Fire history on a desert mountain range: Rincon Mountain Wilderness, Arizona, U.S.A.

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Modern fire records and fire-scarred remnant material collected from logs, snags, and stumps were used to reconstruct and analyze fire history in the mixed-conifer and pine forest above 2300 m within the Rincon Mountain Wilderness of Saguaro National Monument, Arizona, United States. Cross-dating of the remnant material allowed dating of fire events to the calendar year. Estimates of seasonal occurrence were compiled for larger fires. It was determined that the fire regime was dominated by large scale (>200 ha), early-season (May–July) surface fires. The mean fire interval over the Mica Mountain study area for the period 1657–1893 was 6.1 years with a range of 1–13 years for larger fires. The mean fire interval for the mixed-conifer forest type (1748–1886) was 9.9 years with a range of 3–19 years. Thirty-five major fire years between 1700 and 1900 were compared with a tree-ring reconstruction of the Palmer drought severity index (PDSI). Mean July PDSI for 2 years prior to fires was higher (wetter) than average, while mean fire year PDSI was near average. This 490-year record of fire occurrence demonstrates the value of high-resolution (annual and seasonal) tree-ring analyses for documenting and interpreting temporal and spatial patterns of past fire regimes.

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Les archives existantes au sujet des feux et les vestiges de bois calciné prélevés sur des billes, des chicots et des souches furent utilisés pour reconstruire et analyser l'histoire des feux dans la forêt mixte de conifère et de pin située au-dessus de 2300 m dans le Rincon Mountain Wilderness du Saguaro National Monument en Arizona, aux États Unis. Le datage comparé des vestiges de bois calciné a permis de déterminer l'année des feux. Les feux importants ont été compilés en tenant compte du moment de la saison où ils sont vraisemblablement survenus. On a déterminé que le régime des feux était dominé par des feux de surface de grande étendue (>200 ha) qui survenaient au début de la saison (mai à juillet). L'intervalle moyen entre les feux dans la zone d'étude du mont Mica pour la période de 1657 à 1893 était de 6,1 ans, avec un écart de 1 à 13 ans, pour les feux plus importants. L'intervalle moyen entre les feux dans la forêt mixte de conifère (1748 à 1886) était de 9,9 ans avec un écart de 3 à 19 ans. Trente-cinq années où sont survenus des feux importants entre 1700 et 1900 ont été comparées à l'indice de sévérité de la sécheresse de Palmer reconstruit à partir des cernes annuels. L'indice moyen de juillet pour les 2 années qui précédaient les feux était plus élevé (plus humide) que la moyenne tandis que l'indice moyen de l'année du feu était près de la moyenne. Ces données sur les feux pour une période de 490 ans montrent qu'il est important d'analyser les cernes annuels avec une grande précision (annuelle et saisonnière) pour documenter et interpréter les patrons temporels et spaciaux des régimes de feux passés.

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Introduction

The role of periodic fire in forest stands has been studied throughout western North America by examination of basal fire scars on a variety of tree species (Weaver 1951; Kilgore and Taylor 1979; Ahlstrand 1980; Madany 1981; Dieterich 1983; Swetnam and Dieterich 1985; McClaran 1988). Such studies, as well as examinations of stand structure and establishment patterns (Cooper 1960, 1961; White 1985; Pitcher 1987), provide baseline knowledge concerning the ecological role of lightning fire. However, fire regimes vary regionally and may also vary within a limited geographic area owing to changes in elevation and aspect. Therefore, site-specific studies are often necessary to determine local patterns of fire occurrence and their relationship to site ecology. Fire histories derived from fire scars may provide such information. However, the mandate of natural areas to minimize human impacts often limits or precludes the sampling techniques usually employed in fire history studies (e.g., felling or removing partial sections from live trees).

With the use of cross-dating techniques (Stokes and Smiley 1968) this study was able to rely almost entirely on the analysis of remnant (dead) material to reconstruct the local fire regime. This sampling strategy minimized the impact on living trees and allowed reconstruction over a maximum period of time.

Barrett and Arno (1988) and Sheppard et al. (1988) have discussed the use of increment cores as a nondestructive sampling technique for dating of fire scars; however, this technique is most appropriate for determining the dates of single events that occur infrequently (Sheppard et al. 1988). It is not suitable for deriving accurate fire dates in sites with high frequency fire regimes where multiple scarring of stems is common. Use of complete cross sections or wedge sections allows a more thorough analysis of a fire scar sequence and is generally a preferable means of sampling (Barrett and Arno 1988).

Sampling of remnant material is an attractive alternative, or supplement, to the use of samples from living trees at sites where cross dating is possible. However, remnant material, which may contain ancient records, is an ever diminishing resource with a "life-span" limited by the processes of natural decay, and endangered by wildfire and prescribed burning programs (Stokes and Dieterich 1980; VanPelt and Swetnam 1990).

In addition to the need for site-specific information, knowledge of past trends in fire occurrence may contribute to a better understanding of fire–climate interactions. Fur-

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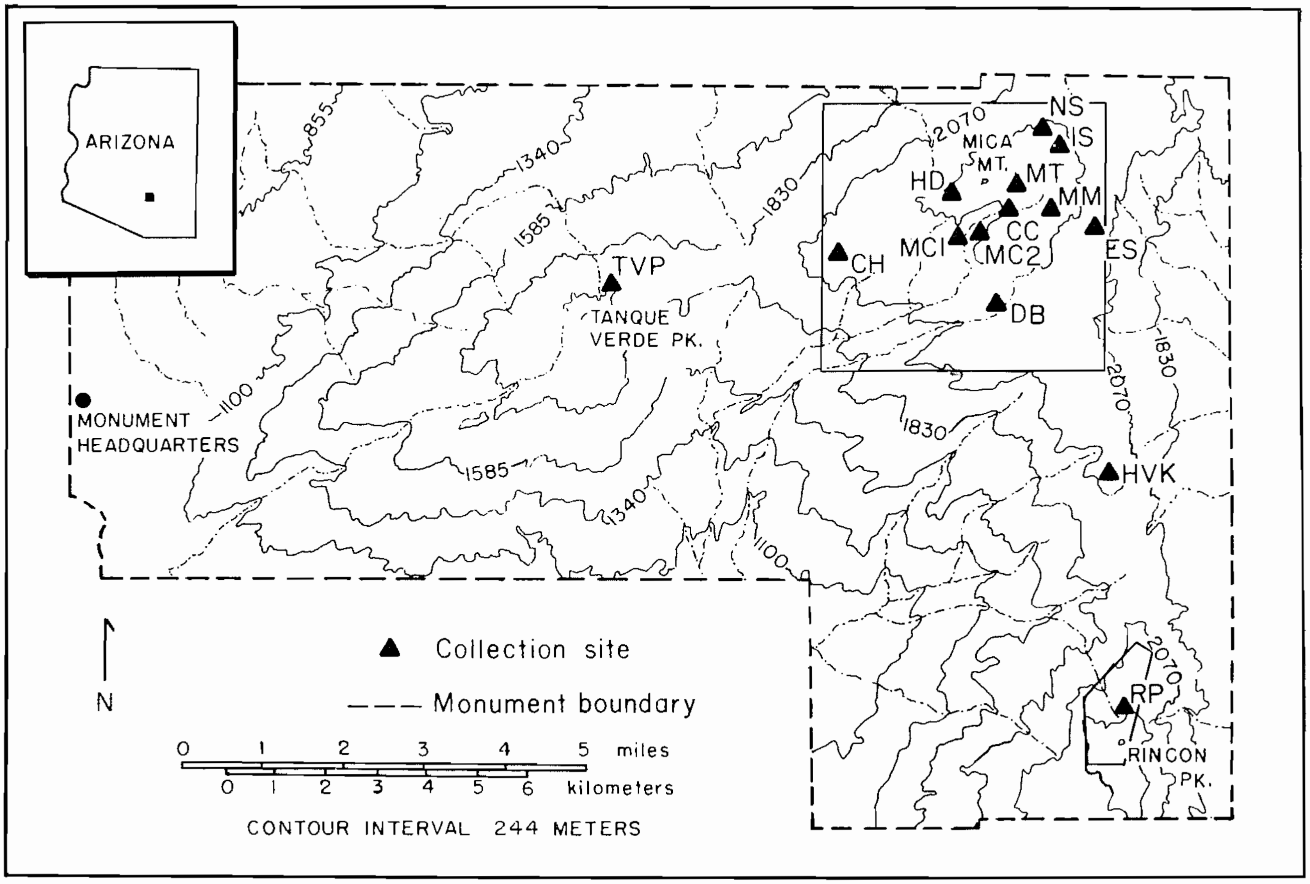

