Cooperative National Park Resources Studies Unit

ARIZONA

TECHNICAL REPORT NO. 29

FIRE HISTORY OF THE RINCON MOUNTAIN WILDERNESS, SAGUARO NATIONAL MONUMENT

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COOPERATIVE NATIONAL PARK RESOURCES STUDIES UNIT
University of Arizona/Tucson - National Park Service

The Cooperative National Park Resources Studies Unit/University of Arizona (CPSU/UA) was established August 16, 1973. The unit is funded by the National Park Service and reports to the Western Regional Office, San Francisco; it is located on the campus of the University of Arizona and reports also to the Office of the Vice-President for Research. Administrative assistance is provided by the Western Archeological and Conservation Center, the School of Renewable Natural Resources, and the Department of Ecology and Evolutionary Biology. The unit's professional personnel hold adjunct faculty and/or research associate appointments with the University. The Materials and Ecological Testing Laboratory is maintained at the Western Archeological and Conservation Center, 1415 N. 6th Ave., Tucson, Arizona 85705.

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August 1990

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Prepared for Saguaro National Monument

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INTRODUCTION

> "These Rincon Mountains are a mass of rock fashioned by plutonic and atmospheric forces into every variety of shape and form - an imposing exhibition of blocks and boulders, bold bluffs and promontories, broad, slippery slopes, peaks, domes, and crests, and jagged and serrated ridges. In their dazzling, reflected sunlight, they are anything but an attractive prospect to a traveler. We are told that the summit is, in the main, level, grassy and well timbered, and that near the highest point is a good sized lake; also that few people are well enough acquainted with the range to guide us through it...." (Bigelow 1968, 191)

Late in May of 1886 Lt. John Bigelow led two troops of U.S. calvary up into the Rincon Mountains in search of Apache Indians who had been sighted in the area. On May 28 he camped with his troops near the summit of Mica Mountain, probably in the vicinity of the present site of Manning Cabin and, finding neither lake nor Apaches, recorded the following description of the area:

> "Our camp is as pleasing to the eye as it is restful to the body. From the ridge on which the officers have established themselves I look down upon the two rows of saddles of the two troops, each with its cook fire at one end; and beyond, the sparkling creek by which they are flanked, upon the steep backbone or watershed of the mountain. Retiring over a springy sward, a distance of a few yards, I overlook a broken timbered declivity, and extending out from it a dry, dusty plain. In my front are the hazy Tucson Mountains, near the foot of which I descry the shimmering town of that name; on my right the glaring, frowning Catalinas, and on my left, separated by a valley, the purple Whetstones and Santa Ritas...." (Ibid, 194-195)

This description of the Rincon Mountains is particularly relevant to this study because in June of that year the last of a centuries-long series of widespread, episodic fires was recorded by fire scarred trees on Mica Mountain. The abrupt cessation of large fires was linked to the Lieutenant's visit, for in that year the Western Apaches were finally vanquished by the U.S. Army (Lt. Bigelow was participating in this effort) and unrestrained settlement was possible in southern Arizona for the first time since Columbus' landing. This event signaled the beginning of an era of rapid change in this region which has not ceased to this day.

By peering back in time, this study is an attempt to examine, reconstruct, and thereby gain a better understanding of some of the natural processes which resulted in a landscape "...as pleasing to the eye as it is restful to the body." A place where the travelers found a large, ice-cold spring "...surrounded by tall, fresh grass, and overshadowed by fine old pines."(Bigelow 1968, 194). Historical research and dendrochronological analysis of fire scarred cross sections from snags, stumps, and downed logs were combined to compile a fire history. The information gathered during the course of this study will (1) benefit resource management in planning strategy for long term fire management in the Rincon Mountains and (2) increase awareness and support among the general public for fire management policy through the interpretative role of Saguaro National Monument.

Numerous studies have documented the dramatic changes in forest stands which have taken place throughout the western United States since the turn of the century. The open park-like stands of ponderosa pine that were described by travelers in the nineteenth century can only be found in limited areas today. Dense thickets of reproduction and an increase in shade tolerant species since the turn of the century have altered the character of the pine forests. In many cases these changes can be attributed directly to land management practices initiated since settlement. In particular, widespread grazing of cattle and sheep on arid and semiarid ranges and the initiation of wildfire suppression had significant impacts. (Leopold 1924, Weaver 1951, Cooper 1960,1961, Hastings and Turner 1965, Biswell et al. 1973, White 1985). Destructive crown fires, which a variety of evidence suggests were rare in the southwestern ponderosa pine stands during the nineteenth century, have destroyed large tracts of mature timber over the last 50 years (Cooper 1960). In contrast, south of the U.S.-Mexico border, where wildfire suppression has been limited, open-park like stands of ponderosa pine matching the early descriptions still characterize forest structure (Marshall 1963). A recent fire scar study conducted in northern Sonora found that the pattern of frequent scarring, a pattern which ceased around 1900 north of the border, continues uninterrupted into the 1970's (Swetnam 1983*a*).

Conservation of natural ecosystems and scenic resources are primary objectives of National Park Service (NPS) land management policy. The important role played by natural fire in ecosystem dynamics as a positive, regulatory process has been emphasized recently in NPS policy. Since 1963 when the Leopold panel (Leopold et.al. 1963) envisioned conservation as the preservation of a "vignette of primitive America", a great deal has been learned about the role of disturbance within ecosystems. The present consensus in NPS policy is that resource conservation is not the preservation of a 'snapshot', as it was interpreted in 1963, but the conservation of a dynamic process within which fire and other natural disturbances must be allowed to resume their proper role. Disturbance and change are natural, and indeed inevitable, influences which contribute to the overall health and resilience of ecosystems. When an attempt is made to withhold these processes from a system, stagnation and instability are often the result.

Reintroduction of a potentially powerful disturbance such as fire, however, demands careful planning as well as a thorough understanding of the role fire played in the undisturbed ecosystem. Fire can be both a powerful servant or a terrible and destructive master. Without due attention to these preliminary steps, development of a sound management policy is impossible. The one hundred intervening years since the cessation of the natural fire regime in the Rincons have wrought very significant changes both on the structure of forest stands, and on fuel loadings throughout the stands. Thus, any attempt to re-establish the natural fire cycle presents a considerable challenge to those charged with the task of managing natural areas. This study is an attempt to help meet that challenge by providing base line information on the role of natural fire in the upper elevations of the Rincon Mountains over the past several centuries.

Specific objectives of this study are to (1) estimate fire intervals for various sites and community types; (2) estimate the season of fire occurrence; (3) consider the relationship between fire and climate; (4) discuss the relationship of human populations to the fire regime; and (5) consider the implications for fire management in the Rincon mountains.

BACKGROUND

DESCRIPTION OF THE RINCON MOUNTAINS

The Rincon Mountain Unit of Saguaro National Monument encompasses an area of 63,000 acres (25,000 ha) consisting of the main mass of the Rincon Mountains, Tanque Verde Ridge, and the bajada area surrounding the monument headquarters (Fig. 1).

The headquarters area is situated within the Sonoran desert scrub vegetation zone at an elevation of 2,700 ft. (800 m). The area's vegetation is dominated by the giant saguaro cacti and many species of desert trees and shrubs. From the desert floor the mountains ascend to an elevation of over 8,600 ft. (2,600 m) at Mica Peak, and 8,500 ft. (2570 m) at Rincon Peak. The area above 7,500 ft. (2,300 m) supports a dense, mixed conifer and ponderosa pine forest. This dramatic change in elevation over a short distance gives rise to a complex association of vegetational habitat types and ecotonal gradations linked to changes in elevation and aspect. At least 986 species of plants, 40% more than would be expected in an area of this size and range of elevation, occur in the Rincons attesting to the variety of conditions available (Bowers and McLaughlin 1987). Over the range of elevations, five distinct cover types are encountered (Table 1). Annual precipitation varies considerably with 13 inches (330 mm) falling at the lower elevations and 25 to 30 inches (640-760 mm) near the summit (Bowers and McLaughlin 1987). A snow pack often develops during the winter months above 7,000 ft. (2,100 m), with considerable accumulation on north facing slopes.

GEOLOGY

The Rincon mountains, and several adjacent ranges are classified structurally as metamorphic core complexes. These ranges were uplifted during a mid-Tertiary mountain building episode associated with continental stretching. Similar ranges are found in a north - south trending band stretching from Mexico to British Columbia (Krantz 1985).

The main mountain mass, an uplifted dome of basement rock, is composed of granitic gneiss and related rocks derived from pre-Cambrian and Tertiary protoliths of quartz monzonite. Remains of the overlying strata, mostly limestones of Permian age, are found outcropping at various points around the mountains perimeter (Davis 1987). The present form of the Rincons is the product of extensive weathering, erosion, and continued faulting over the last thirty million years.

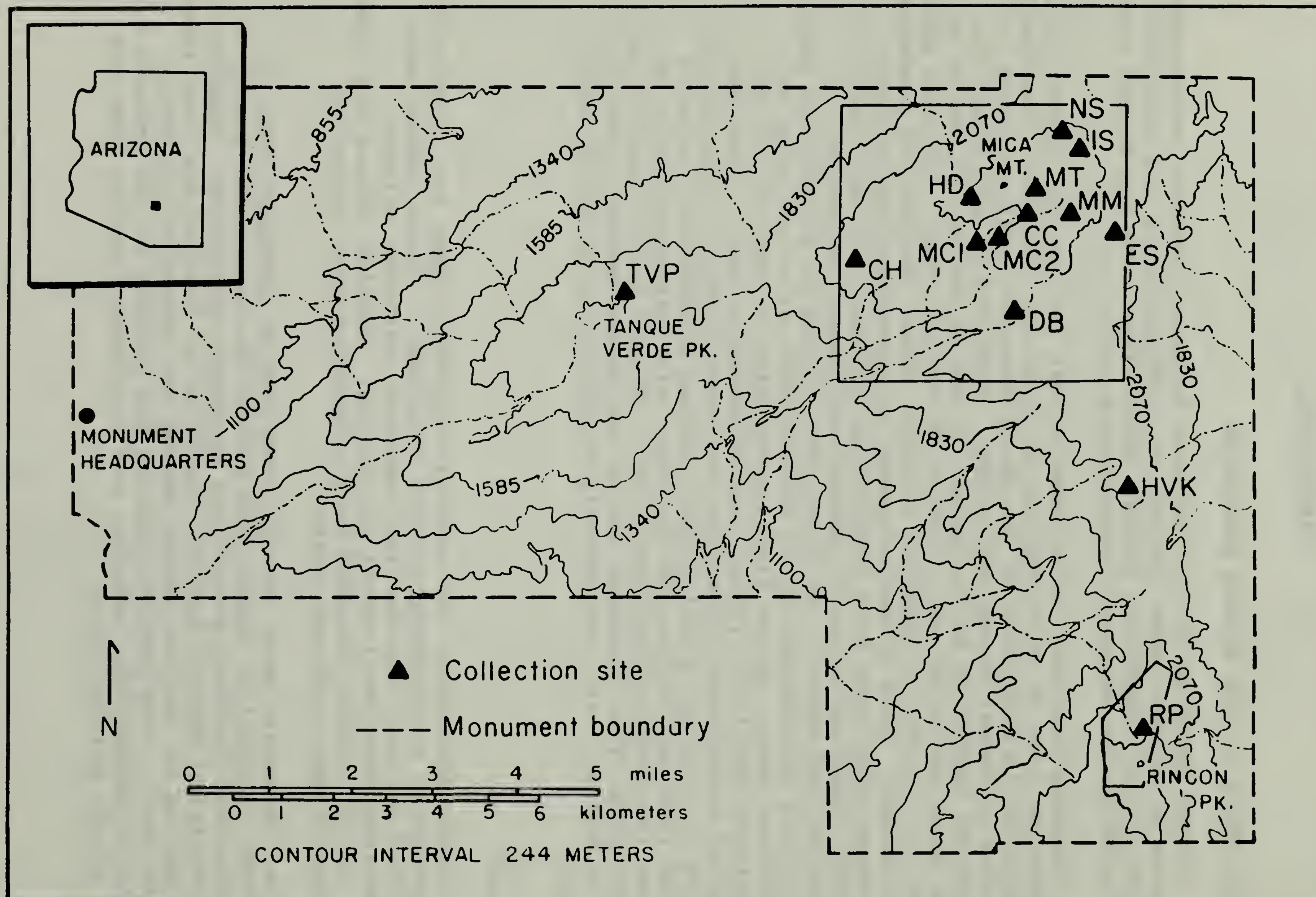

Figure 1. Map of the Rincon Mountain Unit of Saguaro National Monument. Mica Mountain study area and Rincon Peak collection site outlined. Collection sites are designated by a two or three character code (*see* the "Study Area and Collection Sites" Section for explanation of codes).

Table 1. Vegetation Types of the Rincon Mountains[1].

Cover Type	Elevation ft. (m)	Average July Temperature ^0F (^0C)	Average Precipitation inches (mm)	Prominent Species
Desert scrub	2,700-5,200 (823-1585)	94 (34)	3-11 (26-279)	Saguaro (*Carnegiea gigantia*) Palo Verde (*Cercidium microphylla*) Mesquite (*Prosopis velutina*) Ocotillo (*Fouquieria splendens*) Creosote Bush (*Larrea tridentata*) Prickly Pear (*Opuntia spp.*) Jojoba (*Simmondsia chinensis*)
Desert Grassland	4,000-5,000 (1219-1524)	85 (29)	12-16 (305-406)	Mesquite Ocotillo Sotol (*Dasilyrion wheeleri*) Bear Grass (*Nolina microcarpa*) Alligator-bark Juniper (*Juniperus deppeana*)

Table 1 (Continued).

Cover Type	Elevation ft. (m)	Average July Temperature ^{0}F (^{0}C)	Average Precipitation inches (mm)	Prominent Species
Pine-Oak Woodland	4,400-6,100 (1341-1859)	82 (28)	14-18 (356-457)	Arizona Rosewood (*Vauquelina Californica*) Mexican Blue Oak (*Quercus oblongifolia*) Arizona White Oak (*Quercus arizonica*) Pinyon Pine (*Pinus discolor*)
Pine-Oak Forest	5,300-8,000 (1615-2436)	74 (23)	18-22 (457-559)	Chihuahua Pine (*Pinus leiophylla*) Pinyon Pine Emory Oak (*Quercus emoryi*) Arizona White Oak Ponderosa Pine (*Pinus ponderosa*)
Mixed Conifer /Pine Forest	7,000-8,600 (2134-2621)	68 (20)	18-30 (457-462)	Ponderosa Pine Douglas Fir (*Ptsudotsuga menziezii*) White Fir (*Abies concolor*) S.W. White Pine (*Pinus stroboformis*) Gambel Oak (*Quercus gambelli*)

[1] Adapted from Simpson and Wells (1984).

CLIMATE

The basin and range country of southern Arizona is subject to a bi-seasonal distribution of precipitation with both winter and summer maxima. The Tucson basin receives an average of fifty-eight percent of its annual precipitation between May and October with the peak occurring during July and August. The winter maximum occurs during December and January. The percentage of the annual total arriving during the summer increases to the south and east and decreases to the west and northwest of Arizona. Thus, while southern California's climate is dominated by winter precipitation, southeastern New Mexico and western Texas receive a majority of their precipitation during the summer (Hastings and Turner 1965).

A description of the yearly climatic cycle as it affects the fire regime begins in April with the melting of the winter snow pack. Winter storms are infrequent by this time and a drying trend sets in. This pre-summer drought intensifies through May and June and frequently no precipitation occurs during this period. Occasional isolated 'dry' thunderstorms may occur during this drought, however, and these storms, while bringing little or no effective precipitation, often generate considerable lightning and, therefore, fire activity.

