# Multi-century history of wildfire in the ponderosa pine forests of El Malpais National Monument

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## Introduction

In recent years, an important land-management concept has evolved based on principles formulated in conservation biology and landscape ecology. *Ecosystem management* seeks to sustain the viability of ecological systems by maintaining or restoring past processes that created and shaped these ecosystems over long periods (Kaufmann et al., 1994). To do so requires knowledge of (1) the ecological processes that were historically important, (2) the temporal and spatial scales on which these processes operated, and (3) the natural range of variability (i.e. the upper and lower limits) of these processes (Allen, 1994; Morgan et al., 1994). In many areas of the western U.S. humans have so greatly altered ecosystems that many ecological processes (e.g. wildfires, erosion, and insect outbreaks) currently operate outside of their historic range of variability (i.e. outside the physical capability of the ecosystem). Therefore, ecosystem management emphasizes the restoration of more stable and sustainable environmental conditions and processes, especially in "...pieces of the landscape made uncommon by human activities" (Kaufmann et al., 1994).

Wildfire in particular is a process that currently functions outside of its normal range. Over the millennia fires co-evolved with ecosystems and became an integral process in the maintenance of the mosaic pattern of open meadows, grasslands, woodlands, and forests we see today. However, human-related activities such as livestock grazing and fire suppression have so impacted western forests that catastrophic, stand-replacing fires are much more likely than the low-intensity surface fires that once characterized many western forests (Swetnam, 1990; USDA Forest Service, 1993). To better understand impacts due to wildfire and other ecological processes upon present and future environmental conditions, reference "templates" should be established based on the role of ecological processes prior to Euro-American settlement (approximately 1880) (Allen, 1994; Kaufmann et al., 1994). A key recommendation of federal agencies is additional research on the history of fire to learn about its role in shaping western forest landscapes (USDA and USDI, 1989; Kaufmann et al., 1994; Swanson et al., 1994), in order to place the present-day wildfire situation in better perspective for those charged with managing public lands. In this sense, *the past is the key to the future.*

Restoring fire as a vital ecosystem process requires reassessments of past fire-management policies: Should all wildfires continue to be suppressed, or should wildfires be allowed to burn under certain environmental conditions (i.e. a "prescription" for fire)? Should fuel loadings in western forests be allowed to increase, or should agencies use management-ignited prescribed fires to reduce high fuel loadings? If agencies do use prescribed fires as a tool to preempt wildfires, what knowledge and justification is necessary to implement such a policy? To what degree have we changed the landscape of western forests, and what do these changes imply about future wildfire occurrences? At El Malpais National Monument, past policies were incompatible with the fundamental objective "... to restore the natural function of fire within the ecosystems of the park to the greatest extent possible" (USDI National Park Service, 1992). However, restoration of fire within the monument is challenging because of the lack of information on the range within which past fire functioned. Management of fire is further complicated by the complex geology, diverse landscape, and various human-related factors (e.g. grazing, logging, and fire suppression) that have influenced the malpais landscape.

Our research sought to establish reference conditions within which fire functioned as an ecosystem process at El Malpais National Monument prior to Euro-American settlement (approximately 1880). We had four objectives. (1) Because of the complexity of the malpais landscape, it was imperative to compare past fire histories in various habitat types within and adjacent to the monument. (2) We wished to establish the upper and lower limits, as well as the average conditions, within which fire functioned. (3) We wished to investigate any changes in past fire over both time and space, and propose possible explanations for these changes. (4) Using these results, we wished to make preliminary recommendations for managing fire that would take into consideration the complexity of the malpais landscape and the historical perspective of human land-use patterns.

## Habitat types and sites selected for fire history

El Malpais contains numerous lava flows of varying sizes and ages (Fig. 1) that create vegetative associations in various successional stages. This landscape heterogeneity suggests that the probability of fire ignition and spread is highly variable, depending on the physical and vegetative characteristics of the individual habitat (Touchan and Swetnam, 1995). Hence, no single fire regime (i.e. fire frequency, size, and severity) is likely to characterize the fire history of all habitats within the monument. We therefore sampled several representative habitat types.