FIG. 1. Map of the Rincon Mountain Unit of Saguaro National Monument. Mica Mountain study area and Rincon Peak collection site are outlined. Collection sites are designated by a two or three character code (see text for explanation).

thermore, information from accurately dated site fire histories may be combined to extract a regional signal which can be analyzed for associations with climate on a regional scale (Swetnam 1990).

This study combined information derived from modern fire records, analysis of fire scars, and historical accounts to reconstruct fire history of the montane zone in the Rincon Mountains over the last 490 years. The reconstruction includes estimates of fire intervals, minimum size, seasonal timing, and comparison with a tree-ring reconstruction of regional drought.

Site description

The Rincon Mountains

The Rincon Mountain Unit of Saguaro National Monument encompasses 25 000 ha, including the main mass of the Rincon Mountains, Tanque Verde Ridge, and the alluvial slopes surrounding the monument headquarters (Fig. 1). The area is within the basin and range province of southern Arizona.

The lower reaches of the monument, dominated by saguaro cacti (*Carnegiea gigantea* (Engelm.) Britt. & Rose) and several species of desert trees and shrubs, are within the Sonoran desert scrub vegetation zone. From the desert floor the mountains ascend to over 2600 m at Mica Mountain, and just under 2600 m at Rincon Peak. Elevations above 2300 m support mixed-conifer timber or open pine forest, depending on aspect. Stands vary from closed canopy with dense understory to relatively open conditions on the drier slopes (Bowers and McLaughlin 1987). There are few topographic barriers to fire spread. Those that do exist are of limited extent, consisting mainly of large rock faces and rocky outcrops. Drainage bottoms are often dry and covered with litter.

Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *glauca* (Beissn.) Franco) and white fir (*Abies concolor* (Gord. & Glend.) Lindl.) communities dominate cooler north- and northeast-facing slopes, while northwest-facing slopes support a mixed community, including Gambel oak (*Quercus gambelii* Nutt.), southwestern white pine (*Pinus strobiformis* Engelm.), ponderosa pine (*Pinus ponderosa* Dougl. ex Lawson, var. *arizonica* (Engelm.) Shaw and var. *scopulorum* Engelm.), and Douglas-fir. A few scattered stands of aspen (*Populus tremuloides* Michx.) are also present. South-facing slopes support moderately xeric pine communities of varying composition with various evergreen oak species playing a larger role at lower elevations. Typical species include arizona white oak (*Q. arizonica* Sarg.), emory oak (*Q. emoryi* Torr.), and silverleaf oak (*Q. hypoleucoides* Camus). Considerable area near the summit of Mica Mountain supports open stands of pine (*P. strobiformis* and *P. ponderosa*) with grassy understory punctuated by a number of open meadows. Widespread grass species include pine dropseed (*Blepharoneuron tricholepsis* (Torr.) Nash), arizona wheatgrass (*Elymus arizonicus* (Scribn. & Sm.) Gould), mountain June grass (*Koeleria cristata* (L.) Pers.), screwleaf muhly (*Muhlenbergia virescens* (H.B.K.) Kunth),