In early July a breakdown of high pressure over Arizona allows moist air from the Gulf of Mexico and/or the Gulf of California to flow over the state. Orographic and convective thunderstorms associated with the moist air mass are generated in increasing numbers during July and August, tapering off through September. A second drying trend sets in October and is broken by the arrival of large winter storms from the Pacific, often in late November.

Fires generated by lightning are possible from April through November, with peak fire activity occurring just before the height of the monsoon at the end of July. By August, while thunderstorm activity is often very high, upper elevations are typically saturated with moisture and fire activity is very limited. When drier conditions return toward the end of September, few thunderstorms occur and fire activity remains low.

Knowledge derived from a variety of sources indicates that the climatic cycle just described has dominated the southwestern region for the last 8,000 years (Vandevender and Spaulding 1979). This climatic regime is also responsible, to a large degree, for the present distribution of vegetation.

Prior to 11,000 years ago, during the last glacial period, both climate and the distribution of vegetation types was significantly different. With relatively more winter precipitation and cooler summer temperatures, vegetation zones were depressed and the extent of both coniferous forests and woodland communities was considerably greater. The melting of the continental ice sheets over the 3,000 year span from 11,000 before present (BP) to 8,000 BP changed the atmospheric circulation patterns and set the stage for the development of the present regime. Forests and woodlands retreated up slope as mean summer temperatures rose and the seasonal moisture balance shifted. The basin and range country became a series of mountainous islands within a desert sea. Although there have been continued fluctuations in climate over the past several millennia, they have been of less dramatic consequence, and it is assumed that the synoptic weather patterns and distribution of vegetation have remained relatively stable during this period. Thus, it can be inferred that the present fire regime of southern Arizona, dominated by lightning from summer storms, evolved about 8,000 years ago.

FIRE ACTIVITY IN THE SOUTHWESTERN REGION

The lightning fire season in southern Arizona begins in May and runs into October, with the peak occurring in July. Southwestern New Mexico, where the fire season begins slightly earlier (often in early April), experiences a greater number of spring fires. In northern Arizona, which receives more spring precipitation than the other two areas, the fire season is shifted toward mid or late summer (Barrows 1978). In all three areas, however, the month of June dominates the lightning fire season in the severity (as measured by the area burned) of the fires which occur. Almost 60 % of the area burned by lightning fires within the National Forests of Arizona and New Mexico originate from June fires. By contrast, May accounts for 17.1 % of the area, July for 18.1 % and August for only 2.5 % [Barrows 1978].

The Coronado National Forest, a section of which borders the Rincon Mountain unit on the east as well as portions of the northern and southern boundaries, leads the Southwest in the average annual area burned by lightning fires as well as in area burned per million protected acres (Annual average: 6,312 acres; 3,401 acres / million acres protected: Barrows 1978).

The peak zone of lightning fire occurrence by elevation in southern Arizona is 5,500 ft. to 7,500 ft. (1700 m to 2,300 m) with 53 % of the total occurrence. The Barrows' study concluded that lightning fire occurrence in southern Arizona was distributed randomly by aspect and was weighted heavily to the ponderosa pine habitat types (48 %), followed by grass (26 %), brush (14 %), mixed conifer (6 %) and woodland (6 %).

LIGHTNING FIRE AND THE ECOLOGY OF THE PONDEROSA PINE AND MIXED CONIFER FOREST TYPES OF SOUTHERN ARIZONA

The occurrence of lightning ignited fires in the ponderosa pine and mixed conifer forests of the southwestern United States was one of the most dramatic and widespread influences on forest stands before 1900, perhaps second in importance only to climatic conditions in shaping the distribution of plant species. Actually, lightning and fire occurrence have a direct link to climate and could be considered a component of it. Lightning periodically thins and prunes forest stands by igniting wild fires and destroying individual trees. Ridges and mountain tops experience a high incidence of lightning strikes, and tree mortality within stands due to lightning can reach significant proportions in these locations (Avery et. al. 1976).

The role of episodic fire in forest stands has been studied throughout the west by examining fire scars occurring on coniferous tree species (Stokes and Dieterich 1980). Such studies, as well as examinations of stand structure and establishment patterns (Cooper 1960, 1961), have provided a base line of knowledge concerning the ecological function of lightning fire. This role may be summarized as follows: patches of mineral soil are laid bare by combustion of woody debris. Conifer seedlings establish readily in these openings and if conditions remain favorable for several years many will survive. As these thickets mature, the amount of fuel in the form of litter increases and subsequent fires thin the stand. Survivors of these fires become more resistant to crown damage as lower branches are scorched and die back. Nutrient cycling is enhanced by the combustion of litter, and a grassy understory is encouraged at the expense of woody vegetation and less fire tolerant tree species. An open stand structure is maintained and encouraged as repeated fires keep subsequent reproduction from developing in the litter beds beneath mature trees. The cycle is repeated as older trees die, fall, and are consumed by subsequent fires, consequently exposing a fresh seedbed (Wright and Bailey 1982). Standing snags play an additional role in the fire cycle as the initiators of fires, for, when ignited by lightning they are often the source of fires.

The pre-settlement mean fire interval in ponderosa pine forests has been found to vary depending on conditions specific to the site. The range in Arizona and New Mexico is from 1.8 to 9.8 years (summarized by Swetnam 1985)

Much less is known about fire ecology of the mixed conifer forests of the Southwest. It is generally assumed that fire frequency is somewhat lower in this forest type, with intervals ranging up to twenty years due to more mesic conditions which characterize these sites (Ahlstrand 1980; Dieterich 1983). However, in some lower elevation stands the interval may be on the order of 5 to 12 years, more closely resembling the frequency in the ponderosa pine type (Weaver 1951). Basal fire scars are relatively common in some stands, particularly on drier sites. Several of the dominant species (Douglas fir and white fir in particular) develop thick, fire resistant bark which enables them to survive surface fires. The occasional occurrence of crown fires at longer intervals (>100 yrs.) in this type has been assumed, but little research has been done on the subject. Stands of aspen within mixed conifer forests often indicate the past occurrence of a crown fire (Jones and DeByle 1985). The mixed conifer forest of the Rincons is restricted to limited areas on north facing slopes, and one would expect the fire frequency in both forest types to be closely linked.

METHODS

This research was conducted in two phases. One phase involved the study and analysis of historical records. The other consisted of dendrochronological analysis of tree-ring samples including (1) crossdating of fire-scarred samples and assigning calendar dates to the fire scars; (2) comparison of the firescar chronology to a reconstruction of regional drought; and (3) analysis of the position of fire scars within the annual ring.

HISTORICAL RESEARCH

Primary sources (including newspaper accounts, journals and documents) and secondary sources (such as historical, ecological and anthropological analyses) were examined for references to fire occurrence, dates of human occupation, and land use patterns.

Modern records of fire occurrence, including seasonal occurrence, spatial patterns of ignition, and other recorded data provide a valuable perspective on data generated from fire scars. Saguaro National Monument has maintained records of fire occurrence within the monument boundaries since 1937. These records include the date, size, location, fuel type, and a narrative description of larger fires. A study by J. Barrows (1978) analyzed fire occurrence for the U.S. 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.

DENDROCHRONOLOGY

Fire-scarred samples were selected from 13 sub-sites to attain broad spatial coverage, including a range of slope aspects (Arno and Sneck 1977). Since individual trees rarely record every fire that burns within their vicinity and scar preservation is often a problem on older specimens, samples were collected in clusters when ever possible (Arno and Sneck 1977; Kilgore and Taylor 1979).

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.

Two criteria were used to select specific samples: (1) number of scars showing as evidenced by the number of healing ridges observed on the scarred surface or "cat face" and (2) state of preservation (i.e. degree of decay present) (Swetnam 1983*b*). Occasionally two or more cross sections were cut from the same tree when it appeared that all of the scars present on the cat face would not be visible on a single section (Dieterich and Swetnam 1984).

Trees respond to injury through a process of sealing off injured areas from healthy tissue by including pathogen resistant compounds in woody tissue around the site of the wound (Shigo and Marx 1977). Conifers appear to concentrate resins at the injury site and dendrochronologists have observed that the entire stem around the site of the wound may become impregnated with resin over time. This resinous portion resists decay very effectively and may persist for long periods of time in an excellent state of preservation. Fire scarred remnants exhibiting this phenomena were sought out as potential samples.

The samples were packaged in paper feed sacks to minimize damage during transport and packed out of the backcountry by mule or occasionally transported by helicopter when cargo space was available.

Samples were sectioned with a band saw and belt sanded with a series of progressively finer grits (to 400 grit where necessary) to prepare the surface so that the cellular structure was clearly visible. A finely prepared surface was necessary in order to accurately assess the year and season of scarring and enable accurate crossdating.

In conjunction with collection of fire-scarred 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). The ring patterns on the fire-scarred samples were crossdated using the master chronology developed from the living trees. The fire dates were then assembled into a master fire chronology. 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 only recorded by 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).

Fire Occurrence and Drought

A tree-ring reconstruction (Stockton and Meko 1975) of the July Palmer Drought Severity Index, or PDSI (Palmer 1965), was used to examine the possibility of a relationship between fire occurrence in the Rincon Mountains and regional drought. The July PDSI was deemed appropriate for comparison to fire occurrence because the index takes into account the water budget of the previous several months. The PDSI thus provides an indication of the burning conditions (including fuel and soil moisture) prevailing during the fire season (which typically extends from May through August). To produce these reconstructions the western U.S. was divided into 40 sections, based on climatic patterns, and the PDSI values were reconstructed for each section. The reconstruction for area 6 which includes southern Arizona, Southern New Mexico, and northern Chihuahua and Sonora was used. This reconstruction has some limitations in that it is neither specific to the Tucson basin (its signal is regional in nature and thus may not always reflect conditions in the Rincons) nor are the techniques used for the reconstruction currently considered state of the art (Stockton per. comm.). However, the comparison was deemed worthwhile and, for the moment, no better reconstruction is available.

Seasonal Occurrence of Fires

An additional source of information concerning local and regional variations in fire regime is the position of fire scars within the annual ring (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 which mimic 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, a consensus determination was made by examining both scars.

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 (1924) suggests that it begins stem enlargement within a week of ponderosa pine growing on the same site, but has a shorter overall growing season. Southwestern white pine was assumed to be comparable to ponderosa pine for the purposes of this analysis.

Six seasonal categories for fire scars were established (Fig.2): **D** dormant season (appearing between rings); **EE** early-earlywood (1st 1/3 of earlywood[1]); **E** generic earlywood, no further distinction possible; **ME** mid-earlywood (second 1/3); **LE** late earlywood (third 1/3); **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.

The procedure developed for identifying seasonal occurrence of fire scars has some limitations, including (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, micro-site and species. Despite these limitations the seasonal data provide a unique estimate of relative and intra-annual timing of past fires.

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[1] Earlywood refers to the band of large, thin-walled, light-colored cells which are formed early in the growing season. Small, thick-walled, dark-colored latewood cells are formed later in the growing season and make up the dark band which forms the boundary of the annual growth ring in conifers.

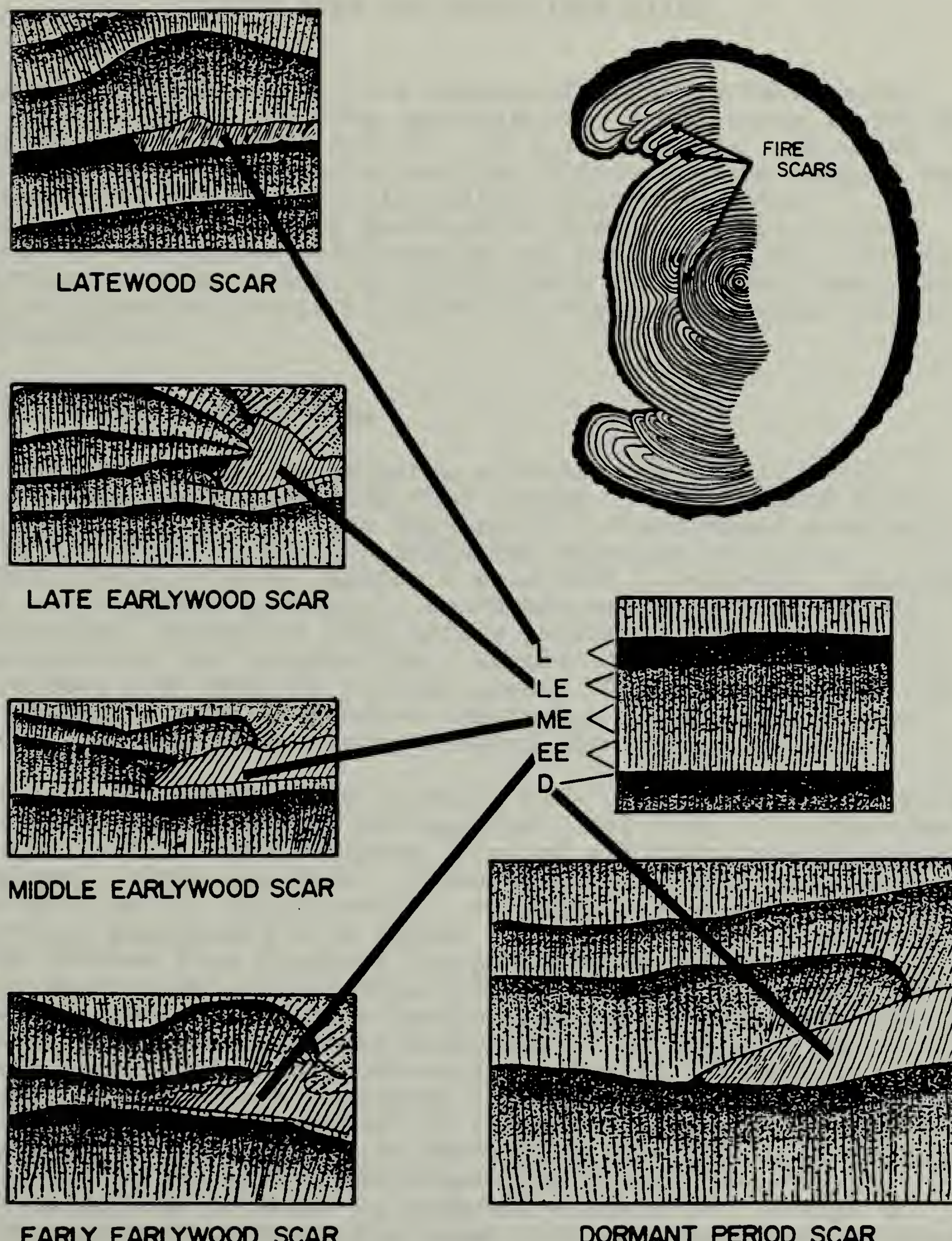

Figure 2. Examples of the intra-annual position of fine-scars and a typical fine-scarred crossection.

STUDY AREA AND COLLECTION SITES

This study focused on the fire regime of Mica Mountain above 7,000 ft. (2,100 m), an area approximately 6,000 acres (2,248 ha) in extent (see Figures 1 and 3). This is the area from which the largest and most complete collection of fire scarred samples was obtained. The other collection sites, Rincon peak and Tanqueverde ridge, will be referred to where appropriate and analyzed to the degree permitted by the data collected. Future collection in these areas, by providing a better data base, would permit an up-dated report to extend coverage to a larger portion of the mountain.