### Cinder cones and shield volcanoes

To characterize the fire history in ponderosa pine forests on cinder cones and shield volcanoes (Fig. 2), we collected samples at: (1) Cerro Rendija, an eroded, low-lying shield volcano in the western portion of the malpais; (2) the eastern flank of Cerro Bandera, a slightly eroded cinder cone in the northwest corner of the malpais; and, (3) Lost Woman, a cinder cone also in the northwest portion of the malpais, but separated

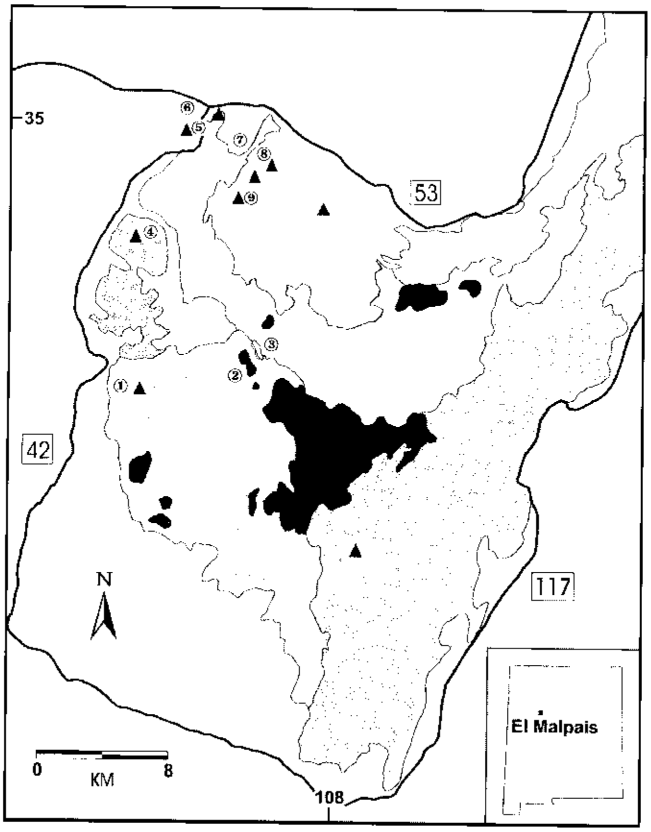


FIGURE 1—El Malpais National Monument, showing boundaries of major lava flows and locations of the nine sites sampled: (1) Hoya de Cibola, (2) Mesita Blanca, (3) Hidden Kipuka, (4) Cerro Rendija, (5) Cerro Bandera East, (6) Cerro Bandera North, (7) Candelaria, (8) La Marchanita, and (9) Lost Woman. Triangles denote major cinder cones and shield volcanoes.

from the other two sites by the Bandera lava flow. All three sites are adjacent to surrounding grasslands with a long history of grazing (Mangum, 1990). The forests in these areas were logged of many of their larger trees, and the numerous stumps contained well-preserved fire-scarred specimens. Occasional dense ("doghair") thickets of young ponderosa pines occur on the slopes of these landforms, most likely because

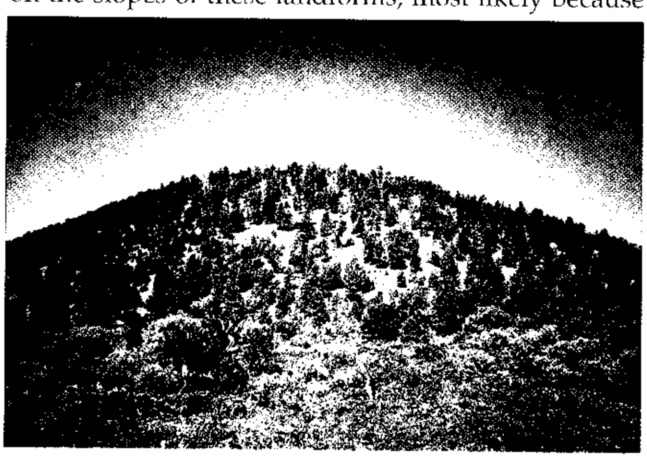

FIGURE 2—Cerro Bandera cinder cone viewed from the east on the Bandera lava flow, showing the open ponderosa pine forests on its east flank.