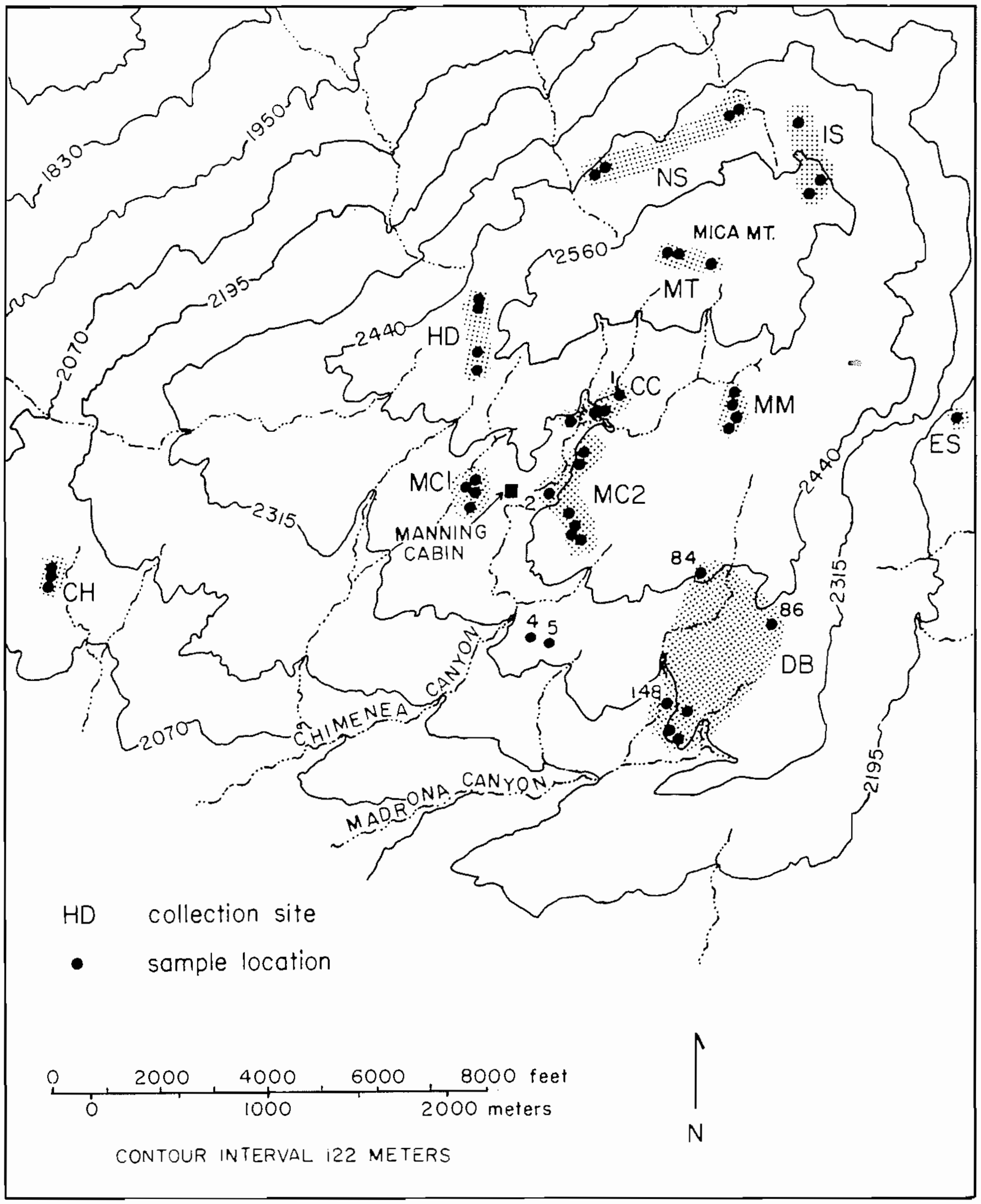

FIG. 2. Map of the Mica Mountain study area with the location of sample trees (dots) and groups (stippled). Sample trees from the 1983 study are noted by their National Park Service identification number.

and a needlegrass (*Stipa pringlei* Scribn.). Shrubs such as buckbrush (*Ceanothis fendleri* Gray) and mountain spray (*Holodiscus dumosa* (Nutt.) Heller) are also abundant. Owing to the nearly ubiquitous presence of southwestern white pine, this forest type will subsequently be referred to as open pine forest, as distinguished from the more typical southwestern ponderosa pine forest.

Average annual precipitation varies with elevation from 330 mm at Monument headquarters to 760 mm near the summit of Mica Mountain (Bowers and McLaughlin 1987). A snow pack often develops above 2100 m, with considerable accumulation on north-facing slopes.

The basin and range province of southern Arizona has a bimodal precipitation regime with maxima during the monsoon season in July and August and the winter months of December and January (Hastings and Turner 1965).

Fire-scarred specimens were collected from Rincon Peak, Tanque Verde Peak, and Happy Valley Knoll as well as from Mica Mountain. However, this analysis focuses on the fire regime of Mica Mountain above 2300 m (Fig. 2), as the most complete collection of samples was obtained within this approximately 1600-ha area.

Methods

Modern fire records and historical research

Saguaro National Monument has maintained fire records within the monument boundaries since 1937. These records include date, size, location, fuel type, and a narrative description of the larger fires. Barrows (1978) analyzed fire occurrence for the United States Forest Service Region 3 (Arizona and New Mexico) for the period 1960–1974. These two sources were used to examine fire occurrence during the modern period. Additionally, a literature search was conducted to locate references to fire occurrence in the Rincon Mountains.

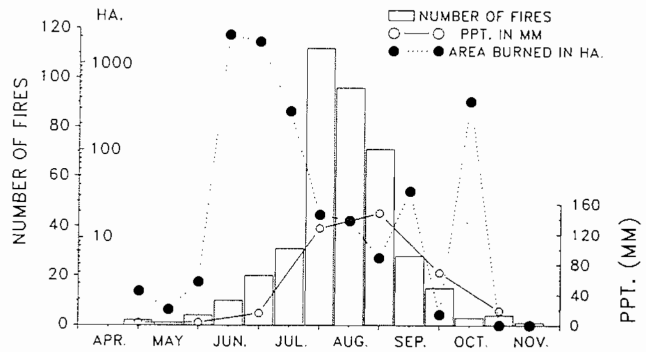

FIG. 3. Mean total monthly precipitation (PPT.) on Mica Mountain during the fire season versus the number of lightning fires and area burned from 1937 to 1986. Number of fires and area burned are cumulative totals by 2-week periods. Note log scale for area burned.

Dendrochronology

Fire-scarred samples were selected from 13 subsites to attain broad spatial coverage, including a range of aspect and plant associations (Arno and Sneck 1977). Samples were collected in clusters, whenever possible, as individual trees rarely record every fire that burns within their vicinity and scar preservation may be poor on older specimens (Arno and Sneck 1977; Kilgore and Taylor 1979).

Although some remnants (logs, snags, or stumps) had been dead only a few years, effort was made to locate specimens of greater antiquity as evidenced by the amount of weathering and erosion of sapwood. As an alternative to felling some snags, wedge sections were removed from the face of the scar as described by Arno and Sneck (1977). Sampled trees included 25 ponderosa pine, 20 southwestern white pine, and one silverleaf oak. Wedge samples collected from seven living trees in 1983 by National Park Service scientists were also used.

A belt sander was used to prepare samples for analysis. A series of progressively finer abrasive belts (to 400 grit where necessary) were used to prepare the surface so that cellular structure was clearly visible. Sanding direction was changed 90° with each new grit to completely remove scratches left by the previous grit. A finely prepared surface was essential to accurately assess the year and season of scarring and enable accurate cross dating. A binocular microscope (×7–30 variable power) was used to examine the samples.

An increment borer was used to extract cores from living trees at selected sites within the study area. These cores were used to develop a control chronology as an aid in dating the remnant material for which the outside or "bark" date was unknown (Douglass 1941; Stokes and Smiley 1968). Ring-width skeleton plots from the fire-scarred samples were cross-dated using the master chronology developed from the living trees. The fire scar dates were assembled into a master fire chronology by combining individual tree records into group chronologies. The dates arrived at for the samples were checked by another dendrochronologist to ensure accuracy.

A major fire is defined here as a fire recorded by more than one group of trees, with an estimated minimum size of 200 ha, based on the average distance between collection sites. Fires recorded by only a single group were excluded when determining the mean fire interval (MFI) for the study area as a whole. Fire return intervals (FRI) for a point or group of trees include all fires recorded by that group (Romme 1980).

Drought

A tree-ring reconstruction (Stockton and Meko 1975) of the Palmer drought severity index or PDSI (Palmer 1965) for July was used to examine the relationship between fire occurrence in the Rincon Mountains and regional drought. The portion of this reconstruction for a region including southern Arizona, southern New Mexico, and northern Chihuahua and Sonora was used for the comparison. July PDSI was deemed appropriate for comparison to fire occurrence as the index takes into account the water budget of the previous several months. Therefore, it provides an indication of the burning conditions (including fuel and soil moisture) prevailing during the fire season, which typically extends from May through July.

Seasonality

Additional information concerning local and regional variations in fire regime can be determined from the position of fire scars within the annual ring (Weaver 1951; Ahlstrand 1980; Barrett 1981; Dieterich and Swetnam 1984). A compilation of the relative position of many scars can reveal seasonal patterns of fire occurrence at a given site. Since the seasonal timing of fires may have important effects on patterns of plant establishment and mortality, this information may be useful in the historical analysis of plant community dynamics. Seasonal information combined with fire interval data may also be used in designing prescribed burning programs that simulate natural burning patterns.

