hastings and Turner 1965; Humphrey 1963, 1958, 1984; Leopold 1924; McPherson 1995; Swetnam and others 1992, 1989). However, these findings encompass a broad variety of conclusions due largely to a lack of direct quantitative evidence of the role of fire in these communities.

Lightning and fire records from the Coronado National Forest demonstrate that, although lightning ignitions concentrate on mountain peaks, they are not uncommon in the foothills and grasslands (Baisan 1990; Baisan and Swetnam 1990; Barrows 1978). Regardless of the point of origin, given low fuel moisture conditions, rapid fire spread, and topographic position, once fires enter the grasslands, they typically spread quickly over large areas. Newspa-

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per and historical accounts from the late 1800s, for example, refer to "millions of acres" of grasslands and woodlands burning between May and July (Bahre 1985, 1991; Humphrey 1958).

The ecosystem management initiative (USDA 1992, 1993a, 1993b) has sparked interest in the ecological role of fire in the grasslands, savannas, and woodlands and its eventual use to emulate presettlement forest conditions and to restore or sustain biodiversity and productivity (Allen 1994; Allen et al. 1995; Kaufmann and others 1994). Fire history information obtained in canyon-gallery forests, adjacent to the semidesert grasslands, will provide tangible evidence (i.e. fire-scar chronologies) of grassland fire frequencies to support the reintroduction of fire in these borderland ecosystems. The overall objective of this project is to reconstruct the fire histories for several pine-oak forest sites adjacent to semidesert grasslands. Although additional sampling is planned, six collections of fire-scarred samples were obtained from sites in Rhyolite, Pine, Turkey Creek, and Rucker Canyons in the western Chiricahua Mountains, McClure Canyon in the northeast Huachuca Mountains, and Caj n del Oso in the northern Sierra de los Ajos of Sonora, Mexico (Fig. 1).

Data from Pine and Rhyolite Canyons (Swetnam and others 1989, 1992) are presented here and compared to a higher elevation site at Rustler Park