FIGURE 3—Overlooking the La Marchanita site from the Candelaria cinder cone, with the Bandera lava flow in the background. The La Marchanita site is representative of the ponderosa pine forests on older, highly eroded lava flows.

of fire suppression. Under presettlement conditions, these thickets would have been reduced in size and density by episodic, low-intensity surface fires.

**Ancient eroded basalt flows**

We analyzed the fire history of ponderosa pine forests on ancient, highly eroded basalt flows by collecting fire-scarred samples from: (1) the low-lying open ponderosa forests north of Cerro Bandera; (2) the woodland savanna surrounding La Marchanita Cave; and, (3) a site north of the Bandera lava flow on the Candelaria property (Fig. 3). Soils at these sites are highly developed and deeper than soils on younger basalt flows, and support abundant grasses and woodland savannas that grade into open ponderosa pine forests. Extensive logging, grazing, and fire suppression have occurred in these areas, because they are relatively accessible to springs, major roadways, trails, and rail systems (Mangum, 1990).

**Younger basalt flows**

We collected one site, on the Hoya de Cibola lava flow (Fig. 4), a young, moderately eroded lava flow characterized by pahoehoe lava that creates a broken topography with numerous fissures. Forest litter accumulates in the fissures. Aerial photographs of the 1989 Hoya Fire Complex showed surface fires spreading across large areas by means of the litter that accumulated in these fissures. The lava flow supports an open ponderosa pine forest on shallow soils with patchy grass cover. This site is immediately adjacent to grasslands with a long history of grazing. The broken topography and rough terrain would inhibit grazing directly on the lava flow, but the ability of fire to spread to the lava flow may have been reduced due to grazing. Fires have been suppressed in this area up to the present, but we found no evidence of logging.

**Isolated kipukas**

This was the fourth and final habitat type we sampled (Fig. 5). Kipukas are "islands" of original substrate material (such as sandstone, limestone, or older