Individual fire scars were examined and relative positions of scars within rings were recorded. When both sides of a fire-scarred stem recorded a fire date, both scars were examined and a single value was recorded.

Phenological information for ponderosa pine growing on a nearby mountain range (Fritts 1976) was used for estimating the seasonal timing of fire injuries. In addition, scars resulting from fires of known calendar date were examined in an attempt to refine the estimates developed.

Few specifics are known concerning the cambial phenology of southwestern white pine. MacDougal and Shreve (1924) suggest that it begins stem enlargement within a week of ponderosa pine growing on the same site, but has a shorter overall growing season. It was assumed to be comparable to ponderosa pine for the purposes of this analysis.

Six seasonal categories for fire scars were established: D, dormant season (appearing between growth rings); EE, early earlywood (first one third of earlywood); E, generic earlywood, no further distinction possible; ME, mid-earlywood (second one third); LE, late earlywood (third one third); L, latewood. D will be interpreted as late April or early May occurrence, EE as May or early June occurrence, E will be considered neutral in weight (May, June, or July), ME as June or early July occurrence, LE as late June or July occurrence, and L as August or early September occurrence. A D scar occurring in conjunction with L scars in the previous year could represent fire occurrence during the fall months, however, this combination was not observed. Additionally, fall fires are rare in the modern record.

The procedure developed for identifying seasonal occurrence of fire scars has some limitations including the following: (1) ring widths at the site of the injury are often so small that the exact position of the scar within the ring is impossible to determine; and (2) the initiation and cessation of cambial growth may vary by year, tree age, micro-site, and species. Despite these limitations, the seasonal data provide a unique estimate of intra-annual timing of past fires.

Results and discussion

Modern lightning fire data

Regional data indicate that fires ignited by lightning occur from April through November. The highest rate of ignition occurs at the end of July just before the height of the monsoon season (Barrows 1978). By August, while thunderstorm activity is often very high, the soil, litter, and woody fuels at upper elevations are saturated with moisture and fire activity is limited. When drier conditions return toward the end of September, few thunderstorms are occurring and fire activity remains low.

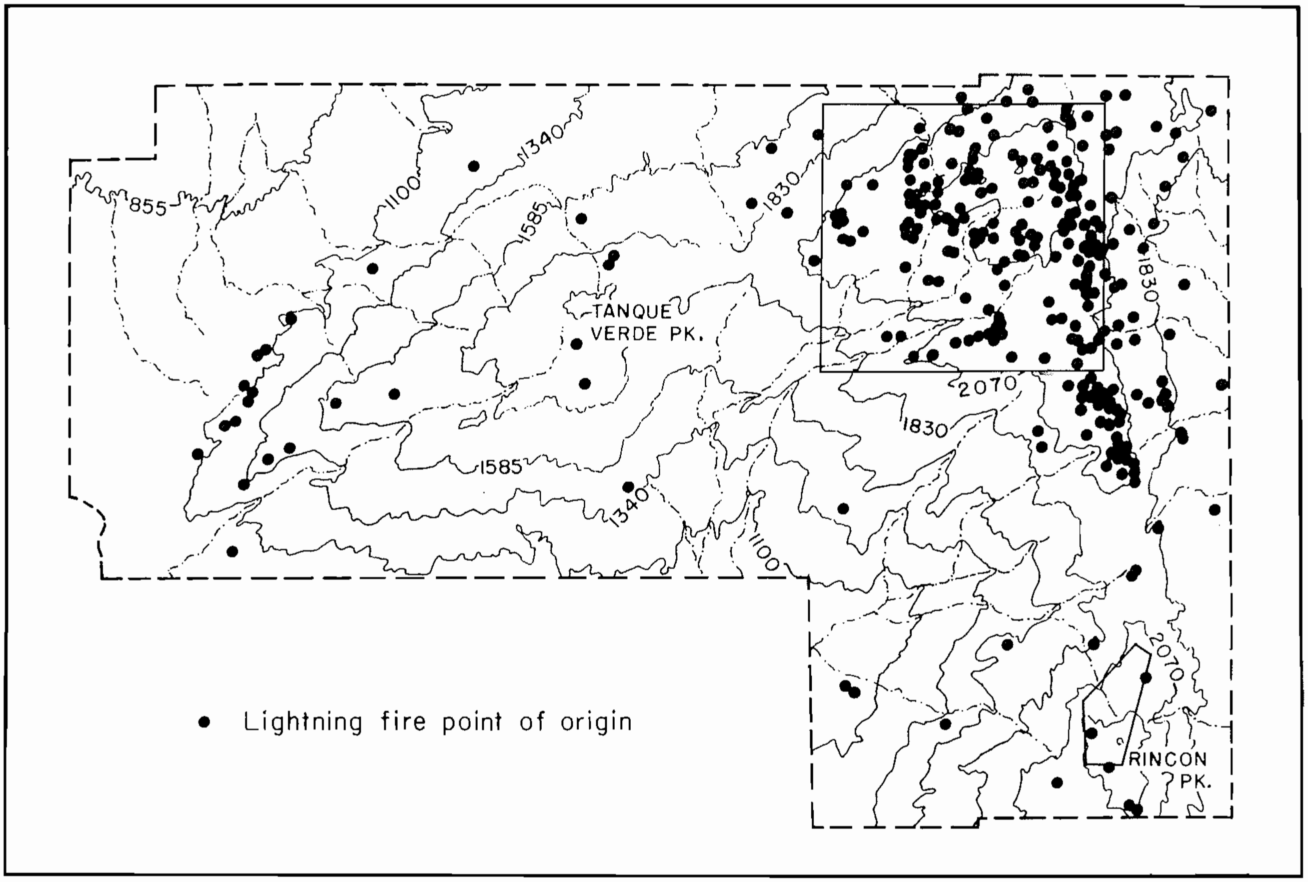

FIG. 4. Locations of lightning ignitions in the Rincon Mountains from 1937 to 1986.

Although the highest rate of lightning ignition occurs in late July, the month of June dominates the area burned with almost 60% of the average yearly total. By contrast, May accounts for 17%, July for 18%, and August for little over 2% (Barrows 1978). This disparity between the rate of occurrence and the area burned results from the arid conditions preceding the monsoon during which "dry" thunderstorms may ignite fires without contributing significant moisture. Under such conditions fires may spread rapidly.

The peak zone of lightning fire occurrence by elevation in southern Arizona is 1700–2100 m with 53% of the total occurrence. The Barrows' study concluded that lightning fire ignitions in southern Arizona were distributed randomly by aspect and were weighted heavily to the ponderosa pine habitat types (48%), followed by grass (26%), brush (14%), mixed-conifer (6%), and woodland (6%).

Saguaro National Monument recorded 411 lightning fires between 1937 and 1986. The annual average was eight ignitions (range, 1–21) during this period (Fig. 3). The greatest rate of ignition occurs between July 15 and August 15 coinciding with the increase in precipitation. The total area burned is greatest in June. The October peak is the result of one large (360 ha) fire ignited on October 1, 1956, which was not detected for several days.