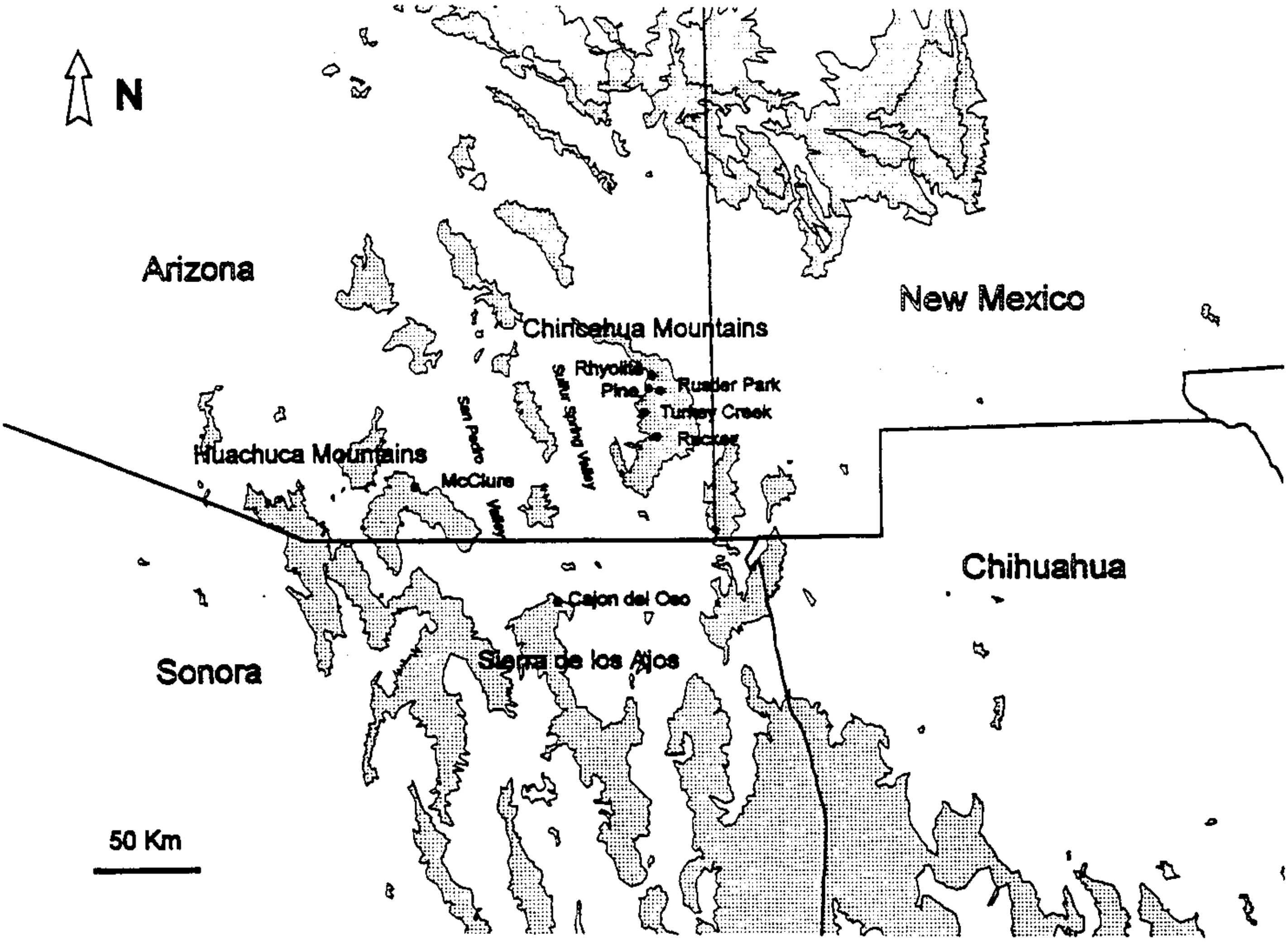

Figure 1. Madrean Province gallery-pine oak forest fire history reconstruction sites for the Southwest Borderlands project. Sites include Rhyolite, Pine, Turkey Creek, and Rucker Canyons within the Western Chiricahua Mountains, McClure Canyon at Fort Huachuca Military Reserve, and Cajón del Oso, in the Sierra Ajos, Sonora, Mexico. Map modified from Marshall (1957) by Bennet and Kunzmann (1992).

(Seklecki and others, this volume). We propose that fires recorded in these gallery forests provide strong evidence for the range of fire frequencies sustained by the adjacent grasslands. Given the highly dissected topography and the geomorphic and vegetative barriers separating these gallery forests, we hypothesize that fire spread primarily between canyons through the lower savanna/grasslands, as opposed to having spread from higher elevations. Intercanyon synchrony of fire dates would support this hypothesis and therefore historical fire frequencies in gallery forests provide a conservative (i.e., minimum) estimate of fire frequencies sustained in the lower semidesert grasslands.

HISTORICAL ECOLOGY

The rich cultural history of this region in context with fire reconstructions, in some cases, may account for anomalous patterns in past fire regimes. Fire histories in the Southwest, as a whole, show close association to regional climate reconstructions (Swetnam 1990; Swetnam and Baisan 1995) although individual sites occasionally exhibit unique fire patterns and characteristics attributable in some cases to anthropogenic effects (Baisan and Swetnam 1995). Early historic Amerind cultures that inhabited this region include the Sobaipuri (Pima), and later the Suma, Concho, Janos, Jacomes, Manos, and Apache (Bolton 1919; DiPeso 1929; Forbes 1966, Opler 1941, 1969). The Chiricahua Apache, the southern-most Athabascan group of hunters and gatherers, entered the province by at least the late 1600s (Aschmann 1956; Bolton 1967; Worcestor 1979) and raiding and warfare tradition resulted in conflict with Sobaipuri, then Spanish, Mexican, and later American regiments (Basso 1971; Castetter and Opler 1936; Naylor and Polzer 1986). Traditional use of fire by Apaches is suggested as a possible cause of anomalous fire patterns seen in certain locations of the borderlands area (Morino 1996; Seklecki and others, this volume).

Most historic ethnographic accounts of anthropogenic fire use in the Southwest Borderlands correspond with wartime periods (Bartlett 1954; Bourke 1887/88; Cole 1988; Sweeney 1991). These tentative wartime periods (late 1600s, 1748-1786, and 1831-1872) coincide with intervals of above average fire frequencies in the Chiricahua Mountains that may be associated with warfare tactics carried out by, and perhaps against the Chiricahua Apache (Kaib and others 1996). The temporal and spatial influence of anthropogenic-enhanced fire regimes may be inferred through historic ethnographic accounts, together with climate and fire histories, fire-scar seasonality, and through the spatial analysis of such patterns. The scale of anthropogenic fire influence will be the topic of future work in this region.