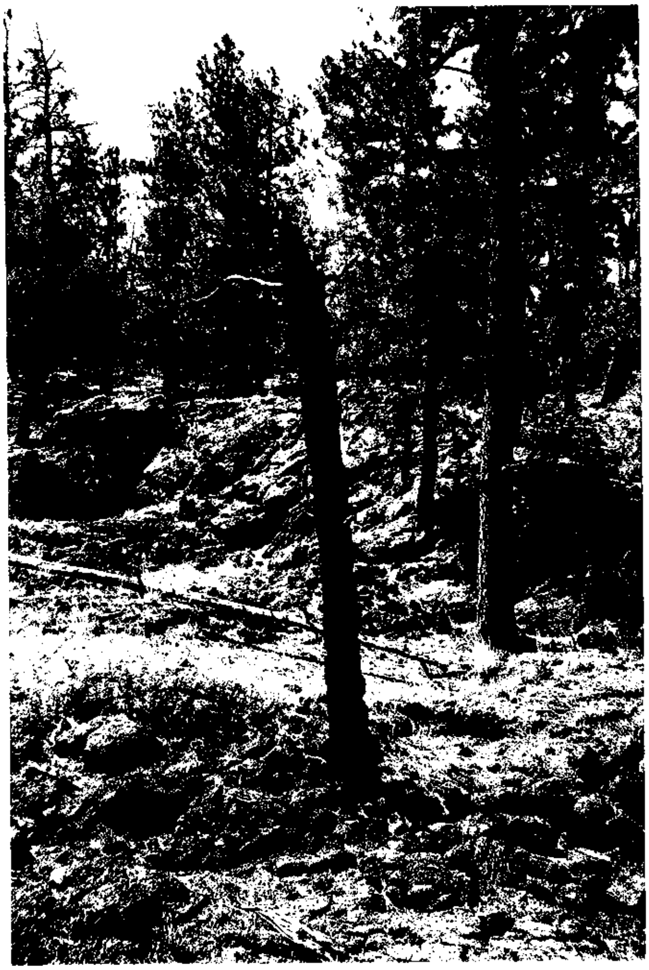

FIGURE 4—The Hoya de Cibola lava flow site, representative of the younger, moderately eroded lava-flow habitat. This photograph was taken in 1992 within the periphery of the 1989 Hoya Complex fires. Other than isolated charred logs (note fire-charred tree in foreground), there is little evidence of this fire today.

lava) surrounded by younger lava flows (Lindsey, 1951). We collected samples at: (1) Mesita Blanca, a kipuka surrounded by the Hoya de Cibola lava flow; and (2) Hidden Kipuka, located approximately 1 km

FIGURE 5—The interface between the Hoya de Cibola lava flow (at right) and the grasslands, ponderosa, and piñon–juniper forests (at left) at Hidden Kipuka.

FIGURE 6—An old ponderosa-pine log at the La Marchanita Cave site, showing the characteristic basal wound caused by fire. By using such well-preserved fire-scarred samples, we crossdated fire scars back to the 1300s, currently the longest continuous fire history in the Southwest.

FIGURE 7—A stump located on the Cerro Bandera cinder cone east slope, with a very large fire-scarred area on its uphill side. Left from previous logging earlier this century, this sample contained a record of 23 fire scars dating back to A.D. 1640.

to the northeast of Mesita Blanca and bounded by the Hoya de Cibola lava flow to the west and by the Bandera lava flow to the east. These kipukas support both ponderosa pine forests and piñon–juniper woodlands, and have well developed grass cover. Because of their isolation, these sites were not logged. Fire-suppression effects are probably minimal. The surrounding rough terrain, lack of water source, and limited forage prevented extensive grazing on these kipukas.

## Methods of reconstructing fire history

Wildfire patterns prior to Euro-American settlement were analyzed to establish reference conditions of wildfire as an ecosystem process. Most western forests preserve such records in the growth rings of conifer species such as the ponderosa pine (Figs. 6, 7). Before the Euro-American settlement, low-intensity surface fires were characteristic of western pine forests. These fires sometimes wound the lower portion of the stem by killing the outer layer of living

FIGURE 8—Portion of a fire-scarred cross section showing a record of numerous fire scars (arrows) from the low-intensity, frequent surface fires characteristic of the malpais area prior to 1880. This one tree contained a record of 30 fires dating to the late 1500s.

cells, usually on the uphill side of the tree where fuels collect. In subsequent years, the tree will form successive growth layers (tree rings) over the old wound. Usually another surface fire occurs later on to once again kill the outer layer of cells before the tree has completely overgrown the old wound. The probability of subsequent fires scarring the tree is increased, because flammable resins in the initial wound increase the likelihood of fire re-igniting on the old wound. Hence, once scarred by fire, ponderosa pines tend to be good "recorders" of frequent, low-intensity surface fires (Fig. 8).

At each site, we collected cross sections from stumps, logs, and snags that showed evidence of repeated scarring by fire. Small wedges were also cut from a few fire-scarred living trees to obtain dates of the most recent fires (Arno and Sneck, 1977). In the laboratory, all cross sections were sanded with progressively finer sandpaper until the cellular structure of each tree ring was visible under magnification. We then crossdated all tree rings and fire scars to their exact year of formation. Crossdating is the cornerstone of dendrochronology, using both graphical and statistical methods to ensure exact year assignment to each individual tree ring (Fritts, 1976; Holmes, 1983; Swetnam et al., 1985).

All fire-history information was entered into databases and analyzed using software developed specifically for this project (Grissino-Mayer, 1995). For each site, we first constructed master fire charts that displayed the spatial and temporal patterns in past fire regimes as recorded by sampled fire-scarred trees (Dieterich, 1980). Using these charts, we noted any changes in widespread fires (defined as those fires recorded by the majority of trees sampled within the study areas) within and between sites.