Eighty-two percent of the recorded lightning ignitions occurred above 2000 m in elevation and were concentrated on Mica Mountain (Fig. 4). Relatively few fires occurred on Rincon Peak during this period, which is nearly identical in elevation. Forest Service records show a similar pattern of scattered fire occurrence on the southern flank of this peak, which is part of the Coronado National Forest. Local ranchers in the 1930s explained the unequal distribution of fires by noting that the sharply defined, exposed rock summit of Rincon Peak seemed to draw lightning to it. Since the forested area does not ascend to the summit, few fires were ignited there (McDougall 1937). In contrast, Mica Mountain lacks a well-defined summit and is heavily forested, providing ample fuel and ignition points. Tanque

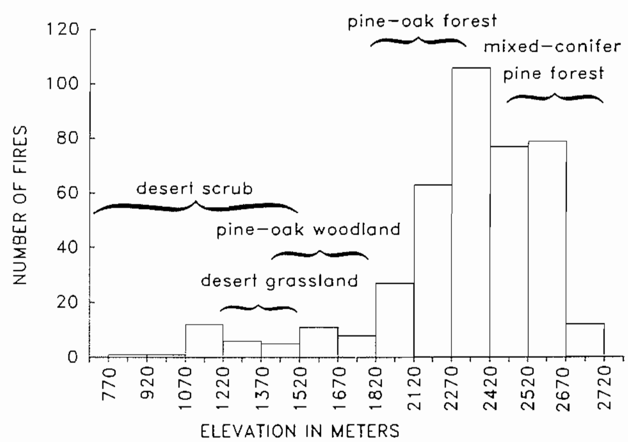

FIG. 5. Number of lightning fires 1937–1986 by elevation and cover type. Cover type is inferred from elevation. Type designations are from Bowers and McLaughlin (1987).

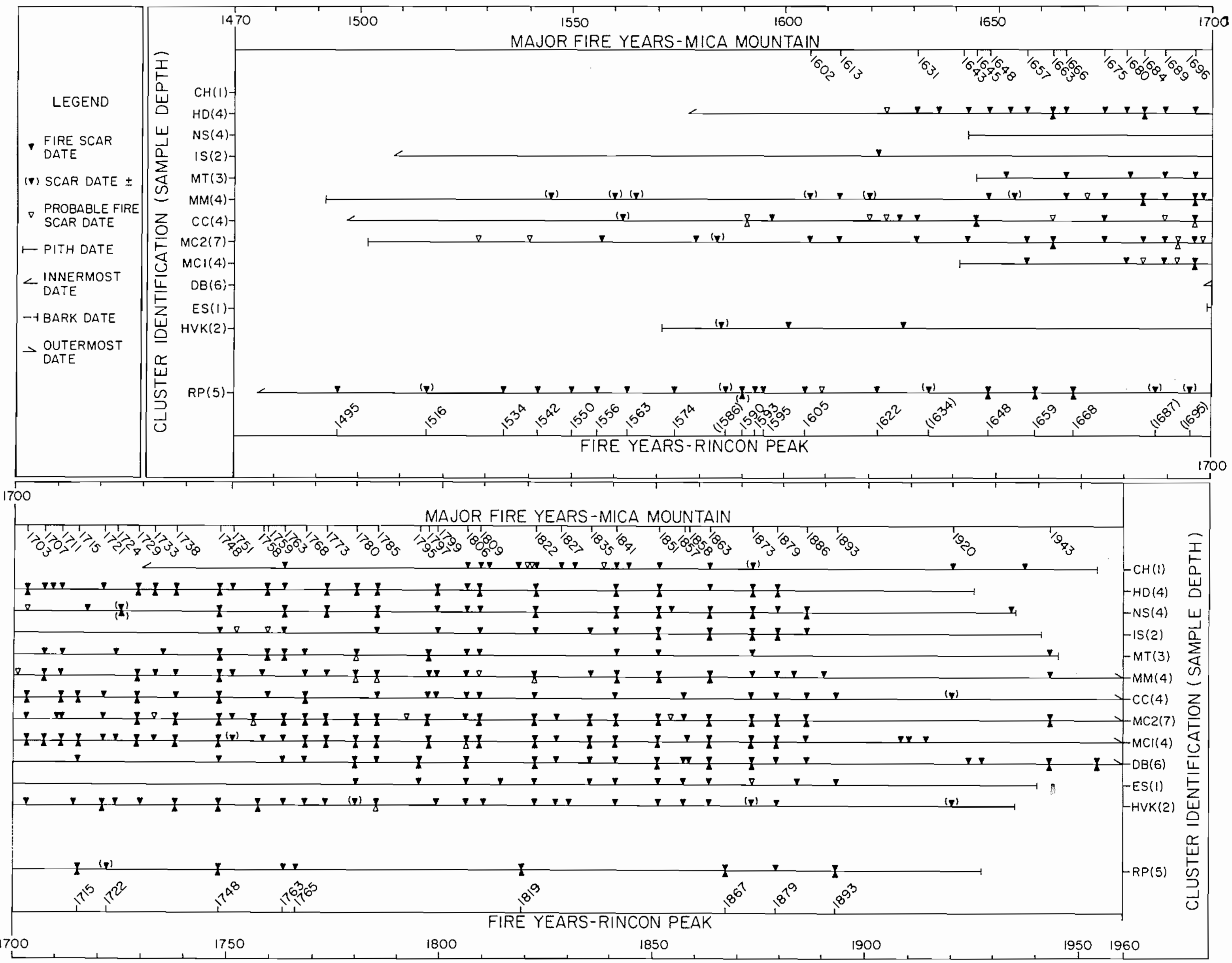

FIG. 6. Master fire chronology for the Rincon Mountains. Fire dates extend from 1495 to 1954. Major fire years are noted in margins (top for Mica Mountain study area, bottom for Rincon Peak collection site). Each line represents the fire scar information derived from all samples within a collection site. Triangles occurring both above and below the line indicate that more than one tree at the site recorded the fire. Collection site identification code and greatest sample depth (number of fire-scarred trees) are noted for each line. The regular pattern of area-wide fire occurrence is visible as the vertical alignment of triangles.

Verde Peak has had widely scattered fire occurrence with the exception of a slightly clustered pattern northeast of Monument Headquarters between 900 and 1200 m (Fig. 4). The reason for this clustering was not determined, but it indicates that factors other than elevation affect ignition rate.

The distribution of fires by cover type shows 89% of the total fire occurrence is split between pine–oak forest (48%) and ponderosa pine and mixed-conifer forest (41%). The remaining 10% is scattered in the lower elevations, 3% occurring within the desert scrub (Fig. 5).