THE MICA MOUNTAIN STUDY AREA

This study area (Fig. 3) supports a coniferous forest which varies in species composition with aspect. Cooler north and northeast facing slopes have Douglas fir (*Pseudotsuga menziesii*) / white fir (*Abies concolor*) dominated communities while northwest facing slopes support a more xeric community, including Gambel oak (*Quercus gambelii*), southwestern white pine (*Pinus strobiformis*), ponderosa pine (*Pinus ponderosa*, var. *arizonica* and *scopulorum*) and Douglas fir. Stands of aspen (*Populus tremuloides*) are found in limited areas. The forest varies from closed canopy stands with dense understory to relatively open conditions on the drier slopes (Bowers and McLaughlin 1987).

Slopes with southerly aspect support pine communities of varying composition with evergreen oak species (including *Q. arizonica*, *Q. emoryi*, and *Q. hypoleucoides*) playing a larger role at lower elevations. Flats and drier slopes near the summit have open stands of pine (*P. strobiformis / P. ponderosa*) with grassy understory punctuated by a number of open meadows. Common grasses include pine dropseed (*Blepharoneuron tricholepsis*), Arizona wheatgrass (*Elymus arizonicus*), mountain junegrass (*Koeleria cristata*), Pringle needlegrass (*Stipa pringlei*) and screwleaf muhly (*Muhlenbergia virescens*). Shrubs such as mountain spray (*Holodiscus dumosus*), buckbrush (*Ceanothis fendleri*), and mountain snowberry (*Symphoricarpos oreophilus*) are widespread (Bowers and McLaughlin 1987). This forest type will subsequently be referred to as "open pine forest", to distinguish it from the more familiar ponderosa pine forest, due to the nearly ubiquitous presence of southern white pine. Strips of riparian vegetation follow drainages with semi-permanent surface flow. There are no perennial streams within the upper elevations although flow in the lower reaches of several drainages approaches permanence. Thus, there are few topographic barriers to fire spread.

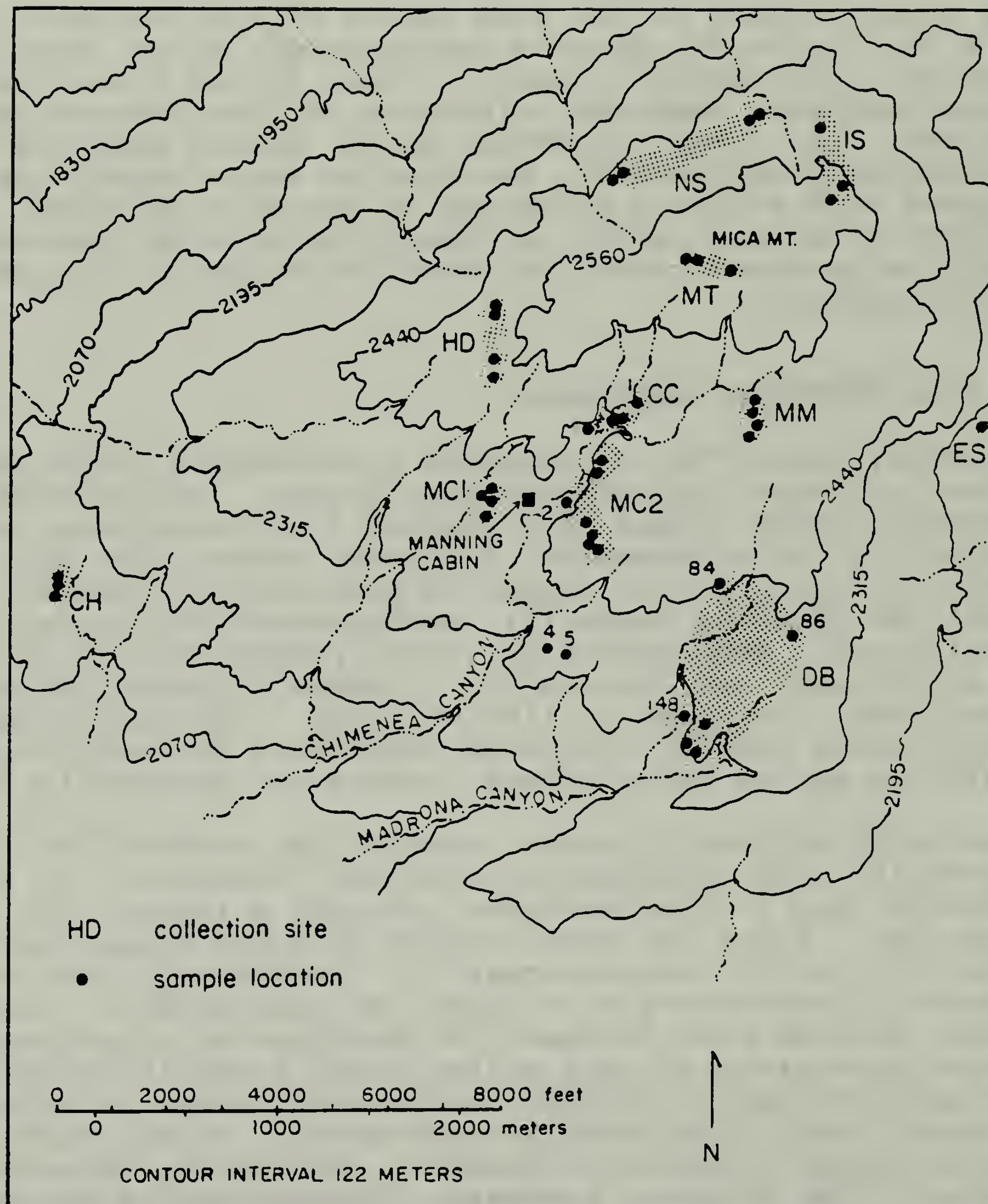

Figure 3. Map of the Mica Mountain study area with the location of sample trees (dots) and groups (stippled). Sample trees from the 1983 study are noted by their National Park Service identification number. *See* the "Study Area and Collection Site" section for explanation of the collection site codes. *See* Fig. 1 for the location of the study area.

Those barriers that exist are of limited extent, consisting of either large rock faces or jumbled, boulder-strewn slopes with patches of exposed bedrock.

Drainage bottoms are often dry and covered with litter. Changes in fuel composition would appear to be the main constraint on fire spread. The litter bed of the pine-oak and chaparral communities, which occur below the pine forest, will not support a surface fire as readily as the grass and pine litter found at the higher elevations. However, many of the chaparral species (pointleaf manzanita, *Arctostaphylos pungens;* hairy mountain mahogany, *Cercocarpus brevifloris;* and skunkbush sumac, *Rhus trilobata*) are considered pyrophytes (Wright and Bailey 1982). Accordingly, during the annual fore-summer drought, the changes in fuel composition may not represent a significant fire barrier. Fire-scarred trees and burned stumps which can be found throughout the pine-oak forest and woodland types attest to the presence of fire in these communities. Some past fires probably originated within the lower forest type and spread into the higher elevation stands. For example, the lightning ignited Turkey Creek fire of 1954 originated within the pine-oak woodland community and spread up into the coniferous forest, burning over 4,200 acres (1,700 ha) before it was suppressed. Fires occurring within or spreading into the lower elevations encounter the desert grassland and scrub communities where grass is the primary fuel. The inability of grassy cover to hold a fire overnight, may have limited the tendency of such fires to spread.

Collection sites in the Mica Mountain study area (Fig. 3) include MM (Mica Meadow), MC1 (Manning Camp 1), MC2 (Manning Camp 2), HD (Helen's Dome), NS (North Slope), MT (Mica Tower), IS (Italian Springs), ES (East Slope), CC (Chimenea Creek), and DB (Devil's Bathtub).

RINCON PEAK COLLECTION SITE (Fig. 4)

Rincon Peak (see RP on Fig. 4), capped by a rocky promintory, has limited area above 7,000 feet (2,100 m) in elevation. Vegetation near the summit comprises a complex mosaic. The north face of the peak supports mixed conifer timber, pockets of pinon-juniper (*Pinus discolor/Juniperus deppeana*), areas of oak brush and chaparral, as well as a few small suppressed stands of aspen. Several drainages on the east side have considerable populations of Arizona cypress (*Cupressus arizonica*). Beneath the peak, there are several stands of mature ponderosa pine isolated from the main body of timber beneath the peak by thick oak brush and chaparral vegetation. There are no large areas of open pine forest as are found on Mica Mountain. The lower slopes are similar to those elsewhere in the Rincons, in both topography and vegetation.

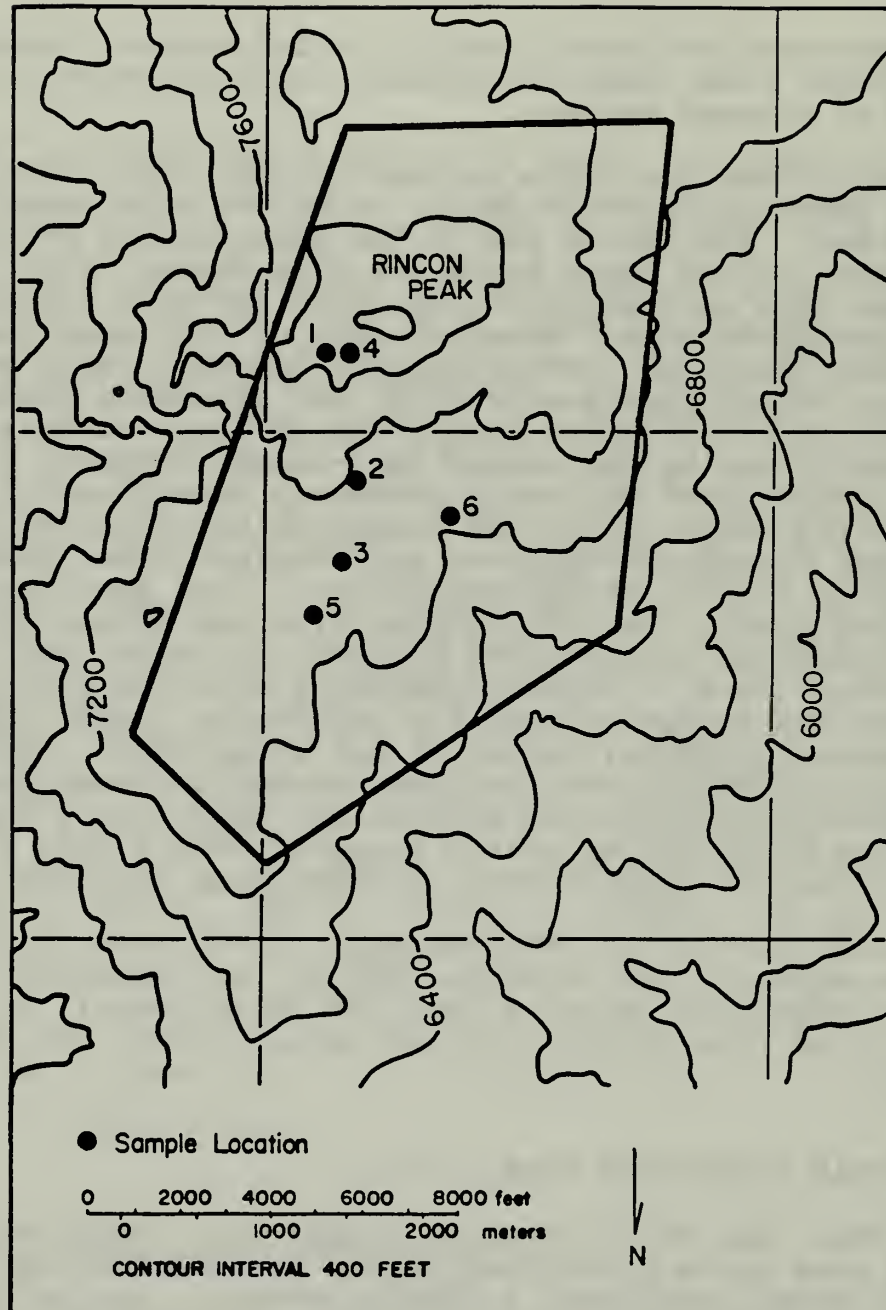

Figure 4. The Rincon Peak collection site and sample locations. *See* Fig. 1 for the location of this study site (RP).

HAPPY VALLEY KNOLL AND TANQUEVERDE PEAK COLLECTION SITES

Two additional samples were collected near Happy Valley Lookout and a single sample was collected in the pine-oak forest near Tanqueverde Peak (TVP on Fig.1). Happy Valley Knoll (HVK on Fig. 1) was severely impacted by the Turkey Creek fire of 1954 and the area is now overgrown with oak brush, hampering the location and collection of samples. More work deserves to be done in this area, particularly in light of the high ignition rate along Heartbreak Ridge. The sample from Tanqueverde Peak proved problematical and was not dated. A much larger collection of samples from this area might bear fruit as there is ample evidence of recurrent fire.

RESULTS AND DISCUSSION

RINCON FIRE DATA

Saguaro National Monument has fire occurrence data for the fifty year period from 1937 to 1986. During this period, 411 lightning fires were recorded for a yearly average of eight ignitions. The range is from a low of one fire, recorded one year, to a maximum of twenty-one fires. Figure 5 depicts the relative timing, precipitation, number of fires, and total area burned (in hectares). The data is for lightning fires only (**prescribed natural fires**, or **PNFs**, which were allowed to burn after 1971 are not included in the data).

The majority (82 %) of the recorded lightning ignitions occur above 6,500 ft. (2,000 m) in elevation and are concentrated heavily around the summit of Mica Mountain (Fig. 6). Relatively few fires have occurred on Rincon Peak, which is nearly the same height. Forest service records show a similar pattern of scattered fire occurrence on the southern flank of the peak, which is part of the Coronado National Forest. Local ranchers in the 1930's attributed the unequal distribution of fires to the observation that the sharply defined, exposed rock summit of Rincon Peak seemed to draw the lightning to it. Since the forested area does not ascend to the peak, 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. Tanqueverde Ridge has had widely scattered fire occurrence with the exception of a slightly clustered pattern along its northwestern tip between 3,000 and 4,000 feet elevation (Fig. 5).

The distribution of fires by cover type (Fig. 7) (inferred from elevation; type designation from Bowers and McLaughlin 1987) shows that 89 % of the total fire occurrence is split between the pine-oak forest (48%) and the ponderosa pine/mixed conifer forest (41%). The remaining 10 % is scattered in the lower elevations with 3 % occurring within the desert scrub. A number of large fires have occurred in the Rincons after 1912 in spite of the prevention and control efforts instituted at that time. A 600 acre (240 ha) fire occurred in 1927 when the mountains were still part of the Coronado National Forest.[2] The first large fire to occur under National Park Service administration was the Manning Camp fire of June 6, 1943 which burned over 5,000 acres (2,000 ha). The cause of this fire was never positively determined but is generally attributed in the fire records to lightning.

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[2] The exact location of this fire was not determined.