To establish the historical range of variability of past fires, we statistically assessed patterns of fires during the presettlement period (defined as pre-1880) across the four habitat types sampled by calculating the minimum and maximum fire intervals, as well as the Weibull Median Probability Interval (WMPI). WMPI is the fire interval associated with the 50% probability level (i.e. half of all fire intervals will be above and half below this interval) derived from the Weibull distribution, a flexible distribution able to model highly skewed fire-interval data (Johnson and Van Wagner, 1985; Baker, 1992; Grissino-Mayer et al., 1995). Finally, we propose possible explanations for any observed changes in past fire based on habitat characteristics (i.e. substrate, fuel types and amounts, local topography, and land-use history).

## The fire history of El Malpais

We dated nearly 3,000 fire scars recorded on over 700 specimens from 217 trees at nine sites within and adjacent to the monument. Fires occurred in 245 of the 660 years between A.D. 1333 and 1993. However, the number of samples extending prior to A.D. 1500 is low because older, well-preserved samples are rare. The master fire charts constructed for the nine sites clearly show that wildfires were a recurrent process of the malpais landscape for many centuries. The oldest dated fire events occurred in 1367 and 1382 at both the Hoya de Cibola and La Marchanita sites, making these sites the longest continuous fire histories yet developed in the Southwest. The most recent fire event dated was the series of scars caused by the 1989 Hoya Complex fires.

### Spatial patterns of fires within and between sites

The master fire chart for the Cerro Bandera cinder cone (Fig. 9) shows the synchroneity of fires recorded among the sampled trees. At this site, we collected 19 samples at the highest elevations and 13 samples at lower elevations to determine whether differences in fire patterns existed at such small spatial scales. Both subsites were equal in area, approximately 10 hectares, separated by an equivalent-size area. Nearly all fire years were synchronous between the upper and lower areas, suggesting these fires were widespread within the site. Two asynchronous fire years occurred, however. The 1841 and 1923 fires affected primarily the upper areas of the cinder cone, while the 1843 and 1925 fires were confined to the lower slopes.