Fire-scar data

It was possible to cross-date samples from 50 of the 54 fire-scarred trees sampled. Outer ring dates on remnant samples ranged from 1757 to 1983. These specimens preserved over 900 individual fire scars representing 119 separate fire years which were assembled into a master fire chronology (Fig. 6). This reconstruction shows an episodic regime dominated by major fires occurring at intervals of 1–13 years within the Mica Mountain study area. Small fires occurred during some intervals, but the larger fires characterize the fire regime within this study area. Although intervals of 1–3 years occurred between some major fires, in most cases (1795, 1797, and 1799, for example) these represent the burning of separate areas within the study site. The 3-year interval, 1806–1809, between site-wide fires is an exception to this pattern. Intervals between such fires were more commonly 4–7 years. Two fire-free intervals of 10 years duration occurred during the 18th century and several other intervals of this length show little fire activity.

The mean fire interval (MFI) for the entire Mica Mountain study area over the 236-year period (1657–1893) was 6.1 years (Fig. 7). During this period 41 major fires occurred and fire intervals at specific sites ranged up to 20 years. The 32-year interval between 1809 and 1841 in the record of the Mica tower (MT) group is probably an artifact of the limited number of samples collected at that site. The 1822 fire was recorded at every other site within this study area and it is unlikely that the centrally located summit escaped its effects. Gaps in the fire record at Rincon Peak (RP) between 1722 and 1867 are also probably due to limitations of the samples (two badly decayed specimens) spanning that time period.

The synchronous character of this fire regime may result, in part, from the lack of barriers to fire spread within the study area and the inertia resulting from fuel reduction throughout the site. Even though ignition and favorable burning conditions occur on an annual basis, once the fuel base had been reduced by a large fire the potential for re-occurrence of a spreading fire would be lessened for some period of time. Site-wide fires that resulted in uniform fuel reduction would initiate a corresponding cycle of site-wide fuel accumulation, increasing the chance that the next fire would also spread over the entire area. The effect of these surface fires on the fuel base appears to have lasted 3–4 years. Shorter fire intervals of 1 and 2 years were associated with samples collected near open areas or meadows where conditions for herbaceous fuel production are most favorable. Such short fire intervals are uncommon in the presettlement fire regimes of southwestern coniferous forests, except in the ponderosa pine stands of northern Arizona (Swetnam 1990).

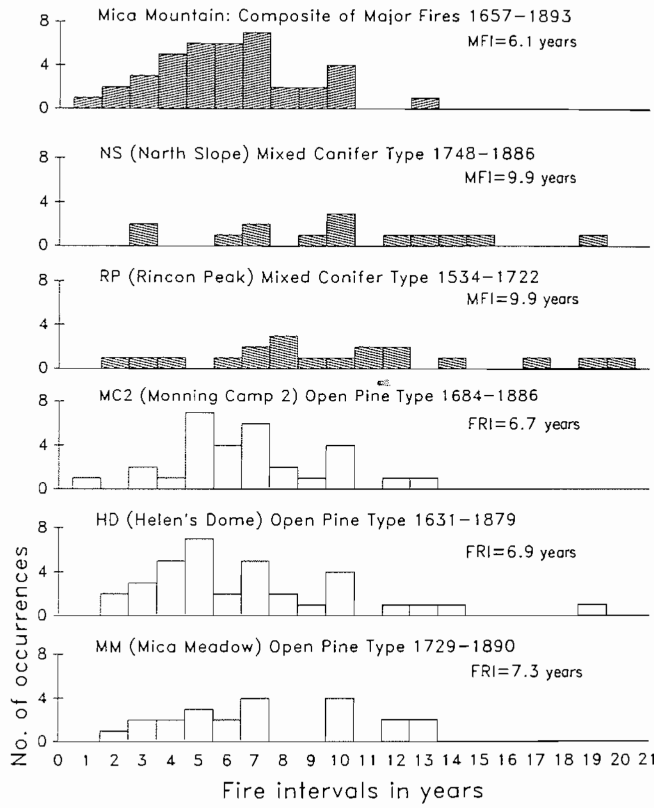

FIG. 7. Fire intervals compiled for several collection sites including a composite for the Mica Mountain study area. All sites show considerable variability.

Open pine forest, typified by the Helens Dome (HD), Manning Camp 2 (MC2), and Mica Meadow (MM) collection sites, occupies much of the Mica Mountain study area. The approximate 7-year FRI at these sites was probably representative of the average return interval in this forest type throughout the study area (Fig. 7).

Both the mixed-conifer sites, with MFIs of 9.9 years, show more decade-or-longer fire-free periods than the open pine sites. Frequent fire occurrence may maintain overstory stability in forest stands by reducing fuel loading in smaller increments, and thinning reproduction on a regular basis. Conversely, increased fuel production on moist sites in combination with decade or longer fire intervals may result in more intense fires with greater mortality of mature trees. Stands of aspen, such as those present within both mixed-conifer sites, often indicate the occurrence of intense fire in the past (Jones and DeByle 1985). Thus, the fire history and overstory mosaic suggest a more dynamic stand history than the more xeric open pine sites.

Evidence of larger scale crown fires was observed at the mixed-conifer site on Rincon Peak. Isolated groups of mature pines, separated from the main stand by oak brush and chaparral, represent the relics of a larger forested area that once surrounded this peak. Modern fire records show only nine fire ignitions on Rincon Peak between 1937 and 1987 as opposed to over 350 on Mica Mountain during this period. It is possible that this low rate of ignition resulted, occasionally, in extended fire-free periods. Such periods might have allowed fuel buildup and regeneration in this steep terrain to reach the point where a crown fire could