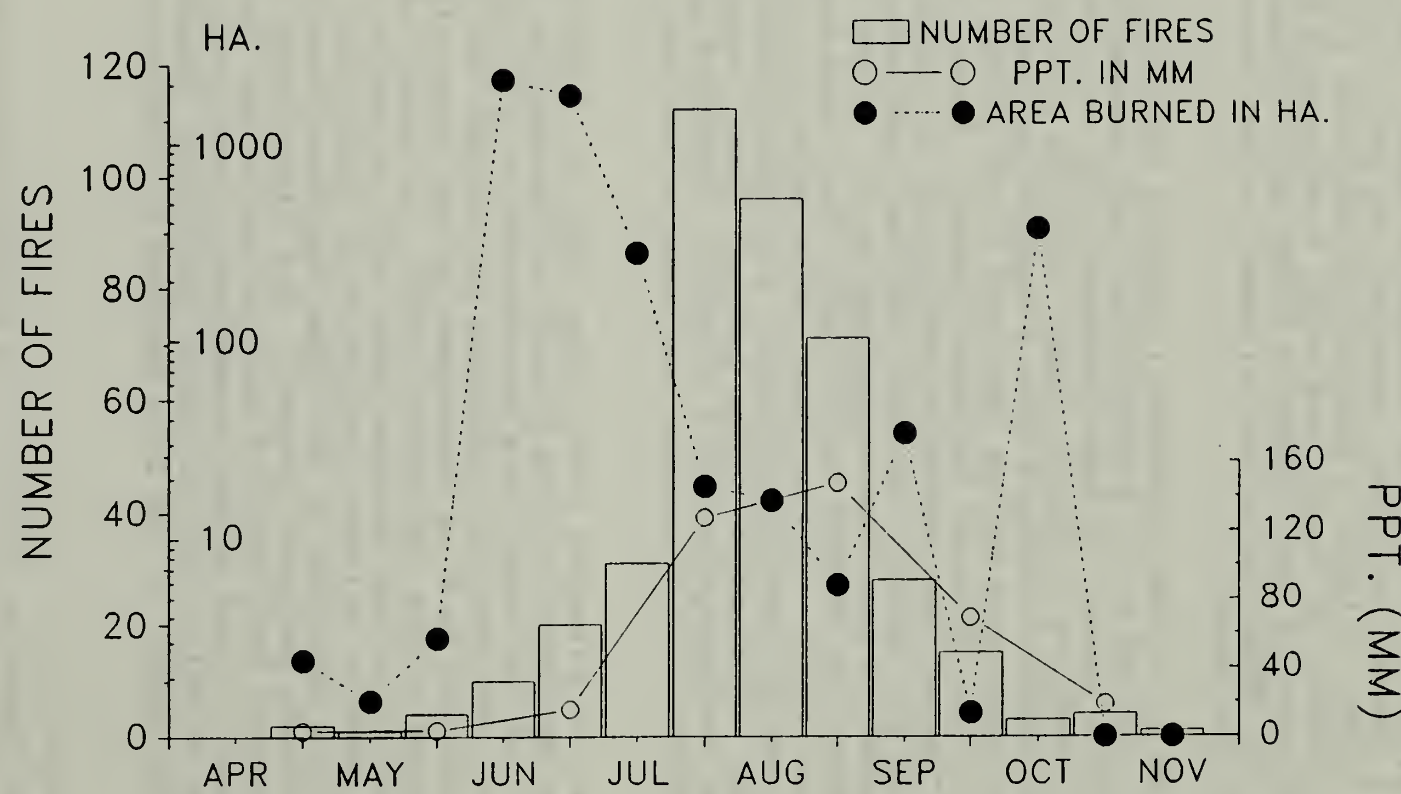

Figure 5. Mean total monthly precipitation on Mica Mountain during the fire season versus the number of lightning fires and area burned from 1937 to 1986. Number of fires and area burned are cumulative totals by two week periods. Note log scale for area burned.

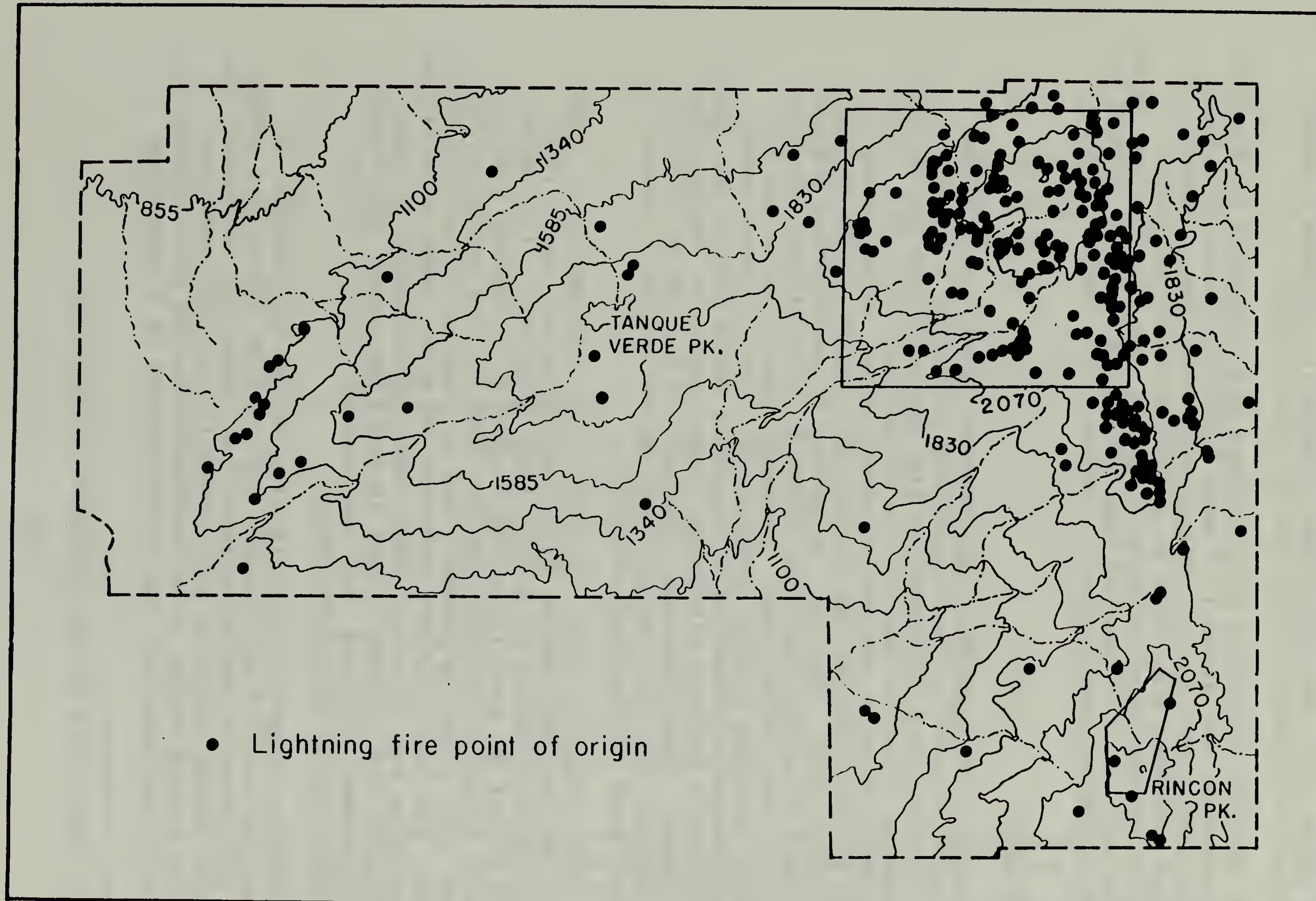

Figure 6. Locations of lightning ignitions in the Rincon Mountains from 1937 to 1986. (*See* Fig. 1 for a details of the map and its location in southern Arizona.)

Six other fires over 10 acres (4 ha) in size have occurred in the monument since 1937, excluding PNFs (Table 2). Figure 8 shows the location and extent of all six of these fires.[3]

In 1971 a natural lightning fire program was initiated at Saguaro National Monument and since 1972 many lightning fires have been allowed to burn under certain prescribed conditions. Several of these fires attained some size in spite of the relatively conservative prescription of this program. The Four Corners fire, ignited on July 28, 1972 spread over 620 acres (250 ha) before it was extinguished by wet weather in August, four weeks later.

FIRE-SCAR DATA

It was possible to crossdate samples from 50 of the 54 fire-scarred trees sampled. These specimens preserved over 900 individual fire scars representing 119 separate fire years which were assembled into the master fire chronology (Fig. 9). This reconstruction shows a pattern of wide-spread, major fires occurring at intervals of one to thirteen years within the Mica Mountain study area. Smaller, or patchy fires occurred during some of these intervals but the larger fires dominate the fire regime within this study area. Although intervals of one to three years occurred between some major fires, in most cases these represented the burning of separate areas within the study site. Intervals between site-wide fires were more commonly four to seven years. Two fire-free intervals of ten 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 234-year period (1657-1893) was 6.1 years (Fig. 10). During this period 41 major fires occurred. Fire return intervals (FRIs) at specific sites ranged up to twenty years. The 32-year interval between 1809 and 1841 in the record of the Mica tower (MT) group is probably due to sample limitations 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 probably due to limited sample depth during 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 burn the potential for re-occurrence of a spreading

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[3] The Chiva fire is not included on this map.

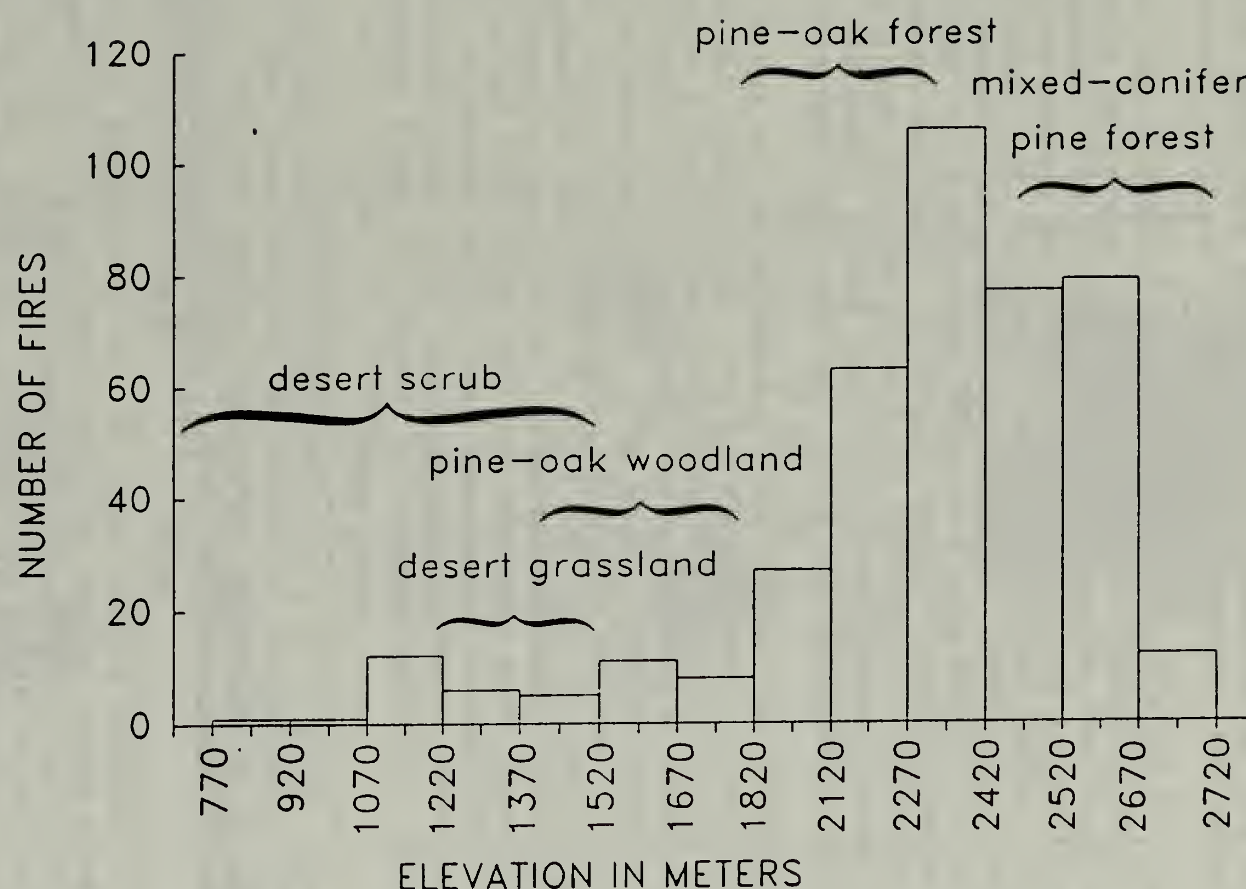


Figure 7. Number of lightning fires 1937-1986 by elevation and cover type. Cover type inferred from elevation. Type designations from Bowers and McLaughlin (1987).

Figure 8. Map of modern wild fires over 10 acres in size.

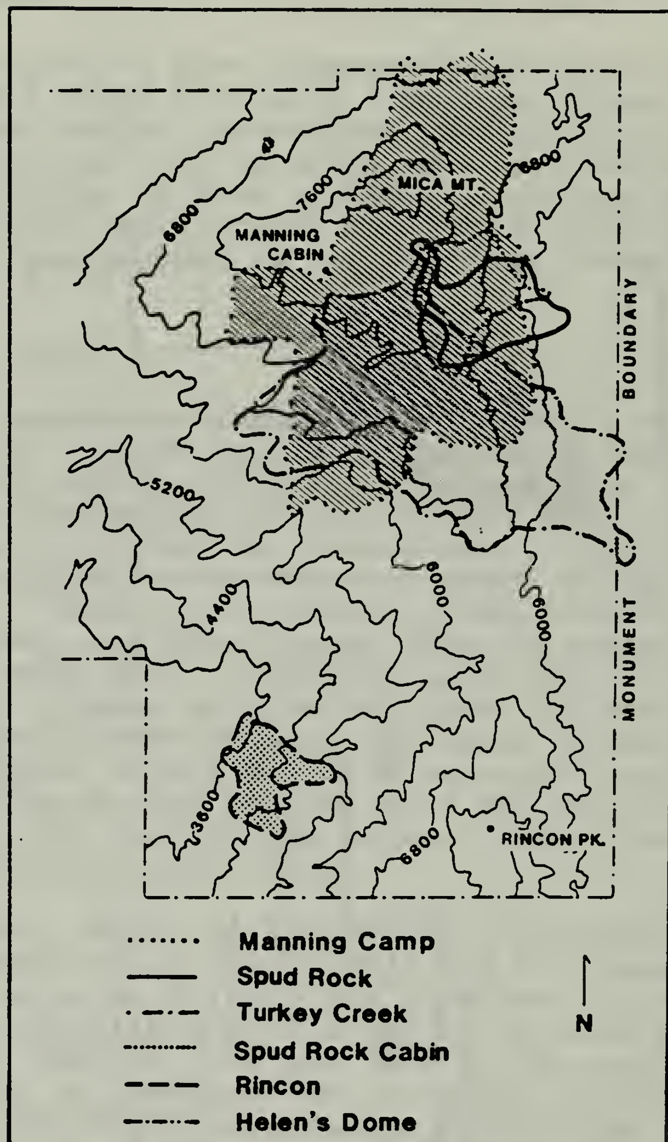


Table 2. Modern wildfires over 10 acres in size.

FIRE NAME	DATE	AREA: HA.	ACRES
Manning Camp	June 6, 1943	2,051	5,065
Spud Rock	July 1, 1950	223	550
Turkey Creek	June 20, 1954	1,729	4,270
Spud Rock Cabin	October 1, 1956	364	900
Rincon	June 5, 1960	40	100
Helens Dome	June 21, 1966	21	9
Chiva	July 5, 1989	3,725	9,000

fire would be lessened for several years. Site-wide fires which resulted in even fuel reduction would thus initiate a corresponding cycle of fuel accumulation, increasing the chance that the next fire would also be area-wide. Based on the data, the fire-reduction value of these surface fires lasted 3-4 years.