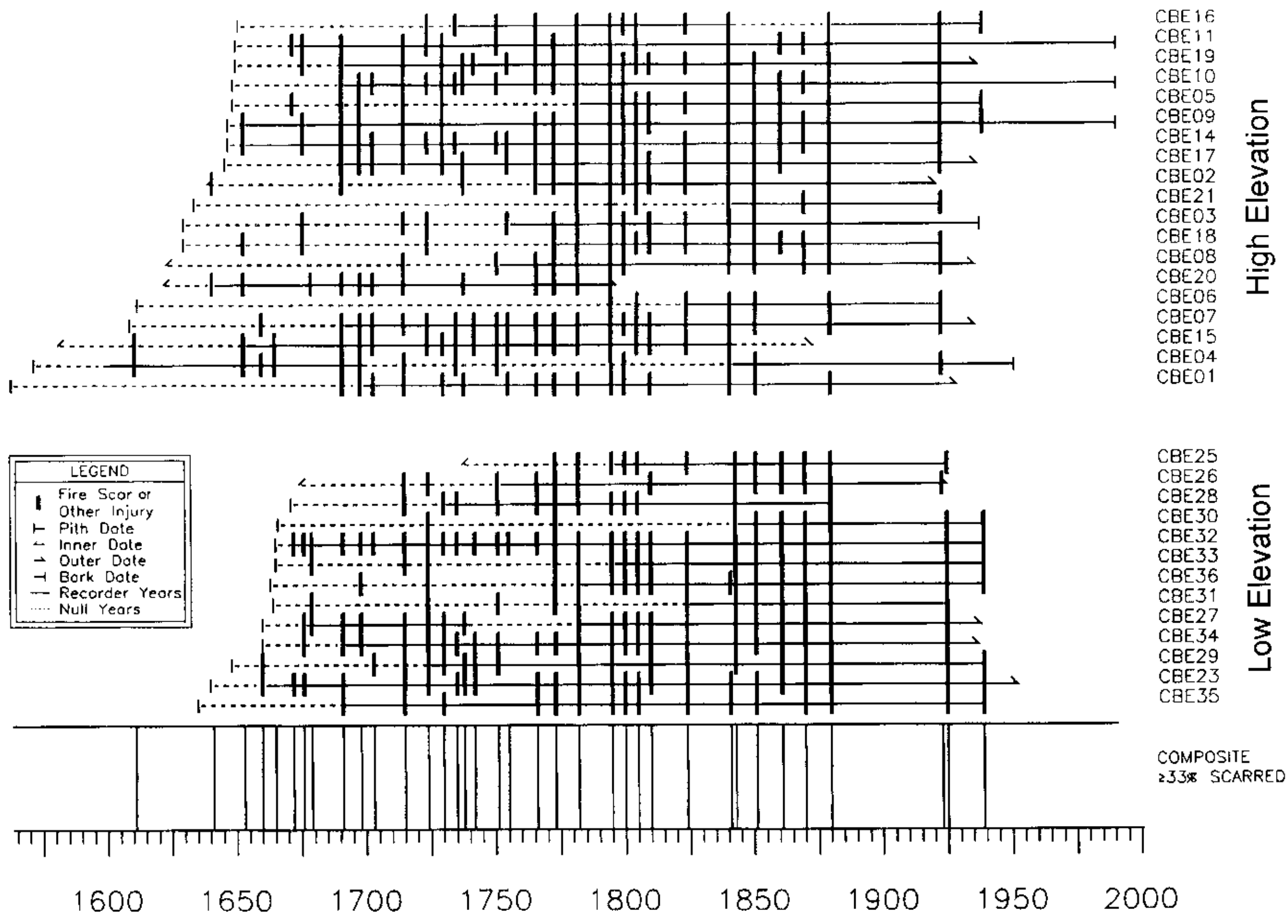


FIGURE 9—The master fire-history chart for the eastern slopes of the Cerro Bandera cinder cone, divided into upper and lower slope samples. The fire history is filtered to show only more widespread fires. Each sampled tree is plotted as a horizontal line. Symbols along this line denote fire years.

Prior to 1880, fires were synchronous between sites as well, suggesting that presettlement fires spread over extensive areas (Fig. 10). Between 1650 and 1880, at least 13 fires occurred at four or more of the sampled sites. Three fires (1824, 1841, and 1861) occurred at six sites, extending over much of the western and northwestern sides of the monument. This synchroneity occurs across habitat types. For example, the 1841 and 1861 fires occurred in all four habitat types. A record of the 1824 fire, on the other hand, was absent from the kipukas. At the Candelaria and La Marchanita sites, fires were mostly synchronous despite extensive aa lava separating these sites (Fig. 1). Because fire spread across this lava is unlikely due to lack of fuels, fire must have spread from outlying areas, or multiple ignitions may have occurred at the two sites.

## Temporal changes in fire patterns

Disruption in episodic fires started occurring approximately at 1880 (Figs. 9, 10). Wildfires that were common before 1880 suddenly ceased. Wildfires did not occur again until 1923 at Cerro Bandera, until 1932 at Cerro Rendija, until 1916 at Candelaria, until 1925 at Cerro Bandera North, and until 1915 at the Hoya de Cibola site. No widespread fire has occurred at the La Marchanita site since 1900. Although smaller fires (i.e. fires that scarred a small percentage of trees) did occur during this 40 year period, some factor prevented them from spreading within each site, in contrast to pre-1880.

Another temporal change in fire patterns occurred beginning approximately at 1940 (Figs. 9, 10). Regardless of extent, fires ceased abruptly at all sites except the two kipukas. For example, at the Cerro Bandera site fire-scarred samples were collected from three living trees, CBE09, CBE10, and CBE11. These trees recorded fires continuously since the early 1600s, yet showed no fires between 1940 and 1992. Similar long fire-free periods occurred at other sites as well: 1916 to the present at the Candelaria site; 1909 to 1976 at the Lost Woman cinder cone; and 1933 to 1989 at the Hoya de Cibola site. These long 20th century fire-free periods were unprecedented in the malpais region for the last 600 years.