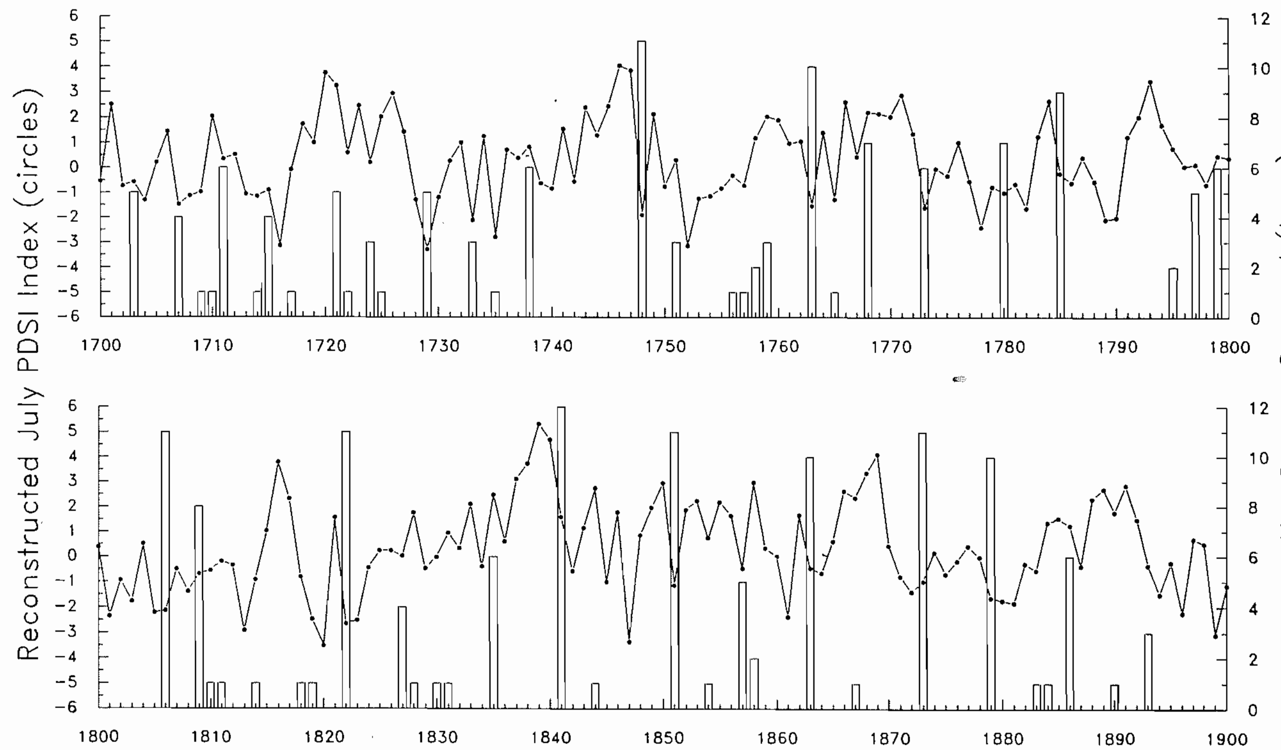

FIG. 8. A tree-ring reconstruction of the July Palmer drought severity (PDSI) index 1700–1900 versus the number of groups of trees recording a fire. All fire years are shown.

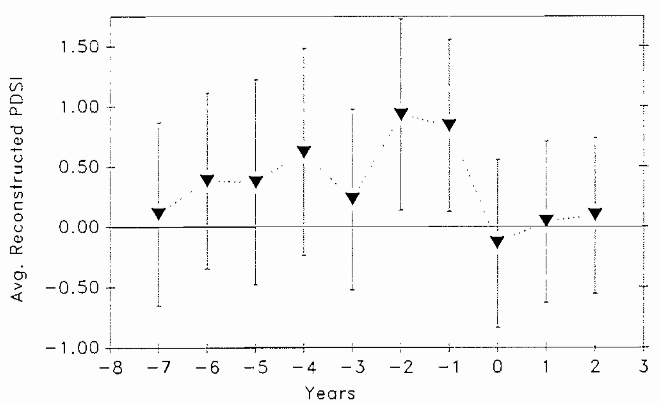

FIG. 9. Average reconstructed July PDSI for 7 years preceding and 2 years following 35 major fire years for the Mica Mountain study area. Error bars represent the 99% confidence interval.

be sustained. A few intense fires at longer intervals probably produced the mosaic of cover types now present at this site.

Although fire-free intervals of 4–7 years were more common, all the areas sampled experienced occasional fire-free intervals of 10 or more years, with some recording a 19-year interval between 1822 and 1841. This is also a period of limited fire activity at several other sites in the southwest, and may be related to regional climatic factors (Swetnam and Dieterich 1985).

Over 50% of the 27 major fires between 1729 and 1886 appear to have burned over the entire study area on Mica Mountain and some probably exceeded 3000 ha in size (Fig. 6). From the modern records of lightning-fire occurrence it is clear that the most favorable burning conditions precede the arrival of the monsoon, as the area burned is greatest in June and results from relatively few fires. The largest modern, lightning-caused wildfires were ignited in June or early July and spread over several thousand hectares in only a few days time, despite active suppression efforts. In contrast, the largest prescribed natural fire (PNF), ignited on July 28, 1972 after the onset of the monsoon, burned for 4 weeks and covered only 250 ha. Before the initiation of fire suppression, ignitions occurring during May would have as much as 8 weeks to spread uninhibited by weather conditions and might attain considerable size. Newspaper accounts of large fires were relatively common during the late 19th century in southern Arizona (Bahre 1985).

The last large fire prior to 1937 occurred in 1886. Smaller fires continued to occur, but the overall pattern changed abruptly at this point. This shift coincides with capture and deportation of Geronimo and the remaining (free) western Apache in 1886 (Thrapp 1967). As a result of the removal of the Apache threat, use of the area by Hispanic and Anglo settlers, particularly for livestock grazing, increased dramatically (Clemensen 1987). Reduction in fine fuels accompanying grazing pressure and the 1890s drought are probably responsible for initiating the change in fire regime. Increased precipitation and the initiation of active fire suppression efforts in the early part of this century were probably also factors.

Fire and drought

The relationship of the fire chronology with the reconstructed July PDSI series is presented in Fig. 8. Although a number of widespread fires occurred during years in which moderate to severe drought conditions prevailed in the region (1715, 1729, 1748, 1806, 1809, 1822, and 1879), the mean PDSI value for 35 major fire years is near the series

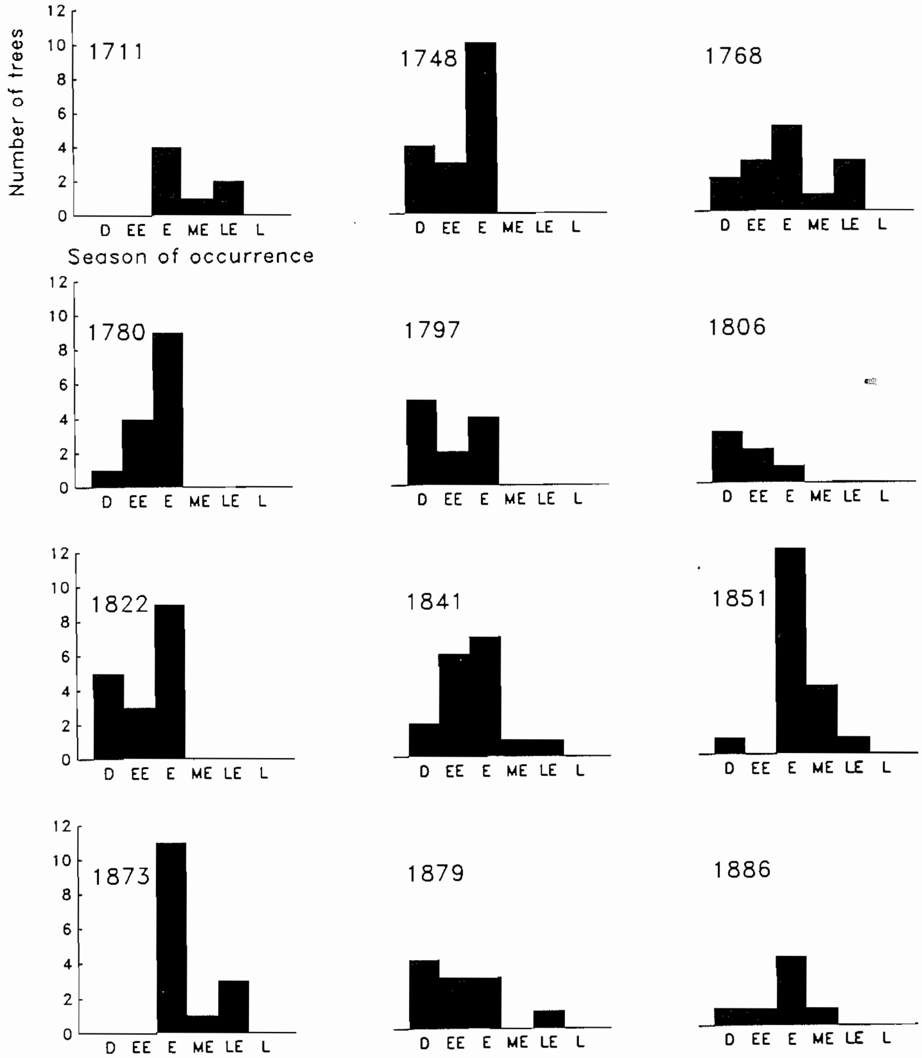

FIG. 10. The intra-ring or seasonal distribution of fire scars for 12 major fire years from 1711 to 1893.