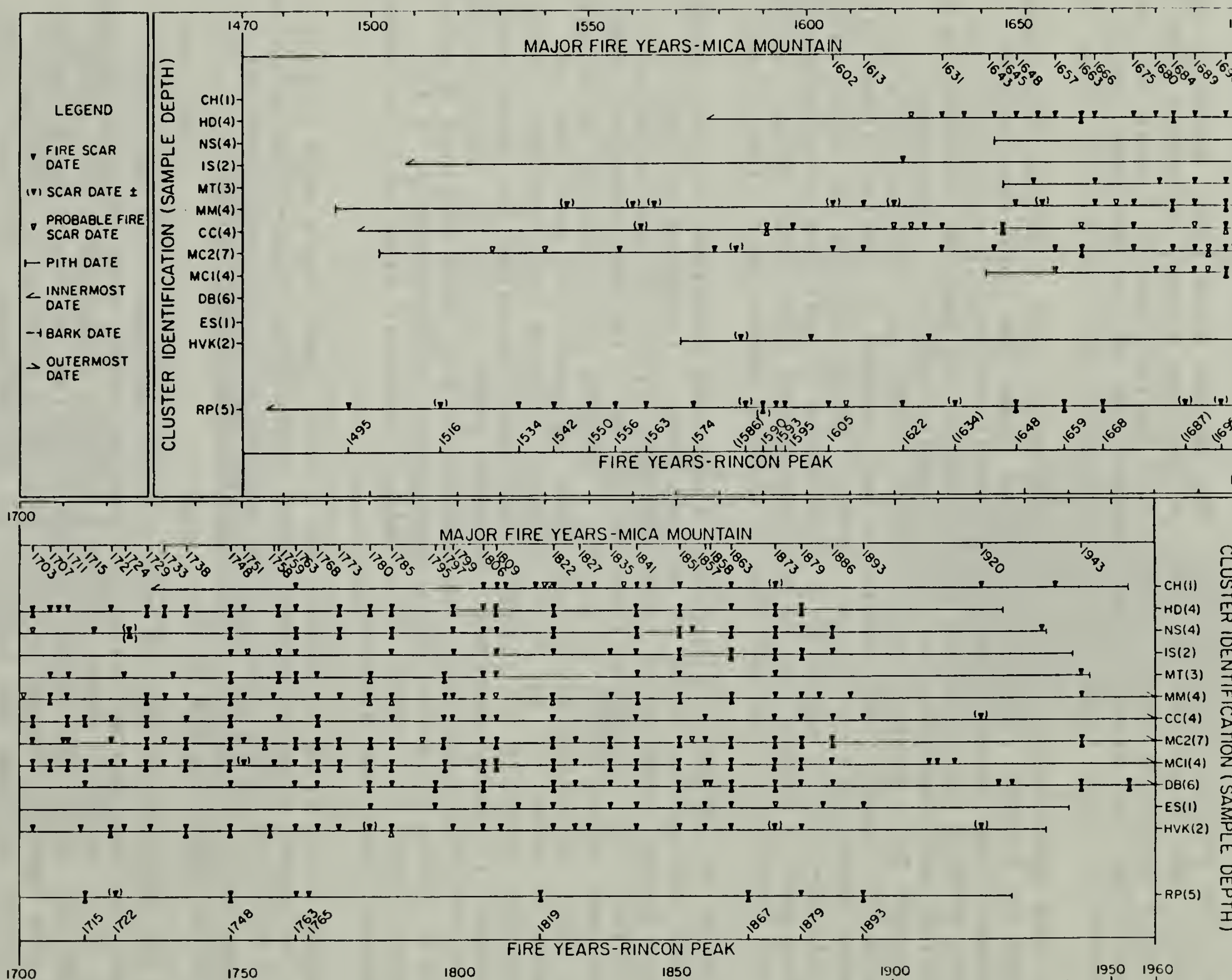
Open pine forest, typified by the Helens Dome (HD), Manning Camp 2 (MC2), and Mica Meadow (MM) collection sites, occupies much of the Mica Mountain study area. The approximately 7 year FRI at these sites was probably representative of the average return interval in this forest type throughout the study area (Fig. 10).

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 out reproduction on a regular basis. Conversely, increased fuel production on moist sites in combination with decade or longer fire intervals may result in hotter fires with greater mortality of mature trees. Small stands of aspen within the mixed-conifer sites are indicators of patches of intense fire in the past. Thus, the fire history and overstory mosaic suggest a more dynamic situation than the more xeric open pine sites.

Evidence of larger-scale crown fires was observed at the mixed-conifer collection site on Rincon Peak. Isolated groups of mature pines, separated from the main stand by oak brush and chaparral, may represent the relics of a larger forested area which 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. This infrequent pattern of ignition probably resulted in occasional, extended fire-free periods. During such intervals, fuel buildup and regeneration in this steep terrain may have reached a point where a crown fire could be sustained. Consequently, a few intense fires at longer intervals could have produced the mosaic of cover types now present.

Although fire-free intervals of 4 to 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. Such variability seems to be characteristic of the site.

Over 50 percent of the 27 major fires between 1729 and 1886 appear to have burned over the entire study area on Mica Mountain (Fig. 9). Some of these fires probably exceeded 8,000 acres (3,000 ha) in size, based on the location of the sample points. From the modern record it is clear that favorable burning conditions precede the arrival of the monsoon, the area burned being greatest in June and resulting from relatively few fires. The largest prescribed fire (PNF) ignited on July 28, 1972 during



LEGEND
FIRE SCAR DATE
SCAR DATE ±
PROBABLE FIRE SCAR DATE
PITH DATE
INNERMOST DATE
BARK DATE
OUTERMOST DATE
CLUSTER IDENTIFICATION (SAMPLE DEPTH)
MAJOR FIRE YEARS-MICA MOUNTAIN
FIRE YEARS-RINCON PEAK
CH(1)
HD(4)
NS(4)
IS(2)
MT(3)
MM(4)
CC(4)
MC2(7)
MC1(4)
DB(6)
ES(1)
HVK(2)
RP(5)
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1800
1850
1900
1950
1960

Figure 9. Master fire chronology for the Rincon Mountains. Fire scar 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.

the monsoon season, burned for four weeks and covered only 650 acres (250 ha). By contrast, the largest modern wildfires ignited in June or early July and spread over several thousand hectares in only a few days time in spite of active suppression efforts. This suggests that ignitions during the fore-summer drought would spread readily. In particular, ignitions occurring during May would have as much as 8 weeks to spread uninhibited by weather conditions and might attain considerable size. Newspaper accounts suggest that large fires were relatively common during the 19th century in southern Arizona (Bahre 1985).

The last of the pre-1900 widespread fires occurred in 1886. Smaller fires continued to occur, but the overall pattern ceases abruptly at this point. This change in regime coincides with the removal of the Apache threat and resulting increased use of the area by both Hispanic and Anglo settlers, particularly for livestock grazing (Clemensen 1987). The reduction in fine fuels accompanying grazing pressure in combination with the 1890s drought and followed by the initiation of active fire suppression efforts in the early part of this century are probably responsible for the change in fire regime.

Two samples from one of the lower elevation groups (CH - Cow Head) and the sample collected from Tanque Verde Peak comprise four of the five samples that were not dated. Neither these samples nor increment cores collected from living trees at these collection sites could be crossdated. This was due to the sporadic formation of intra-annular bands of latewood cells (false rings) which are difficult to distinguish from true annual ring boundaries. These confuse the tree-ring series and make cross dating unreliable. The longer growing season and more pronounced early summer drought present at lower elevations and on exposed slopes below 7,500 feet may be responsible for this phenomenon as drought stress can cause the formation of latewood bands during the growing season (Fritts 1976).

Fire Occurrence and Drought

The relationship of the fire chronology with the reconstructed July PDSI series is presented in Figure 10. Although a number of widespread fires occurred during years that 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 average (Fig. 12).

This is perhaps to be expected, for burning conditions during the fore-summer drought are nearly always favorable, regardless of the general precipitation pattern for a particular year. However, the mean PDSI index value for the two years preceding the fire year was generally positive, indicating wetter than average conditions. In fact, the general trend appears to be

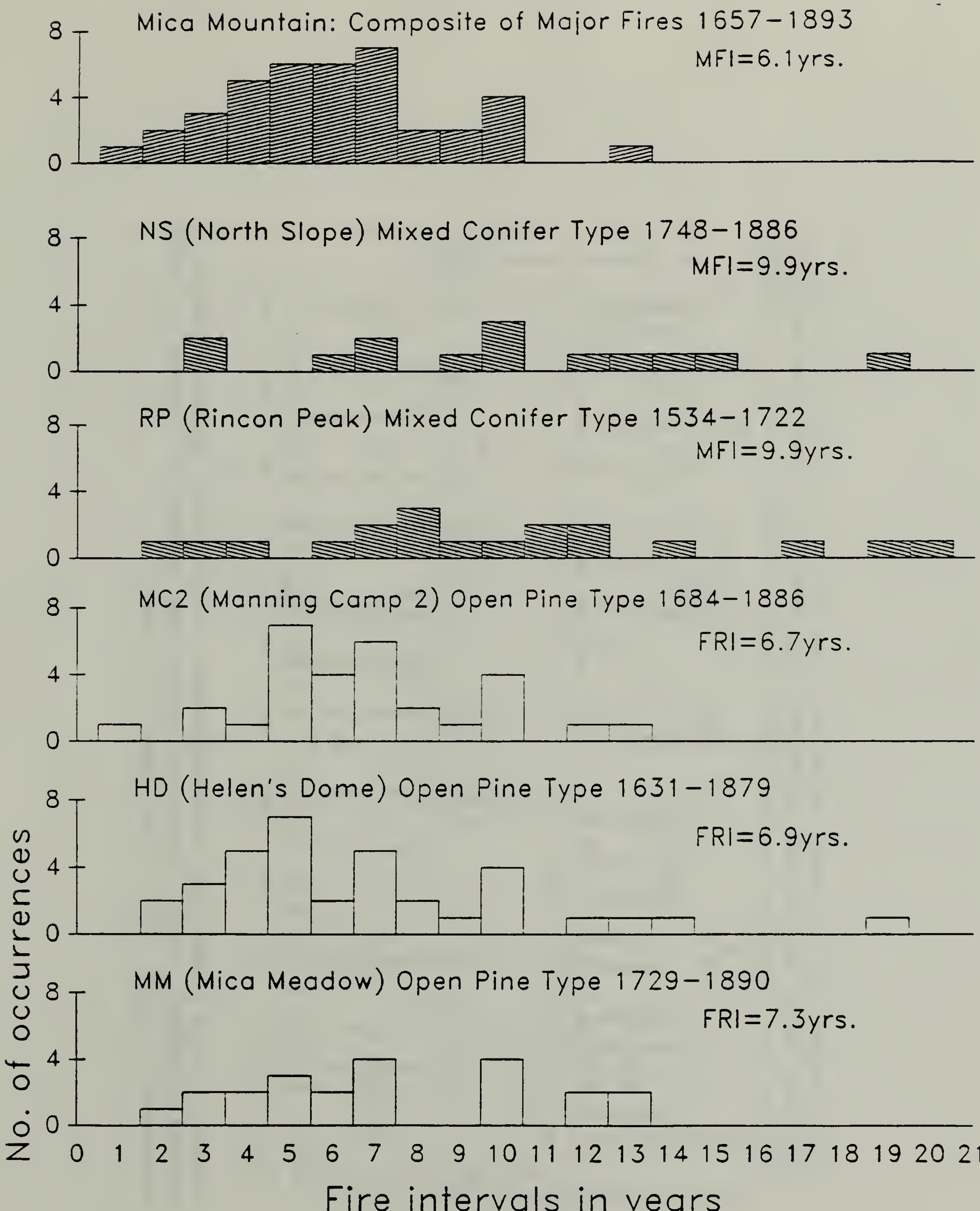

Figure 10. Fire intervals compiled for several collection sites including a composite for the Mica Mountain study area. All sites show considerable variability.

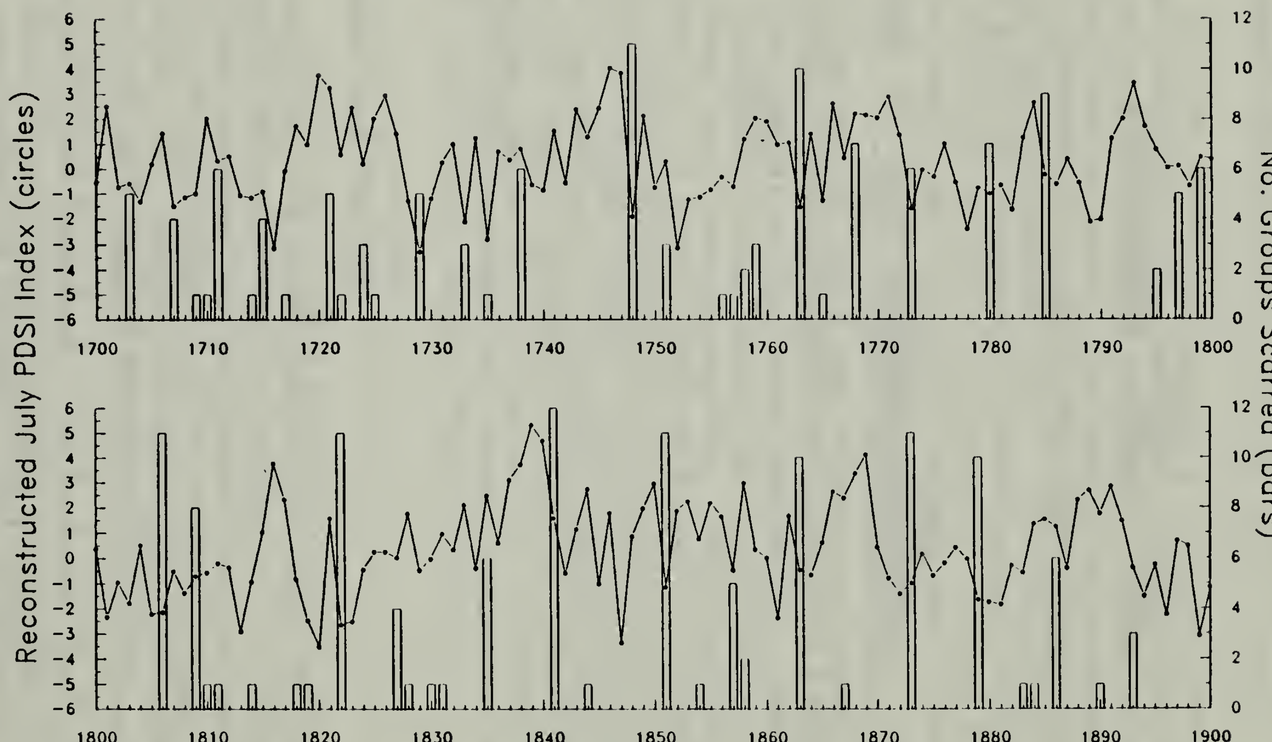

Figure 11. A tree-ring reconstruction of the July Palmer Drought Severity (PDSI) index 1700-1900 versus the number of groups of trees recording a fire. All fire years are shown.