Although the Apaches led by Geronimo did not surrender until 1886, the relocation of the Chiricahua Apaches from their reservation in the Chiricahua Mountains to San Carlos in 1876 marks the beginning of widespread colonization in the Southwest Borderlands by Euroamericans. Intrepid pioneers migrated with mixed herds of livestock, and by the late 1870s, ranching, mining, fuelwood cutting, and logging all contributed to the local economy. By 1880 the numerous ranches in Sulphur Spring Valley contained an estimated eighteen thousand cattle (Bailey 1994; Wagoner 1952, 1961). The completion of the Southern Pacific Railroad in 1881 led to rapid immigration by ranchers with herds of thousands of cattle attracted to the lucrative grasslands and open ranges of Arizona (Wagoner 1961).

Early descriptions of the semidesert grasslands can provide useful information on the past form and function of fires in these systems. In his journals from the Southwest Borderland Apache campaigns in the 1880s, Captain John Bourke boasts: "as for the grasses one has only to say what kind he wants, and lo! It is at his feet—from the coarse sacaton which is deadly to animals except when it is very green and tender; the dainty mesquite, the bunch, and the white and black gramma, succulent and nutritious..... I must say, too, that the wild grasses of Arizona always seemed to me to have but slight root in the soil, and my observation is that the presence of herds of cattle soon tears them up and leaves the land bare" (Bourke 1891/1971, p. 140). Bourke witnessed the land degradation that followed the overstocking of the common-held rangelands in the 1880s (Bahre 1991; Hastings 1959).

Thirty years earlier, John Bartlett recorded fire effects on mesquite in his borderlands "explorations and incidents" (1850-1853, p. 75): "Where the prairies are frequently burned over, the tree is reduced to a shrubby state, a great number of small branches proceeding from one root, which goes on developing and attains a great size...... These roots , dug up and dried, are highly prized for fire-wood." Bartlett (1850-

1853, p. 75, 186, 344) notes on several occasions "the scarcity of firewood" in the semidesert grasslands and their dependence on mesquite roots for fuel. In the past mesquite was uncommon due to frequent fires, although present conditions are different, and in places of the San Simon, Sulphur Spring and San Pedro Valleys, large mesquite thickets are not uncommon (Bahre 1995b; Buffington and Herbel 1965; Hastings 1959). Although fires in settlement days were common, their effects were short lived and often beneficial as illustrated by this report in the Arizona Daily Star, Sept. 2, 1880: ...the grass over areas that were burned over this season is now knee high and looks as fresh as spring time in this locality [Patagonia]....(Bahre 1991).

The rapid rise in mining, logging, and primarily the livestock industry in the 1880s, all contributed to the landscape fragmentation and disruption of fuel continuity which severely limited fire spread (Bahre 1995a). The frequent surface fires which these grasslands and forests had sustained for several centuries, as illustrated by our fire history reconstructions (see fig. 2 and 3), were no longer recorded by pine trees following this period. Subsequent fire suppression policies (Swetnam and Baisan this volume) further altered the character and function of fire in these ecosystems (Baisan and Swetnam 1994; Leopold 1924; Marshall 1962). A century of fire exclusion has resulted in a dramatic transformation in ecosystem structure (Cooper 1960; Weaver 1951; Marshal 1957, 1963), and a concurrent shift from frequent surface toward infrequent uncontrollable stand replacing fires. The benign fires which commonly swept across this region, following a century of fuel accumulation, are now different in nature (i.e. 1994 Rattlesnake Burn, Chiricahua Mountains) and likely outside the natural range of fire regime variation.