average (Fig. 9). This is perhaps to be expected, because favorable burning conditions during the fore-summer (May and June) drought are nearly always present, regardless of the general precipitation pattern on a particular year (Weaver 1951). However, the mean index values for the 2 years preceding the fire year were significantly positive, indicating wetter than average conditions during the spring and early summer months. The fire years 1748, 1841, and 1851 typify this pattern (Fig. 8). This evidence suggests that the interaction of climate and fine fuel (herbs, grasses, deciduous leaves, etc.) production was particularly important to the occurrence of major fires. Moist conditions during the fore-summer, which inhibit fire activity during this critical period, may encourage production of fine fuel, thus priming the area for the subsequent fire season. Ignitions, as indicated by the modern data, are always present but are more apt to result in spreading fires under these conditions.

Cable (1975) and Winter (1976) found an association between increased perennial grass production and above average summer precipitation occurring in consecutive years, for a semi-desert grassland southwest of the Rincons. Presumably, the grass species present in the study area respond in a comparable manner for their phenology is similar (Gould 1951). *M. virescens*, which is presently abundant on old burns (Bowers and McLaughlin 1987), may flower twice during a single season and thus might particularly benefit from favorable moisture conditions. Rogers and Vint (1987) discuss a similar fire – fuel – climate interaction for areas of the Sonoran desert north of the study area. They found an increased probability of fire occurrence following 2 years of above average winter precipitation. Elevated precipitation was linked to increased production of winter annuals providing additional ground fuel which is normally sparse in this ecotype.

Fire activity on a regional scale may bear a more direct relationship to drought, as the dry years of 1748, 1822, and 1879 show up repeatedly as fire dates in other fire histories in the southwestern United States (Swetnam 1990). Synoptic weather patterns that affect fuel moisture in the spring, the arrival of the monsoon, and the occurrence of dry lightning storms may also play a role in determining regional patterns of fire occurrence (Swetnam and Betancourt 1990).

Seasonal occurrence of fires

Seasonal position was determined for 65% of the scars examined from the Mica Mountain fire chronology. Of these, 87.5% were identified as earlywood scars, 12.0% as dormant season scars, and 0.5% as latewood scars. These percentages confirm a late spring through mid-summer fire season for the study area over the complete length of record, which is consistent with the modern fire occurrence data (see Fig. 3). Fall fires appear to have been unimportant in this area.

Fire scars from the large fires occurring on June 6, 1943 and June 20, 1954 were examined for position as a check on the seasonal designations. Only one sampled tree, a ponderosa pine, clearly recorded these fires. It showed one third of the growth ring formed by June 6th and one half formed by June 20th. These scars were noted as ME and LE, respectively, which is consistent with the seasonal interpretations.

These data, sorted by fire date, were assembled into a series of histograms for 15 major fires between 1700 and 1893 (Fig. 10). The 1748, 1780, 1797, 1806, and 1822 fires occurred early in the growing season, probably during the month of May. The 1711, 1851, and 1873 fires occurred well into the growing season, probably during late June or July.

Prescribed natural fires in wilderness areas of the Southwest often continue to burn for a month or longer, with periods of inactivity punctuated by brief intervals of relatively rapid spread under favorable conditions. The range of values for the fires of 1768 and 1841 may represent this type of behavior. Another possibility is that the range of values resulted from separate fires occurring at different times during the same year. Modern fire records confirm that multiple ignitions from the same storm are a regular occurrence. In addition, some years show over 20 starts in a fire season. Such occurrences surely contributed to the apparent size of some pre-1900 fires.

Two of the major fires occurring before 1900 are mentioned in historical accounts. In 1879 the Arizona Weekly Star published the following notes; "Fires have been raging in the mountains east and south of here (Tucson) for some time past..." May 22, 1879. "The southeastern slope of the Santa Catarina (Catalina) and the west slope of the Rincone (Rincon) mountains have been ablaze for the last four days..." June 19, 1879 (cf. Bahre 1985). The seasonal histogram for the fire year 1879 shows a concentration of EE and D scars, three E scars, and one LE scar. It is possible that the EE and D scars were created by an early season fire (the Rincon Mountains are directly east and within easy view of Tucson) referred to in the May 22nd account, and that the LE scar is related to a second fire of June 15–19. Lt. J. Bigelow refers to a fire burning in the Rincons on June 4th, 1886 (Bigelow 1968). The histogram for this fire year shows a spread from D to ME, which is not inconsistent with this date.

Conclusion

Dendrochronological dating techniques permitted the use of remnant material to derive this high resolution fire history providing a 490-year record of fire occurrence. The reconstructed fire regime was dominated by large (200 to 3000+ ha), episodic, early-season (May to early July) fires occurring at intervals of generally less than a decade. Comparison of the well-dated fire chronology with tree-ring estimates of climatic conditions (July PDSI) indicate the importance of prior years to fire occurrence. This climatic linkage to fire probably operates by limiting the potential for fire spread and accelerating the accumulation of fine fuels during relatively wet years, thus predisposing the landscape to large-scale fire events during subsequent average or dry years. Additional centuries-long fire chronologies and more refined climatic comparisons are needed to identify spatial and temporal patterns operating on a regional scale. Research of this type is of increasing importance as we enter a climatic era that may be altered by accumulating greenhouse gases, with possible repercussions on important landscape processes such as fire.

This fire history provides a useful ecological benchmark for land managers attempting to restore the fire process to montane wilderness areas of southwestern United States. The estimated mean fire intervals and detailed seasonal observations of past fire occurrence provide a reference point for developing and conducting prescribed burning programs aimed at simulating past fire regimes. The striking reduction in recorded fire scars after the late 19th century (Fig. 6) parallels nearly all other fire scar chronologies that have been compiled for the western United States, and is strong evidence that the natural fire process was essentially eliminated at that time. As noted by Weaver (1951) and Cooper (1960), among others, the resulting accumulation of live and dead fuels may be shifting these forests away from a low intensity surface fire regime toward high intensity stand replacing fire regimes. Several large stand replacing fires have occurred in the ponderosa pine and mixed-conifer types in other similar mountain ranges in southern Arizona and New Mexico in the 1980s, and such a fire occurred during the dry year of 1989 to the north and west of the study area in the Rincon Mountain Wilderness. The difficult challenge facing land managers is to restore stability in these forests by reintroducing low intensity surface fires, while avoiding the hazards of high intensity wildfires.

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