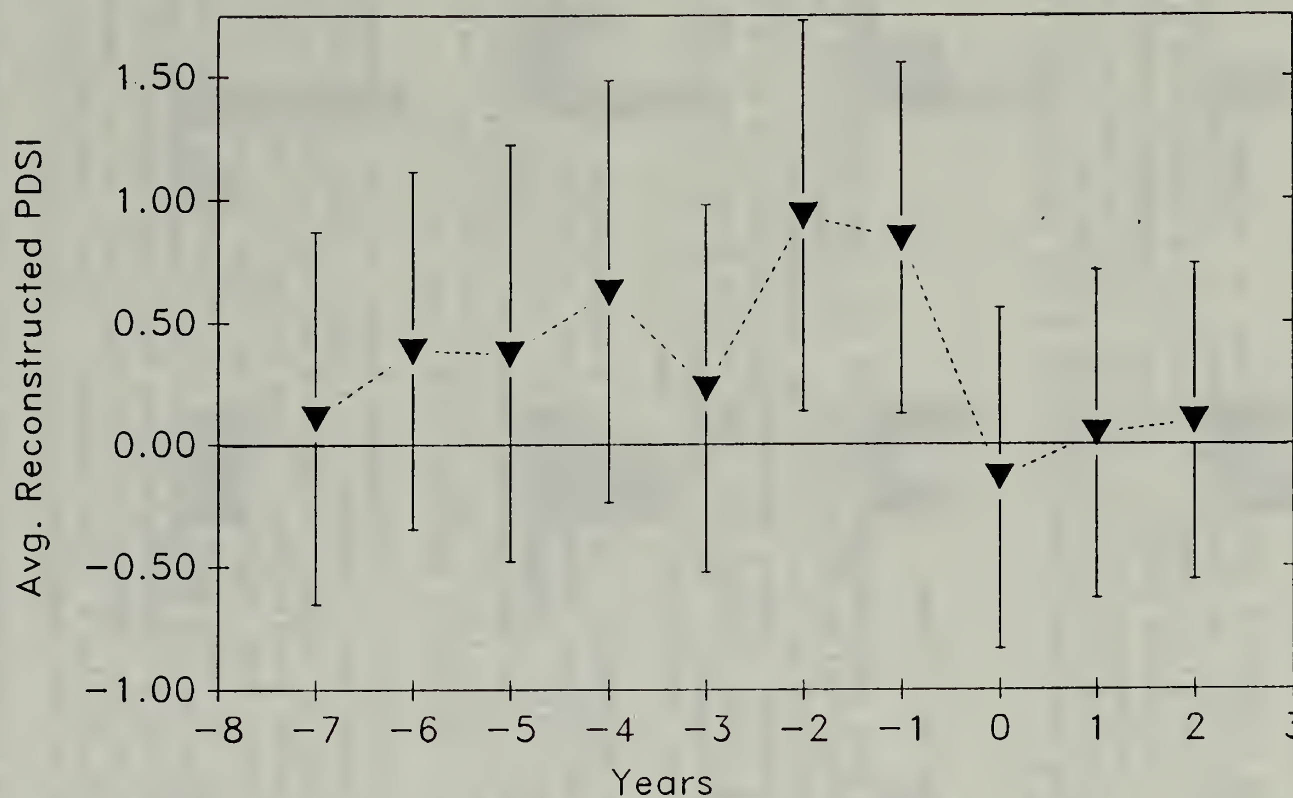

Figure 12. Average reconstructed PDSI for seven years preceding and two years following 35 major fire years for the Mica Mountain study area. Error bars represent the 99% confidence interval.

wetter than average conditions prevailing for two to six years followed by a fire occurring during an average or slightly droughty year. This trend indicates that the wet years inhibited fire activity and encouraged production of fine fuels (herbs, grasses, deciduous leaves, etc.). Ignitions, as indicated by the modern data, are always present but are more apt to result in spreading fires under these conditions.

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 U.S. (Swetnam 1990). Synoptic weather patterns which affect fuel moisture in the spring, the arrival of the monsoon, and 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. This conclusion is also consistent with the modern fire occurrence data (see Fig. 4).

Data from the Mica Mountain chronology were sorted by fire date, and a series of histograms constructed for 15 major fires between 1700 and 1893 (Fig. 13). 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 spread of values in some cases results from separate fires occurring at different times during the same year. Multiple ignitions from the same storm are a regular occurrence in the modern record and particular years have produced over 20 starts in a fire season. Such occurrences surely contributed to the apparent size of some pre-1900 fires.

Fire scars from the large modern fires occurring on June 6, 1943 and June 20, 1954 were examined for position as a check on the designations. Only one sampled tree, a ponderosa pine, clearly recorded these fires. It showed 1/3 of the ring formed by June

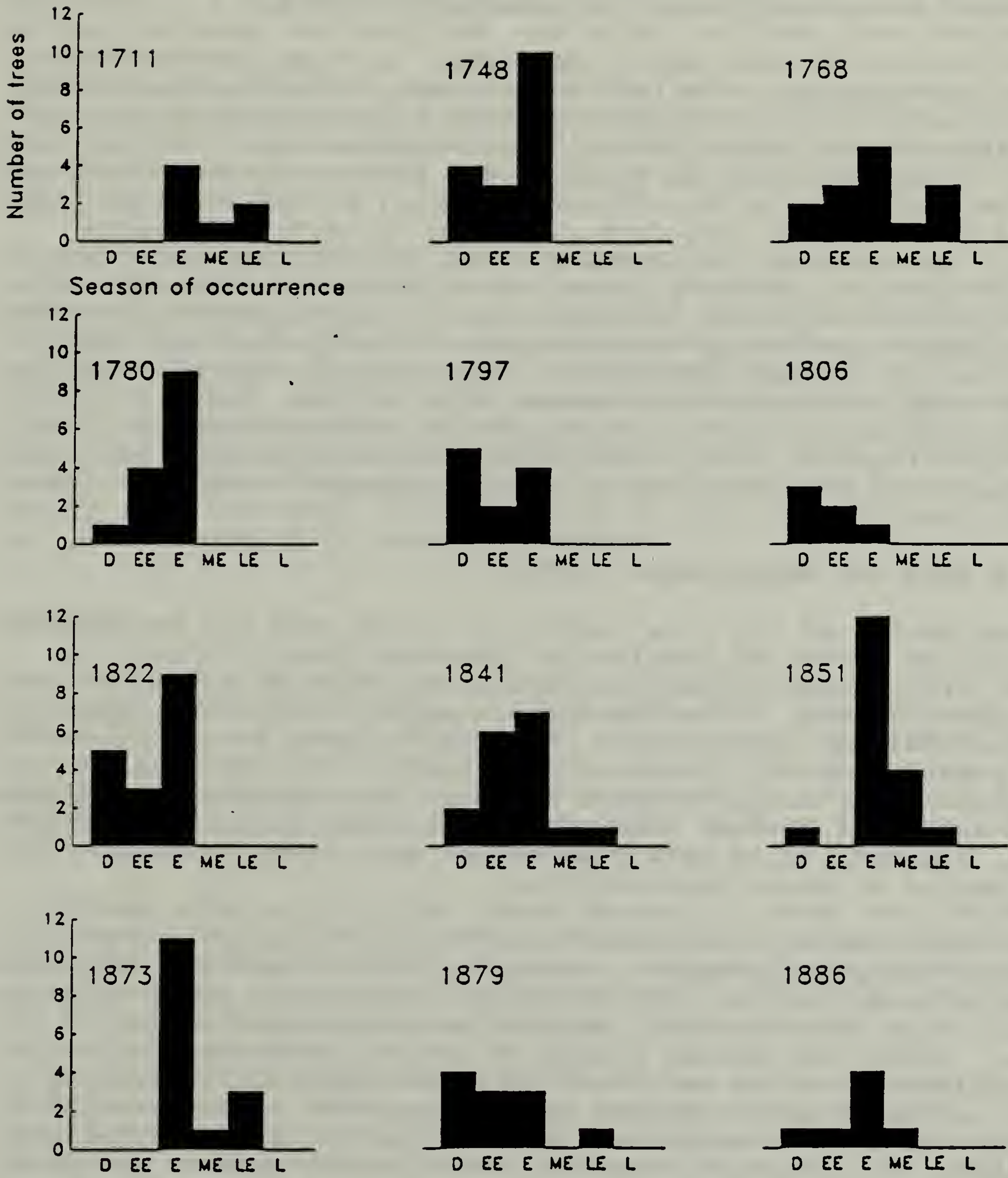

Figure 13. The intra-ring or seasonal distribution of fire scars for 12 major fire years from 1711 to 1893.

6th and 1/2 formed by June 20th. These scars were noted as ME and LE respectively confirming the seasonal estimates.

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 of 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 22 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.

RINCON PEAK AND TANQUEVERDE RIDGE

Reconstruction of the fire regime at Rincon Peak was hampered by the limited number of samples (6) obtained from this site. A number of these contained only few scars, and one could not be confidently dated. From the dated samples, a MFI was computed for two periods: 1534 - 1722, MFI = 9.9 years; 1867 - 1893, MFI = 13 years. Some of the fire dates (1648, 1715, 1748, 1763, 1879, and 1893) match the Mica Mountain fire chronology. However it is not clear whether these data represent single, very large fires, separate fires occurring on the same year, or some combination of these possibilities.

All of the samples were collected from the steep north facing slope of the peak between 7,000' and 8,500' elevation. This area supports mixed conifer timber, pockets of pinon - juniper, areas of oak brush and chaparral, as well as a few small stands of aspen. There are several stands of mature ponderosa pine which are isolated from the main body of timber beneath the peak by thick oak brush and chaparral vegetation. The appearance is of a forested area whose edges have been trimmed back by crown fires leaving a few isolated groups of trees in sheltered or protected pockets.

As previously mentioned, monument fire records show only nine starts on Rincon peak over the last fifty years as opposed to over 350 on Mica Mountain during the same period. Possibly, the low frequency of ignitions reflected in the modern records is an inherent feature of this site. This pattern may also have allowed occasional, extended fire free periods. During such intervals, increased fuel loading and regeneration in this steep terrain may have reached a point where a crown fire could be sustained. A slight increase noted in the MFI on Mica Mountain during the late 18th and 19th centuries may have been exaggerated somewhat on Rincon Peak. Possibly, a few intense fires at longer intervals produced the mosaic of cover types now present. However, the events which produced this pattern occurred before 1900 as there is no modern record of any large fire occurring on the peak above 6,000 feet (1800 m) and the last fire scar date obtained is 1893.

No record was reconstructed for Tanqueverde Ridge. Only a single sample was obtained from this area and it could not be dated. Ample evidence exists of fire occurrence throughout this area in the form of charred logs, snags, and woody debris. Repeatedly scarred trees are also present, including juniper, white oak, and ponderosa pine. However, the only conclusion this study can reach is that occasional fires did occur here. Possibly, some of the fires ignited on Mica Mountain could have spread to this area as well and contributed to fires ignited along the ridge itself. Twenty four lightning fires occurred in this area between 1937 and 1987 according to monument records.

SUMMARY

An examination of figures 9 and 10 reveals a pattern of relatively widespread fires which occurred at intervals of three to ten years. A rough estimate of the minimum range of size for these widespread fires, based on the spatial distribution of samples, is 500 to 8,000 acres (200-3,000 ha). Smaller fires also occurred. However, the fire regime appears to have been dominated by these larger, episodic fires.

A minimum interval of three years appears to have been necessary to generate enough fuel to carry a widespread fire. A four or five year interval was more common. One and two year intervals did occur, but most often, as in the 1795, 1797, and 1799 fires, the areas burned were separate, with little overlap.

Five relatively fire-free intervals of ten years or more in duration occurred on Mica Mountain between 1640 and 1893. Each of these intervals was followed by a widespread fire, or series of fires, recorded by virtually every cluster of trees sampled. The two longest intervals were both preceded by two short interval, widespread fires recorded by most of the sample trees. Perhaps the reduction of fuel by the fires preceding these gaps influenced their length.

Fire occurrence appears to have been confined to the late spring and early summer on Mica Mountain. Although some of the large fires probably burned for many weeks, they all appear to have been extinguished by the monsoons (perhaps having exhausted their fuel source). Late season fires were probably exceedingly rare, as very few late season fire scars were discovered.

Thus, the cycle of fuel build-up and reduction by fire is a variable, dynamic process influenced by several factors. During a fire-free interval of ten years, however, enough fuel was produced to virtually ensure that the subsequent fire would sweep the mountain, reducing the fuel load substantially over the whole area, and initiating another cycle of fuel buildup.

ANTHROPOGENIC INFLUENCE

The question, "what constitutes a 'natural' fire regime?," has received considerable attention in recent years (Lotan et al. 1985). Specifically, determining the extent and relative importance of human influence on prehistoric landscapes is being recognized as an issue with important implications for land management in natural areas. A number of authors including Pyne (1982), Cooper (1960), Dobyns (1978), Hastings and Turner (1965), and Bahre (1985) have discussed the impact of people and human ignition on pre-settlement[4] fire regimes in the Southwest. Several of these authors have hypothesized that human ignition was a significant factor in some areas. Pyne (1982), in particular, has emphasized that Athabascan (Apache) peoples used broadcast fire in upper elevations rather extensively and were a significant ecological force. Therefore, a portion of this study was devoted to an attempt to determine whether, and to what extent, human ignition has been a factor of significance in the pre-settlement fire regime of the Rincon Mountains. Influences of the post Anglo-settlement period were also considered in relation to the cessation of large fires in the late 19th century.

THE PRE-SETTLEMENT PERIOD: HISTORICAL BACKGROUND AND HUMAN IMPACT ON THE FIRE REGIME

The San Pedro River Valley, to the east of the Rincons, has evidence of human occupation dating back more than 10,000 years (Haury 1953, Huckle 1984*a*). Box Canyon, at the southwestern tip of Tanque Verde Ridge, shows relatively continuous record of human use and occupation dating from approximately 5,000 B.C. to around 1450 A.D. Other sites in the cactus forest and in Rincon Valley have evidence of extensive use (Simpson and Wells 1984). The early portion of this period represents use by hunter-gatherer people. Maize was introduced to the area around 1500 B.C. and a slow shift toward agriculture was initiated. Pottery was introduced by about 200 A.D.(LeBlanc 1982). This phase reached a height around 1250 A.D. with people living relatively sedentary lives in small towns or villages and practicing both dryland farming and irrigated agriculture.

For unknown reasons this pattern disappeared around 1450. When Spanish missionaries arrived in 1694, little direct use was being made of the Rincon Mountain area. The nearest residents were Sobaipuri farmers who occupied rancherias along the permanent

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[4] "Pre-settlement" refers the period preceding settlement by Anglo peoples in the late 19th century.

water courses of the San Pedro and Santa Cruz Rivers. There is little evidence that these people were using the upper elevations of the Rincons to any significant extent (Simpson and Wells 1984), although this assessment is based on relatively limited archaeological fieldwork in sites of this time period.

The Sobaipuris were, at this time, fighting and occasionally trading with Apachean groups living to the east (Bolton 1919). The Spaniards encouraged animosity between the groups at the expense of the trade relationship. The conflict served the purposes of the missionaries who used the Sobaipuris of the San Pedro Valley as a military buffer for their missions along the Santa Cruz (Di Peso 1953).

In 1762 the hit-and-run warfare tactics practiced by the Apaches succeeded in driving the remaining Sobaipuris from the San Pedro valley and they retreated to the Santa Cruz Valley. A Spanish garrison was established briefly at Santa Cruz de Gaybanipitea near the San Pedro River but was soon abandoned as indefensible (Di Peso 1953).

Thus, from 1762 to 1886 the Rincon Mountains were part of Apacheria and the San Pedro Valley as well as the adjacent Santa Cruz became a war zone. The Apaches apparently did not live in the San Pedro Valley; their nearest known permanent settlement was in Aravaipa Canyon to the North (Basso ed. 1971). Therefore, the Rincons were peripheral territory. However, the Apaches used mountainous areas as staging points for raids and as secure retreats afterwards. Apache presence in or near the Rincons is noted in several documented references, the last occurring in 1886 (Bigelow 1968).

Firsthand references to the use of fire by Apaches and references to the habits of the Sobaipuris regarding their use of fire were sought and tracked down. While a great deal of material of potential interest exists, sufficient time was not available to locate, read, and properly distill it. However, much was learned from this endeavor and is presented, here, as a start.