SITE DESCRIPTION

Rhyolite and Pine Canyons are two of several intermittent stream systems that drain the western slopes of the Chiricahua Mountains. Ephemeral streamflow, perennial baseflow, topographic sheltering from wind and sun, and cold air drainage all contribute to the relatively mesic conditions that harbor these unique gallery pine-oak forests. Major plant associations found dispersed throughout these rhyolitic canyons include pine-oak forest, southwest riparian deciduous forest, madrean oak woodland, interior chaparral, plains grassland, and semidesert grassland (Brown 1982; Brown and Lowe 1980; Marshall 1957; McClaran 1995; Wallmo 1955). These canyon-gallery forests occupy a topographic niche (1800 - 2500 meters) between the lower oak woodlands and semidesert grasslands and the upper ponderosa pine forests. Major tree species found at the canyon sites include; Apache pine (*Pinus engelmannii*), Chihuahua pine (*P. leiophylla var. chihuahuana*), Arizona pine (*P. Ponderosa var. arizonica*), border pinyon (*P. discolor*), Douglas-fir (*Pseudotsuga menziesii*), Arizona madrone (*Arbutus arizonica*), Arizona cypress (*Cupressus arizonica*), alligator-bark juniper (*Juniperus deppeana*), Arizona sycamore (*Plantanus wrightii*), Arizona walnut (*Juglans major*), silver-leaf oak (*Quercus hypoleucoides*), Arizona white oak (*Q. arizonica*), Emory oak (*Q. emoryi*), and netleaf oak (*Q. rugosa*; Barton 1994; Bennett and others, in Prep; Reeves 1976).

METHODS

Partial and full cross sections from fire-scarred Apache and Arizona pine stumps and logs were obtained using a chain saw along a 600 meter elevation gradient in Pine Canyon. All samples were finely polished with a belt sander, then used to reconstruct a multi-century fire history (Arno and Sneck 1977; Dieterich 1980, 1983; Dieterich and Swetnam 1984; Weaver 1951) using dendrochronological (tree-ring dating) methods (Stokes and Smiley 1968; Swetnam and others 1985). Using statistical and graphical analyses (Grissino-Mayer 1994) we compared the Pine Canyon fire history reconstruction with one developed for Rhyolite Canyon in Chiricahua National Monument (Swetnam and others 1989; 1992), and one developed for a higher elevation ponderosa pine/mixed conifer site at Rustler Park (Seklecki and others, this volume). The period 1700 through 1876 was chosen for analyses, because adequate 18th century sample depth (fire-scarred tree numbers) existed for all sites and 1876 was the last fire event recorded at Pine Canyon (see fig 2 and 3). The 1700-1876 period was analyzed for all fires recorded and all fire dates recorded by two or more trees.

The mean and median fire intervals are considered best measures of central tendency in symmetric

Pine Canyon, Chiricahua Mountains, Master Fire Chronology

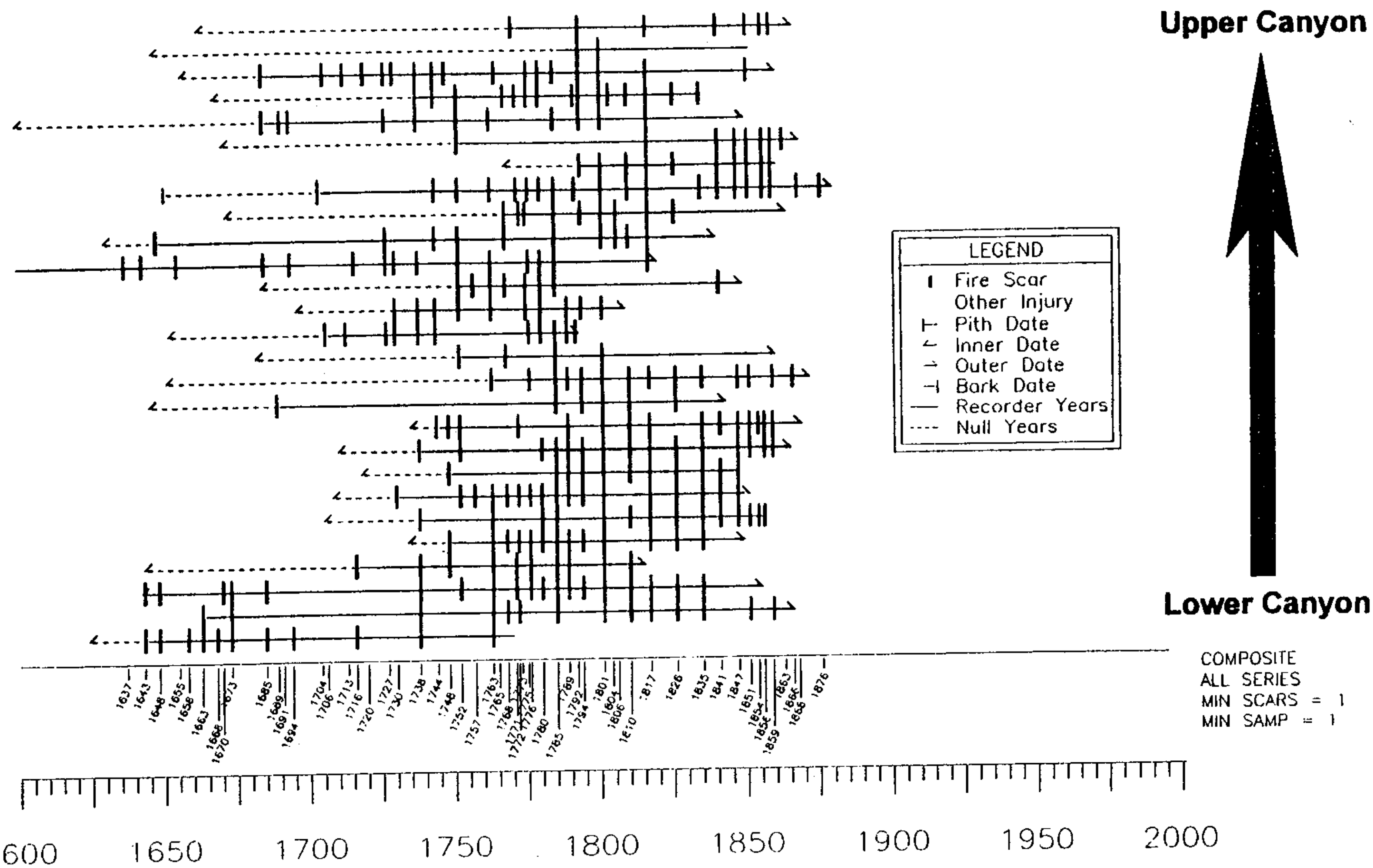

Figure 2. Master fire chronology for Pine Canyon. Horizontal lines represent information from individual trees while vertical bars represent dated fire events (scars).