No reference to Sobaipuri uses of fire that were ecologically significant were located. However, the little that is known about these people suggests that they were sedentary farmers who made little use of, and had little need for, the resources of mountainous areas (Di Peso 1953).

As do all people, the Apache used fire for many purposes. Specific, well documented uses which might have ecological impact are limited to fire hunting (Pinchot 1947, Gifford 1940) and accidental ignition (escaped fire). Fire hunting involves the controlled and limited use of fire in a confined area. Uncontrolled wildfire can be dangerous and must have been respected as such. It is unclear whether this practice was common and widespread enough to be of ecological significance. It is doubtful that accidental ignitions could have been frequent and widespread enough to be an ecologically significant force in a given area.

Apache uses of fire, which have been cited but for which documented, firsthand accounts were not located, are as follows: (1) use of fire to bring rain by setting large tracts of forest alight (Pyne 1982); (2) use of fire in warfare (other than to burn specific structures or goods) (Bourke 1891, 1958 and diaries; Holsinger 1902; Pyne 1982); and (3) use of fire to clear underbrush (Pyne 1982).

Evidence in Bourke's accounts leaves the impression that the documented Apache custom of burning the houses of the dead in a cleansing ritual may have extended to include burning over battle sites where Apache warriors had been slain (Bourke 1891). Another possibility is that this ritual was practiced to confuse the trail of the retreating warriors (Pyne 1982).

Dobyns (1978) constructed an elaborate hypothesis concerning Indian use of fire based on a single instance of an alleged Apache "burning pasturage" and hearsay evidence that some Indians had set logs burning in Aravaipa Canyon. Dobyns (1978) interpreted these incidents as "fire hunting," however it is unclear from reading his translation of a Spanish document why he came to this conclusion.

Conrad Bahre (1985), in a very interesting examination of fire occurrence in southern Arizona prior to 1900, researched newspaper accounts for references to wild fire. He concluded that since newspapers attributed fires burning in the mountains to the Apaches, some of them probably were set by these people. However, an examination of the dates of fire occurrence in the table he presents reveals that all but two of the wildfires documented occurred during southern Arizona's lightning fire season between May and September. Although the Apaches may have set some of the fires mentioned in the newspaper accounts, these accounts were, in most cases speculation from afar by newspaper reporters. Furthermore, lightning was conspicuously absent as a mentioned cause. In all cases where a cause was assigned, fires are attributed to human action, either intentional or accidental.

An excerpt from Lt. Bigelow's account of the Apache campaign of 1885-1886 is of interest here. On June 4, 1886, after having spent the previous nine days scouring the Rincons for sign of the Apaches, his company received the following dispatch from Ft. Lowell near Tucson:

> Signal fires have been seen in the Rincon Mountains the last two nights. A party of eight Indians was seen in San pedro Valley last night. Today Mr. Davis was

> killed at three o'clock, four miles east of Vail's ranch. Lieutenant Weaver and fifteen scouts leave here tonight for the scene of the killing. These Indians have evidently been in the Rincon Mountains for the last two weeks (Bigelow 1968, 202).

Lt. Bigelow comments upon receiving this information:

> ...*These signal fires are doubtless the burning woods that have been observable to us ever since we came here*. I cannot believe in the Indians in the San Pedro Valley, as long as I know nothing as to the persons reporting them. I do not question the killing of Mr. Davis, but think it quite as probable the work of a Mexican or an American as of an Indian." (Ibid, 202; italics added)

The case for Apache ecological impact through widespread use of fire is certainly not clear-cut and is worthy of careful and considered study. However, it seems unlikely that Apache burning practices, whatever they were, had a significant impact in the Rincons, particularly since these mountains were marginal territory.

For the purpose of comparison, the most complete portion of the fire scar record can be separated into two segments. The first segment begins with the fire year of 1657 and ends in 1763, one year after the retreat of the Sobaipuris to Tucson. This date marks the beginning of unrestricted Apache access to the Rincon Mountains. The second segment extends from 1763 to 1886, the year of Geronimo's surrender. The MFI calculated for major fires during the first segment is 5.3 years and is 5.9 for the second segment. When all recorded fires are included, the MFI for the first segment is 3.7, and 5.6 for the second. Thus, fire frequency decreased slightly during the period in which the Apaches had full control of the area. If the Apaches were adding fire to the area, it is not detectable as a decrease in the mean fire interval (due to an increase in the number of fires occuring).

If the Apaches did set fires in the Rincons the result may not be measurable as an increase over lightning ignitions. One alternative explanation for the decrease in fire frequency is that long-term fluctuations in regional climatic patterns can exert subtle influences on local fire regimes, resulting in fluctuations of the mean fire interval over time.

THE ANGLO SETTLEMENT PERIOD

A sample of the late nineteenth century accounts of wildfire occurrence reviewed by C. Bahre (1985) are repeated here.

> "For the last month the country north, south, and east of Tucson has been in a constant blaze. The grasses on the mesas, mountains, and in the valleys, have been eaten up by the flames; during the last two days the fire has traveled over the Santa Catarina [Catalina] Mountains and is burning now miles beyond. It has climbed almost to the summit of the Santa Rita, after devouring most of the pastures below, and bids fair to continue its course until the grass of the whole country has been licked up in flames. . . " Arizona Star, June 23, 1877.

> "Fires have been raging in the mountains east and south of here [Tucson] for some time past. . . " Arizona Weekly Star, May 22, 1879.

> "The southeastern slope of the Santa Catarina and the west side of the Rincone [Rincon] mountains have been ablaze for the last four days. . . " Arizona Weekly Star, June 19, 1879.

> "The fires in the Santa Catarinas continue their destructive work." Arizona Weekly Star, June 26, 1879.

> "For the past two weeks fires have been burning on the Santa Catalina, Santa Rita, Pajarito, and Oro Blanco Mountains; during that time over 100 square miles have been burned over. . . " Tucson Daily Record, June 4, 1880.

> "Immense forest fires are still prevailing in some parts of western New Mexico and southern Arizona. . . " Arizona Daily Star, May 21, 1882.

These widespread fires were generally viewed as depredations on the environment, at least by the editors of local papers. Thus, a local bias in favor of fire control existed well before the U.S. Forest Service made it official policy. However, no means implementing fire control with any consistency existed until after 1912 when Forest Service personnel were stationed in the back country during the fire season (Clemensen 1987).

When Lieutenant Bigelow visited the Rincons in the early summer of 1886 he had trouble finding any knowledgeable guides, for few people except the Apaches were familiar with these mountains at that time (Bigelow 1968). However, there is some evidence that the high country was being used, then, to graze cattle. When Levi Manning built his cabin in 1905 there were abandoned structures and fruit trees in Mica Meadow (Saguaro National Monument records). It is possible that these early users suppressed some fires.

Another factor which may have contributed to the cessation of the fire cycle was the widespread grazing of cattle which reached its height early in the 1890's (Hastings and Turner 1965). Because grass is a primary carrier of fire, severe overgrazing during this period in combination with the effects of the 1890's drought probably had a significant impact on fire size. Another possible impact of cattle grazing on fire size is the habit of cattle to produce trails, particularly in areas with limited water where they must return to a water source repeatedly. Coronado Forest Supervisor Fred Winn commented in his memoirs that cattle trails in the Huachuca Mountains "made excellent fire breaks" (Winn, cited in Bahre 1985).

A third possible influence is climate. The early part of the twentieth century was an extremely wet period in much of the western United States (Fritts 1965; Schulman 1956). It is possible that this factor had considerable influence on fire frequency. No fire occurrence records are available for the Rincons for the period 1907 to 1937, but the evidence in the fire scar record is dramatic and clear cut.

CONCLUSION

Examination of the fire occurrence records for the Rincon Mountains leaves no doubt that lightning is a very effective ignition source. Over the last fifty years, lightning has ignited an average of eight fires each year. At least one lightning fire occurred every year for which records were available. Some years, fifteen to twenty fires occurred.

The pre-1900 fire history, reconstructed from fire scars, revealed a fire regime dominated by a regular pattern of widespread fires. The MFI (mean fire interval) calculated for major fires (fires recorded by more than one group of sample trees (est. min. size: 500 acres [200 ha.]) between 1657 and 1893 was 6 years. The shortest interval recorded between major fires was 1 year and the longest was 13. An interval of at least 3 years appeared to be necessary to generate enough fuel to carry a fire throughout the study area. Intervals between such fires were more commonly in the range of 4-7 years. Of the 27 major fires which occurred between 1729 and 1900, 14 appear to have burned over the entire study area.

The fire interval recorded in the mixed conifer timber of the north slope and on the Rincon Peak was 9.9 years with a range of 3-19 years. The average fire return interval for the open pine forest, which dominates most of the study area, was 7 years with a range of 2-19 years.

The majority of the fire scars examined were positioned within the earlywood portion of the annual ring. Only 0.5% were identified as latewood scars. This evidence strongly indicates a late spring/early summer fire season, throughout the 300 year record.

Examination of the relationship between fire occurrence and the PDSI reconstruction suggests a link between widespread fire occurrence and moderate to severe drought, particularly when preceeded by two or more wet years. This evidence, and observations of the spatial and temporal patterns of fire occurrence, can provide an adequate explanation of the fire regime, as reconstructed. This regime consists of a natural cycle of fuel buildup, ignition, and fuel reduction/ nutrient recycling linked to opportune weather conditions. There is no need to postulate any human influence on this cycle to explain the fire frequency. No evidence of any significant change in the fire regime can be related to anthropogenic influence over the 240 year time span, 1657-1900. For example, analysis of the fire scar data presented earlier shows a MFI of 5.3 years for the period 1657 to 1763, and a MFI of 5.9 years for the period 1763 to 1900. Thus, only a slight change in fire frequency occurred during this period, while the human population surrounding the area was in a constant state of flux and under the influence of a variety of cultures.

Not until the era of Anglo settlement and use of the mountain area did a change in the fire regime occur. Then, however, the change was both swift and dramatic. Simply put, the more-or-less regular pattern of fire occurrence ceased after 1893. The reason for this abrupt change was not simply the advent of effective fire control, but also a change in land use patterns and a different attitude towards wildfire, an attitude which arrived with the Anglo settlers. A temporary wet period which coincided with the advent of organized fire control cemented the change.

IMPLICATIONS FOR FIRE MANAGEMENT

The results of this study provide a fairly detailed perspective on the nature and characteristics of the pre-1900 fire regime. This information, in concert with current knowledge of fire behavior and prescribed fire management techniques, can provide a sound foundation on which to base the reintroduction of the natural fire cycle.

The Rincon Mountains, because of their topographic isolation and wilderness status, provide a special opportunity in this regard. Five potential benefits of reintroduction of natural fire regimes in the Rincons are:

(1) Maintenance of a more natural wilderness ecosystem;

(2) reduction of the potential for catastrophic fire occurrence;

(3) gaining of valuable experience during the reintroduction process;

(4) development of research opportunities concerning the effects of the reintroduction of the natural fire cycle; and

(5) realization of economic savings by reducing the need for fire control efforts in the backcountry.

However, a substantial commitment of resources would be necessary over a 10-15 year period to insure that the process reverts gradually, not catastrophically.

Five implications of the study with regard to prescribed fire management include considerations of burning intervals, seasonal occurrence of fires, fire duration, fire size, and fuel loading.

1) Burning Intervals

The <u>mean interval</u> of the natural fire cycle for the entire study area was 6 years. The <u>fire return interval</u> for the open pine forest type averaged 7 years. The <u>mean interval</u> for the mixed conifer forest type averaged 10 years. These averages suggest that a prescribed burning cycle of approximately 5-8 years would mirror the natural cycle in the open pine type. A cycle of about 8-12 years in the mixed conifer would be appropriate.

It should also be pointed out that the entire Mica Mountain study area experienced occasional fire return intervals of 2-3 years. Therefore, if burn intervals shorter than 5 years be deemed necessary to accomplish fuel reduction goals, 2 years could be viewed as the natural minimum. At the other end of the spectrum 12-15 years would be close to the natural maximum.

2) **Seasonal Occurrence**

The natural fire regime was dominated by late spring/early summer fires. This pattern suggests that, to mimic this fire regime, most prescribed burning should take place between April 15 and August 30. Initial burning prescriptions must necessarily account for extreme weather conditions, which often occur during this period, and high fuel loads, which are also present in many areas.

3) **Fire Duration**

Natural fires probably burned for several weeks to a month or more. Similar behavior should be expected if lightning initiated fires are allowed to burn early in the season.

4)**Fire Size**

Many natural fires appear to have been quite large by today's standards: some of them were 8,000 or more acres in size. It is not clear from the study results what conditions limited fire spread. One possibility is that fuel changes limit fire spread at lower elevations. This issue will necessarily have to be addressed if the natural cycle is to be reinstated.

5) **Fuel Loading**

A necessary first step toward re-establishing a natural fire cycle is an aggressive fuel reduction plan. Although some portions of the study area have remained fairly open, large areas have significant accumulations of woody debris and support dense thickets of reproduction. The combination of high fuel loadings, continuous ladder fuels and steep slopes would necessitate two or three cycles of fuel reduction to protect mature trees in these areas.

Significant mortality of mature trees has been noted following prescribed burns in northern Arizona. This presumably results from damage to the root collar from the sustained high temperatures generated as the duff mound is consumed. This effect could possibly be mitigated by conducting burns when there is sufficient moisture in the litter layer to prevent the duff from being completely consumed.

RECOMMENDATIONS FOR ADDITIONAL RESEARCH

Although this study was successful in reconstructing the fire regime of the open pine and mixed-conifer forest on Mica Mountain, fire regimes in the other vegetation types were not addressed. Additionally, the fire-scar samples collected from Rincon Peak, Happy Valley Knoll, and Tanque Verde Ridge proved inadequate to characterize fire occurrence in these areas. The indication of pre-1900 crownfire occurrence on Rincon Peak is an important finding with implications for the acceptable range of fire management options at this site and would be well worth pursuing. The high number of ignitions shown in the modern record along Heartbreak Ridge make this an area of special interest, however, due to logistical constraints, only two fire-scar samples were collected in this area. Collection of additional samples in this area would enable detailed analysis of fire spread patterns on Mica Mountain under natural conditions. Collection of additional samples in the vicinity of Tanque Verde Peak might allow the reconstruction to be extended to this area as well. Specific recommendations are as follows:

a) Complete fire histories for the pine-oak woodland and pine-oak forest vegetation types.

b) Collect and analyze additional fire-scar samples from Rincon Peak, Happy Valley Saddle, Heartbreak Ridge and the East Slope Trail area, and Tanque Verde Ridge.

As the use of prescription fire moves forward at Saguaro National Monument the type of samples which enabled this project to succeed will become increasingly rare as they succumb to fire and decay processes. Therefore it is important any additional sampling deemed necessary proceed as rapidly as possible in order to salvage the most complete record.

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APPENDIX I

Table 3. Percent trees and groups scarred by fire date.

Fire Date	Number of trees susceptible*	Number of trees scarred	Percent of Total	Number of clusters susceptible	Number of clusters scarred	Percent of Total	Recon. July PSDI Index
1657	6	3	50%	6	3	50%	.63
1663	7	3	43%	6	2	33%	.55
1666	8	3	38%	6	3	50%	-.65
1675	8	4	50%	6	4	67%	-1.19
1680	10	2	20%	6	2	33%	2.49
1681	10	1	10%	6	1	17%	-1.46
1684	11	5	45%	6	3	50%	-1.44
1689	13	5	38%	6	5	83%	.53
1696	15	10	67%	6	6	100%	-.34
1698	15	1	7%	6	1	17%	-2.32
1703	16	9	60%	7	5	71%	-.58
1707	17	6	35%	7	4	57%	-1.47
1709	17	1	6%	7	1	14%	-.98
1710	17	1	6%	7	1	14%	2.05
1711	17	7	41%	7	6	86%	.35
1715	19	5	26%	8	3	38%	-.90
1717	20	1	5%	9	1	11%	-.08
1721	21	6	29%	9	5	56%	3.26
(1724)	21	3	14%	9	3	33%	.22
(1725)	22	2	9%	9	1	11%	2.03
1729	24	13	54%	9	6	67%	-3.28
1733	24	3	13%	9	3	33%	-2.12
1735	24	1	4%	9	1	11%	-2.78
1738	25	14	56%	9	7	78%	.84
1748	29	25	86%	11	1	100%	-1.89
1751	29	3	10%	11	2	18%	.31

(*) susceptible = previously scarred by fire

Table 3 (Continued).

Fire Date	Number of trees susceptible*	Number of trees scarred	Percent of Total	Number of clusters susceptible	Number of clusters scarred	Percent of Total	Recon. July PSDI Index
1756	29	1	3%	11	1	9%	-.30
1757	29	2	7%	11	1	9%	-.70
1758	29	2	7%	11	1	9%	1.19
1759	29	6	21%	11	3	27%	2.04
1763	29	12	41%	11	9	82%	-1.53
1768	29	15	52%	11	8	73%	2.22
1773	30	9	30%	11	6	55%	-1.60
1780	32	12	38%	12	9	75%	-1.00
1785	36	19	53%	12	9	75%	-.23
1795	36	4	11%	12	2	17%	.80
1797	36	16	44%	12	6	50%	.13
1799	36	7	19%	12	5	42%	.48
1806	35	10	29%	12	8	67%	-2.12
1809	35	16	46%	12	8	67%	-.69
1814	34	1	3%	12	1	8%	-.91
1822	34	24	71%	12	11	92%	-2.62
1827	34	4	12%	12	5	42%	.05
1835	32	11	34%	12	6	50%	2.48
1841	32	21	65%	12	12	100%	1.60
1851	32	25	78%	12	11	92%	-1.12
1854				12	1	8%	.77
1857	29	7	24%	12	6	50%	-.46
1863	28	18	64%	12	9	75%	-.46
1873	26	20	77%	12	10	83%	-.97
1879	25	18	72%	12	10	83%	-1.62
1883	25	1	4%	12	1	8%	-.55
1886	24	11	46%	12	7	58%	1.26
1890	23	1	4%	12	1	8%	1.78
1891	23	1	4%	12	1	8%	2.85
1893	23	4	17%	12	2	17%	-.35

APPENDIX II

SAMPLE DATA: SPECIES[5], PITH/BARK OR LAST RING DATE,[6] AND FIRE DATES WITH SEASONAL CODE[7]

1983 COLLECTION

1) **FS-1** [CC][8] PISF (P 1643; B 1983): 1696 E, 1715, (1733)[9], 1748 E, 1785 D, 1797, 1799, 1806 D, 1809 E, 1822, 1841 E, 1857 E

2) **FS-2** [**MC2**] PISF (p 1709; B 1983): (1729), (1733), 1748 E, 1763 E, 1768 ME, 1822 D, (1841), 1851 ME, (1854), 1879 LE, [1921][10], 1943

3) **FS-4** PIPO (I 1699; B 1983): 1785, 1797, (1851), (1863), (1873), 1879 E, 1886 E, 1918 D, 1943

4) **FS-5** JUDE (P 1787; B 1983): 1797 D, (1806 E), 1822, 1841 EE, 1851 E, 1857 E, 1863 E, 1879 ME, 1943 E

5) **FS-84** [DB] PIPO (P 1825; B 1983): (1841), (1851), 1873 LE, 1886 E, 1893 EE, 1924, (1934), 1943

6) **FS-86** [DB] PIPO (P 1829; B 1983): 1857 E, 1873 EE, (1883), 1893 EE, 1943 ME, 1954 LE

7) **FS-148** [DB] PIPO (P 1765; B 1983): 1873 D, 1927 E, 1943 E, 1954

MANNING CAMP GROUPS

M C 1

8) **M 1 C#2** PIPO (pith 1710; L 1943): 1738 LE, 1748 D, 1756 D, 1763 ME, 1768, 1773 E, 1780 E, 1785 EE, 1797 EE, 1809 E, 1822 EE, 1827 EE, 1841 EE, 1851 E, 1857 EE, 1863, 1873 E, 1879 EE, 1886 ME, 1943

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[5] Species code: PISF=*Pinus strobiformis*, PIPO=*Pinus ponderosa*, JUDE=*Juniperus deppeana*

[6] P = pith date, I = first ring of sample, L = last ring present, B = bark date

[7] See text for explanation of seasonal code.

[8] Group with which sample was combined.

[9] Parenthesis indicate a possible scar date.

[10] Square brackets indicate a scar date +/-.

9) **M 1 C#3** PIPO (pith 1687; L 1953): 1729, 1738 EE, 1748, (1756), 1763 D, 1768 D, (1773), 1780 D, 1797 EE, 1809 EE, 1822 EE, 1841 EE, 1851, 1863 D, 1873 E, 1879 EE, 1886, (1943)

M C 2

10) **M 1 C#1** PISF (pith 1502; L 1844): 1557 EE, 1579 E, [1584], 1606 E, 1613 L, 1631 E, 1643 EE, 1657 E, 1663 E, 1675 E, 1689, (1692), 1696 E, (1698), 1703 E, 1710 E, 1711 LE, 1721 E, 1729 E, 1738 E, 1748 E, 1763 ME, 1768 E, 1780 E, 1785 L, 1797 D, 1809, 1822 D

11) **M 1 C#4** PISF (pith 1661; L 1912): [1710], 1738, 1763 E, 1768 E, 1773 D, (1792), 1797 E, 1809 EE, 1822 D/EE, 1835, 1851 E, 1873, 1879 E, (1883 D), 1886, (1893)

12) **M 1 C#5** PIPO (pith 1645+/-; L 1867): [1657], [1692], 1729 E, 1748 E, 1751 ME, 1785, 1797 E, 1799 D, 1809 E, 1822 E, 1835 E, 1841, 1851 D, 1863

13) **M 1 C#6** PISF (pith 1641; B 1876): 1680 D, 1696 E, 1715, 1724 ME, 1729 ME, 1733 D, 1738 EE, 1748 D, 1763, 1768 EE, 1780 EE, 1785 E, 1797 D, 1809 E, 1822 E, 1835 D, 1851 E, 1863 E

14) **M 1 C#7** PIPO (pith 1649; L 1885): 1707 E, 1715 E, 1721 E, 1729 EE, 1738, 1748 D, 1751 EE, 1759, 1768 D, 1780 E, 1797 EE, 1809 E, 1822, 1841 D, 1851 ME, 1858 EE, 1863 ME, 1873 E

15) **M 1 C#8** PIPO (pith 1657; L 1972): 1689 E, 1696 E, 1703 E, 1707 E, 1711 E, 1729 EE, 1738, 1748, 1768 EE, 1773, 1780 E, 1785 E, (1806), 1822, 1835 E, 1841, 1851 E, 1863 ME, 1879 EE, 1886 EE

16) **M 1 C#9** PIPO (pith 1643; L 1934): [1664], 1785 E, 1797, 1806, 1809 E, 1822 E, 1835 E, 1841 EE, 1851 E, 1863 E, 1873 E, 1879 D, 1886 E

17) **M 1 C#10** PIPO (pith 1652; L 1917): 1657 ME, (1684), (1717), (1735 E), 1773 D, 1780 EE, 1797, 1806, 1822 E, 1827 E, 1835 E, 1841 E, 1851 E, 1863 E, 1873 E, 1879 D, 1908 EE, 1910 E, 1913 E

HELEN'S DOME

18) **SPUD ROCK C#1** PIPO (P 1578; L 1814): (1624), 1631 E, 1636 E, 1643, 1648 E, 1653 E, 1657 E, 1663 E, 1666 E, 1675 E, 1684 E, 1689 E, 1696 E, 1703, 1707, 1709, 1721, 1729, 1733, 1738, 1748, 1759, 1763, 1773, 1785, 1799, 1809

19) **H D C#1** PISF (P 1643; L 1904): (1652), 1663 E, 1684 E, 1703 E, 1729 E, 1738 E, 1751, 1759 LE, 1773, 1780 E, 1785, 1799 E, 1809 E, 1822 D, 1841 E, 1851 E, 1863 E, 1873 E, 1879

20) **H D C#2** PISF (P 1638; L 1924): 1680 D/EE, 1684 E, 1703, 1711 LE, 1729 E, 1738 E, 1748, 1759 E, 1780 E, 1799, 1806, 1809 E, 1822, 1841 E, 1851, 1873, 1879

21) **H D C#3** PIPO (I 1730; L 1834): 1733 E, 1748 EE, 1759 LE, 1768 EE, 1780 E, 1785 D/EE, 1799 D/EE

NORTH SLOPE

22) **N S C#1** PISF (P 1643+/-; L 1886): (1703), 1717, [1725], 1748 D, 1785, 1822 D, 1841 D, 1851 E, 1854 EE, 1863 ME, 1873 E, 1879 D

23) **N S C#2** PISF (P 1656; L 1936): [1725], 1748, 1763, 1773, 1785, 1822, 1841 E, 1886

24) **N S C#3** PISF (I 1809; L 1886): 1822, 1841 LE, 1851 LE, 1863 E, 1873 E, (1886)

25) **N S C#4** PIPO (I 1763; L 1890): (1763), 1773 E, (1780), (1785), 1799, 1806 E, 1809 ME, 1822 E, 1841 LE, (1847), 1851 LE, 1863 ME, 1873 E, 1886

ITALIAN SPRINGS

26) **I S C#1** PISF (P 1666; L 1941): 1780 E, (1799), 1809 E, 1822 E, 1835 E, 1841 E, 1851 E, 1863 E, 1873 E, 1879, 1886 E

27) **I S C#2** PISF (P 1702; L 1941): 1748 EE, (1752), (1759), 1763 E, 1780 EE, 1799 E, 1835 E, 1851 ME, 1863, 1873, 1879

MICA TOWER

28) **M T C#1** PIPO (P 1645; L 1841): 1652 E, 1666 ME, 1681 LE, 1689 LE, 1696 E, 1707 E, 1711 E, 1724 E, 1729 E, 1735, 1748, 1759, [1781], 1797 D, 1809 E

29) **M T C#2** PISF (I 1655; L 1865): (1763 D), (1780 E), 1797, 1809,1841, 1851

30) **M T C#3** PISF (P 1699; L 1936): 1748 E, 1759 LE, 1763, 1768 LE, 1780 EE, 1797 D, 1806 EE, 1851, 1873 E, 1920

CHIMENEA CREEK

31) **C C C#1** PIPO (I 1571; L): [1663], (1689), (1696), 1703 E, 1715, 1729 EE, 1738 ME, 1748 EE, 1759 LE, 1768 LE, (1780), (1785)

32) **C C C#2** PISF (P 1481; L 1931): (1563), 1579, [1598], 1627, 1645 ME, 1711 E, 1768 E, 1809 E, 1873, 1879, 1886 D, 1893, [1920]

33) **C C C#3** PISF (P 1539; L 1879): 1597 E, (1620), 1631 LE, 1645 E, 1657 LE, 1675 ME, 1703, 1711 E, 1721 E, 1748, 1768 LE, (1785), (1806), (1822), (1879)

MICA MEADOW

34) **M M C#1** PIPO (P 1652; L 1812): 1684, 1696 E, (1701), 1733 E, 1738, 1748 E, 1773, 1780, 1785

35) **M M C#2** PIPO (P 1645 B 1983+/-): 1666 E, 1675 ME, 1684 ME, 1696 E, (1698), 1703 EE, 1707 ME, 1711 ME, 1729 E, 1738, 1748, 1758, (1768), (1780), 1785 E, 1799 E, (1822), 1841 E, 1851, 1873 E, 1879, 1886, [1891], [1920], 1943 E

36) **M M C#3** PISF (P 1645; L 1921): 1689, 1696, (1707), 1729, 1748 E, 1768 E, 1785, 1806 EE, 1822 E, 1835, 1841 EE, 1851 ME, 1863 E, 1879, 1890

37) **M M C#4** PISF (P 1491±; L 1904): (1494), [1545], [1560], [1565], [1606], 1613 E, [1620], 1648 D/EE, 1654 E, (1671), 1696 E, 1698 EE, 1707 E, (1715), 1748 E, 1751, 1799, (1806), (1809), (1822), 1841 EE, 1863 E, (1865), 1873, 1879 E, 1883 D

EAST SLOPE

38) **E S C#1** PIPO (P 1704; L 1924): 1785 E, 1795 E, 1806 D, 1814 E, (1817), 1822 E, (1827), 1835 EE, 1841, 1851, 1857, 1863, (1873), 1884, 1893

DEVIL'S BATHTUB

39) **D B C#1** PIPO (P 1758; L 1891): 1785 E, 1795 D, 1806 D, 1822 EE, 1827 D, 1835 D, 1841 D/EE, 1851 E, 1857 EE, 1863 D, 1873 LE

40) **D B C#2** PIPO (P 1714; B 1936): 1748 E, 1763, 1768, 1780, 1785, 1795, 1806, 1822, 1835, 1851 E, 1858, 1863, 1873, 1879, 1886, 1891

41) **D B C#3** PIPO (P 1698; L 1862): 1715 E, 1785, 1795 EE, 1822 E, 1851

HAPPY VALLEY KNOLL

42) **H V K C#1** PIPO (P 1585; L 1915): [1585] 1601 EE, 1628 E, 1703 E, [1714 EE], 1721 E, 1724, [1730 E], 1738 E, 1748, 1757 E, 1763 LE, 1768 E, 1773 E, [1781], (1785), (1809), (1841)

43) **H V K C#2** PIPO (P 1717; L 1926): 1721, (1739), 1748 E, 1757 E, 1785, 1799, 1806, [1810], (1818), 1822, 1827, 1841, 1851, 1857, [1879], [1919]

RINCON PEAK

44) **R P C#1** PISF (P 1480 +/-; L 1806): [1495], [1506 ME], [1576 D], 1678 L, 1711 ME, 1715 E, [1747 E], 1763 LE not confident of dating

45) **R P C#2** PIPO (P 1577; L 1919): [1586], 1590 E, 1595 E, 1648, 1659 E, 1668 E, [1695], 1715, 1748, [1752], [(1770)], [1819], 1867, (1893)

46) **R P C#3** PIPO (P 1480±; L 1858): [1497 ME], [1516], [1529], 1534 ME, 1542 E, 1550 E, [1557], [1563 E], 1574 E, 1590 D/EE, 1593 E, [1605], (1609), 1622, [1634], 1648 E, 1659 E, 1668, [1687], 1715 ME, 1729, 1748 E, 1763, 1766, [1819]

47) **R P C#4** PISF (I 1638; L 1757): 1648 E, (1652), 1696, (1704 L, 1710 E, 1714 D), 1748

48) **R P C#5** PISF (I 1858; L 1926): 1867 ME, 1879 ME, 1893 EE

48) **R P C#6** PISF: NOT DATED

COW HEAD

50) **C H C#1** PIPO (I 1695; L 1944): 1763 ME, 1806 E, 1809 EE, 1811 D, 1817, 1820, 1822 EE, 1827, 1831 D, 1841 E, 1844 D, 1849, 1851 E, 1863 ME, [1873], [1892], 1920 D, 1937

51) **C H C#2** PIPO: NOT DATED

52) **C H C#3** PIPO: NOT DATED

TANQUEVERDE PEAK

53) **TVP C#1** PIPO: NOT DATED