Rhyolite Canyon, Chiricahua National Monument, Master Fire Chronology

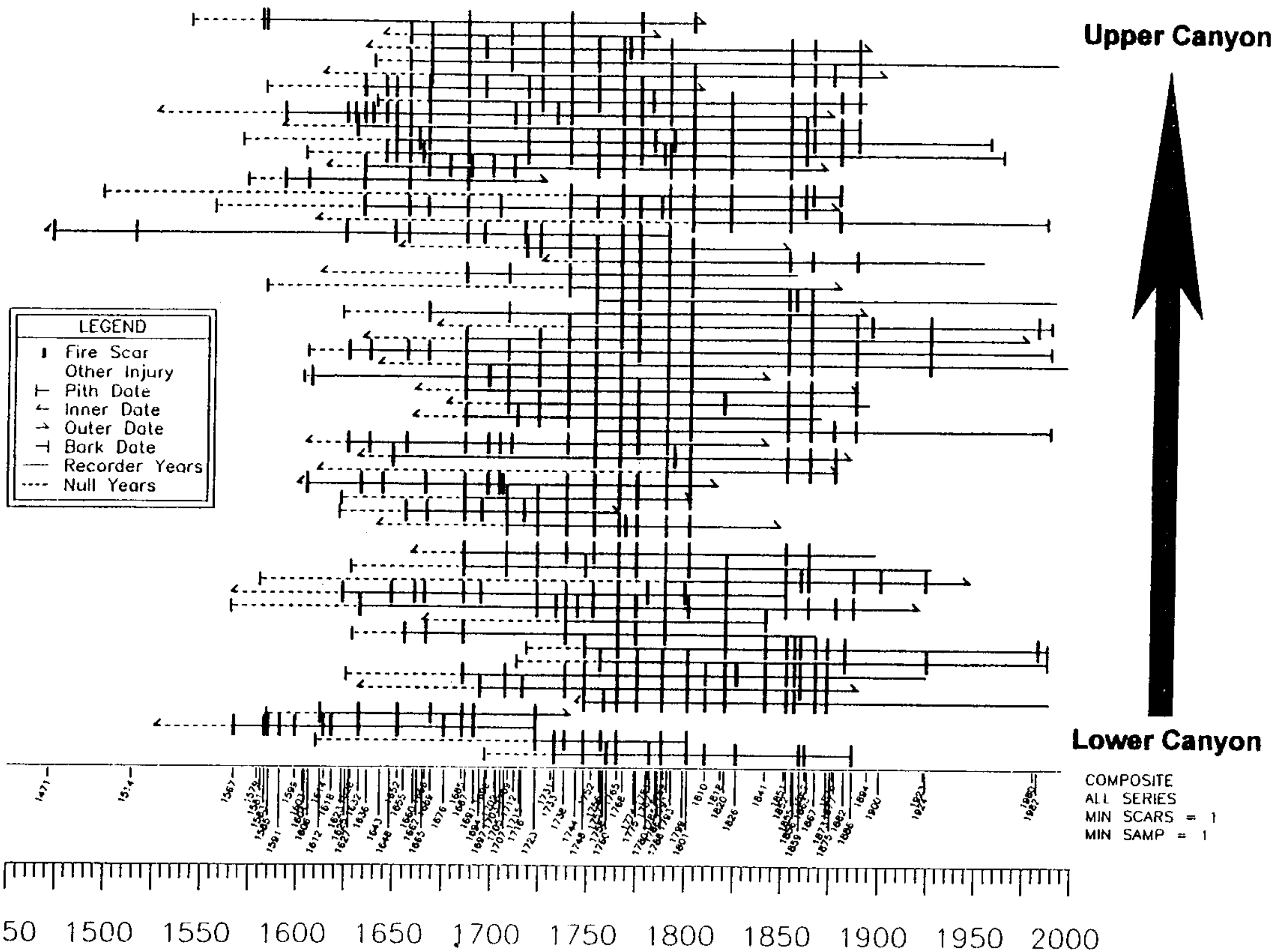

Figure 3. Master fire chronology for Rhyolite Canyon. Horizontal lines represent information from individual trees while vertical bars represent dated fire events (scars).

distributions while the Weibull median probability interval (WMPI; Grissino-Mayer 1995; Weibull 1951) is considered a more robust measure for non-normal distributions. As fire interval data are typically positively skewed, the WMPI is considered a more robust measure of central tendency in fire interval distributions (Grissino-Mayer 1995). Our estimates of fire frequency are based on the least conservative measures of central tendency (i.e. all fires recorded and smallest WMPI) due to the limited samples available at these sites, and the possibility, that all fires were not recorded by sample collections.

All sites were analyzed for spatial patterns of past fire and non-fire event association using a 2 x 2 chi-squared test and Yule similarity index (Grissino-Mayer 1995; Swetnam 1993). The 2 x 2 chi-squared test (Ludwig and Reynolds 1988) is used to test association between two sets of binary data (+,- ; presence, absence) based on four cells (++, +-, -+,—). The 2 x 2 test is analogous to a two coin toss under the null hypothesis that the pattern of fire and non-fire years is statistically independent between sites (Grissino-Mayer 1995). The Yule index (Hubalek 1982) is a measure of association between two sets of binary data and ranges from 0.0 at minimum association to 1.0 at maximum association, with values below 0.5 having little statistical association and those above having proportionately greater association.

RESULTS

A fire history reconstruction was compiled for each canyon site and for the common intercanyon fire dates (Fig 2, 3, and 4). Comparison of fire history reconstructions, fire frequency, and descriptive statistics (Fig 2, 3, and 4; Table 1) reveal that the higher elevation Rustler Park site sustained more frequent fire than the canyon sites. This is not surprising as the Rustler Park site is situated at the mountain crest and accessible to fire spreading from numerous corridors on both sides of the mountain. Between 1700 and 1876, 30 out of 73 fire years (41 percent) were synchronous between Pine Canyon and Rustler Park (separated by 4.8 km). However, only 28 out of 83 fire years (34 percent) were synchronous between Rhyolite Canyon and Rustler Park (12.8 km), while only 21 out of 71 fire years (30 percent) were synchronous between Rhyolite and Pine Canyons (6.4 km). Al-

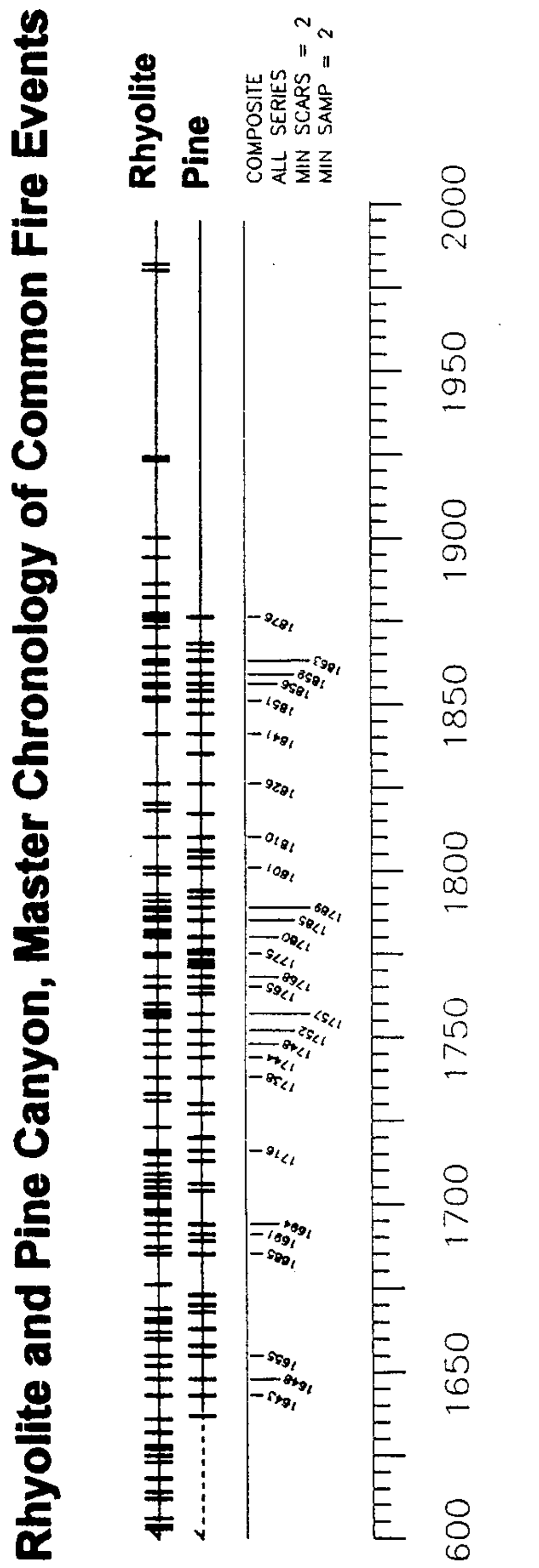

Figure 4. Composite fire chronology of fire-scar dates held in common by Pine and Rhyolite Canyons and interpreted to be grassland-spread fires. Horizontal lines represent fire composites from individual canyons while vertical bars represent the aggregate of fire dates from each site.

Table 1. Descriptive fire statistics for Rhyolite Canyon, Pine Canyon, paired canyons, and Rustler Park sites between 1700 - 1876 for all fire dates, and fire dates recorded by two or more trees. The paired analyses includes the common Pine and Rhyolite fire events.

All Fire Dates Recorded	Pine	Rhyolite	Paired	Rustler
Total Fire Dates	42	50	70	61
Mean Fire Interval (yrs.)	4.2	3.6	2.5	2.9
Median Fire Interval (yrs.)	4.0	3.0	2.0	2.5
Weibull Median Probability Interval (yrs.)	4.0	3.0	2.2	2.7
Interval Range (yrs.)	1-9	1-15	1-9	1-16

Fire Dates Recorded by > 2 Trees	Pine	Rhyolite	Paired	Rustler
Total Fire Dates	33	29	20	50
Mean Fire Interval (yrs.)	4.8	6.2	8.0	3.4
Median Fire Interval (yrs.)	4.0	5.5	5.5	3.0
Weibull Median Probability Interval (yrs.)	4.6	5.6	7.4	3.2
Interval Range (yrs.)	1-11	1-15	3-22	1-16

though only 16 out of 90 fire years (18 percent) were synchronous between all three sites, of the 21 fires years in common between Pine and Rhyolite Can 16 were also common to Rustler Park (81 percent). This suggests that a high portion of the common intercanyon fires (fires which likely spread between the canyons through the grasslands) also spread to Rustler Park, and we would likewise infer these to be larger-scale fire events. These large fire years are well represented in the paired-canyon fire chronology (Fig. 4).

Values for the WMPI range between 3.0 and 4.0 years for all fire dates recorded, and between 4.6 and 5.6 years for all fire dates recorded by two or more trees (Table 1). Because of numerous potential barriers to fire spread at the canyon heads, and in surrounding uplands, we interpret synchronous intercanyon fire-scar dates as fires that most likely spread between the canyons through adjacent grasslands. Therefore, the common intercanyon fire reconstruction provides a reasonable estimate of the temporal patterns of semidesert grassland fires over several centuries (Fig. 4). The common intercanyon values for the WMPI range between 7.4 and 8.1 years for all fire dates recorded by two or more trees (Table 1). Therefore, a conservative estimate of intercanyon fire frequency (i.e., grassland spread) would be 8 years. The range of fire frequency in the semidesert grasslands, given our interpretations, should fall approximately between the individual canyon site fire frequency of 4 years, and the intercanyon fire frequency of 8 years (Table 1). Hence this data suggest a fire frequency in these semidesert grasslands on the order of 4 to 9 years. Because limited fire-scarred samples are preserved in these gallery forests, portions of the multi-century record are incomplete resulting in a conservative estimate of fire frequency. It is possible that the semidesert grassland fire frequency is closer to the shorter estimate of 4 years.

All chi-squared tests were significant ($p < .005$) between the sites (Table 2). Therefore, we conclude that the patterns of fire and non-fire years were not statistically independent between sites. This is not surprising considering the relative proximity between sites, the potential for intercanyon fire spread, and the influence of regional climate. The values of the Yule index further illustrate the degree of association between sites (Table 2).

Table 2. Chi-squared (2 x 2) paired testing of synchronous fire and non-fire events between three sites in the Chiricahua Mountain. All tests were significant ($p < .005$).

Sites for period 1700 - 1876		Rhyolite	Rustler Park
Pine	2 x 2 chi-squared	12.85	33.31
	Yule Index	0.64	0.72
Rustler Park	2 x 2 chi-squared	14.31	—
	Yule Index	.64	—

CONCLUSIONS

The range of fire frequency in the semidesert grasslands falls approximately between the individual canyon site fire frequency of four years, and the intercanyon fire frequency of eight years. Because these multi-century fire reconstructions represent a conservative estimate of fire frequency, we believe that the semidesert grassland fire frequency is probably closer to the shorter estimate of 4 years.

Reconstructed fire histories in the gallery-pine oak forests of Rhyolite and Pine Canyons provide multi-century illustrations of the fire regime patterns in these canyon systems. Additionally they provide evidence of fire frequencies sustained in the adjacent semidesert grasslands. Through the 1600s, 1700s, and 1800s, fires in these canyon forests, and probably also the adjacent grasslands, burned on the order of once every four to eight years. Although we attribute intercanyon fire synchrony to grassland fire spread we would expect some degree of fire synchroneity due to regional climate influence (Swetnam and Baisan 1995). The influence and scale of regional climate-, anthropogenic-, and grassland-fire effects can be estimated through rigorous analysis of previously developed and forthcoming fire chronologies in the Southwest Borderlands, and will be the ambition of future work. Additional chronologies, presently being developed in the Southwest Borderlands, will substantially expand the spatial inference of fire size and spread, and increase our understanding of fires role in these areas. This knowledge will provide land managers in the Borderlands region with three centuries of fire-regime patterns across several vegetation zones for use in education, guidance, and support in fire planning.

This research illustrates the essential function and character of fire, and the changes associated with its removal from these systems. Prescribed fires provide a viable ecological and economical tool that can be used to bring these systems back to presettlement conditions while concomitantly sustaining diversity and productivity. Although, before natural fire conditions can be emulated, planned small scale stand-replacement burns, fall and early spring burns, and various fuel management options should be considered to initially break the forest homogeneity, reduce catastrophic fire risk, and to ultimately restore these systems to a more productive, diverse, and sustainable state.

Future borderland fire history research will increase our knowledge and understanding of fire size and frequencies sustained by the pine-oak forests and lower semidesert grasslands in this region. Crossborder comparisons of fire histories will allow for evaluation of the effects of land use patterns, such as livestock grazing, logging, fuelwood harvesting, and fire suppression, on landscape fire patterns (Savage and Swetnam 1990; Touchan and others 1995). These findings will be directly useful for planning fire management programs aimed to restore fire to these ecosystems at intervals and seasons appropriate for maintaining biological productivity and diversity (Swetnam and Baisan, this volume). Additionally, they will provide managers with information for characterizing the presettlement "range of variability" of fire frequency for these unique systems across local to regional scales (Allen 1994; King 1995; Morgan and others 1994; Swanson and others 1994).

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