## Fire regimes in different habitat types

Statistics of fire in the different habitats of the malpais region over the period 1700–1880 revealed differences as well as similarities among the habitat types

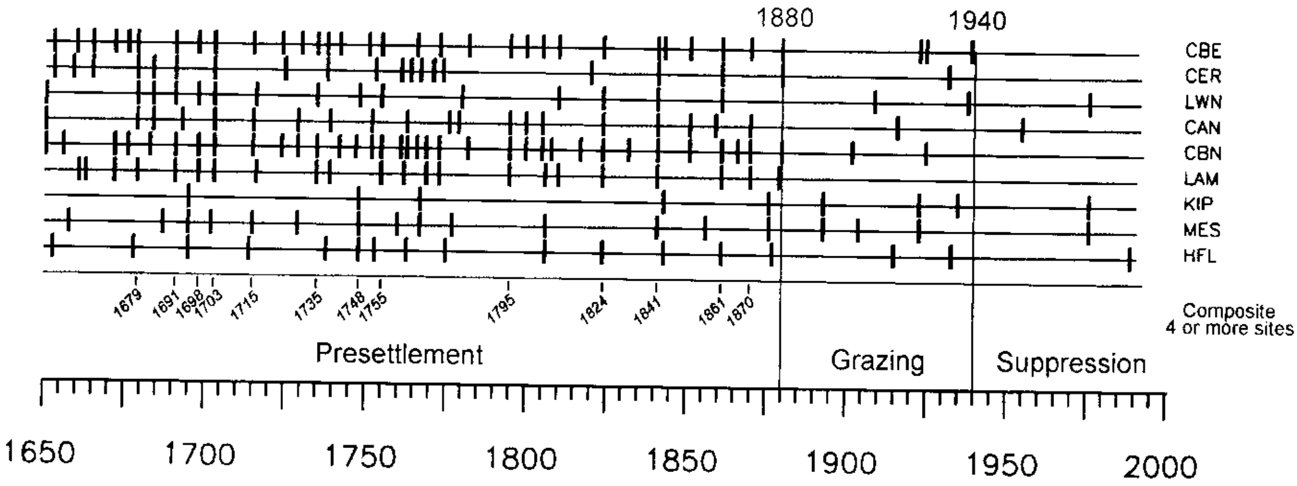


FIGURE 10—Fire history for El Malpais National Monument, filtered to show the most widespread fires at each site. CBE, CER, and LWN represent cinder-cone/shield-volcano habitats, CAN, CBN, and LAM represent ancient basalt-flow habitats, KIP and MES are the two kipuka sites, and HFL represents the younger basalt flows.

(Table 1). At the three cinder-cone/shield-volcano sites, fires occurred approximately once every five to eight years. This frequency is similar to the five to seven years for the three sites sampled on the ancient basalt flows that surround the malpais. When the composite fire information for each of the three sites on these two habitat types is combined, we find that fire occurred in both habitat types approximately once every three years. This contrasts the frequency of one fire every seven years for the combined kipuka sites, and once every 11 years for the Hoya de Cibola site. In general, fires during the presettlement period were much more frequent in the ponderosa pine forests and grasslands on cinder cones, shield volcanoes, and outlying pine savannas than on the kipukas and younger basalt flows.

Combining all nine sites to provide an overall assessment of presettlement fires in the malpais area, fire occurred at our sites at least once every two years during the period 1700 to 1880. Analyzing only those fires that affected at least 25% of all trees within each study area (i.e. widespread fires that were perhaps more ecologically important), we found fires occurred on average in the sampled areas about once every 2 fi half years.

## Conclusions

The fact that fires occurred frequently at El Malpais National Monument for hundreds of years is an important finding. If the National Park Service is to restore natural processes of El Malpais in order to more closely approximate presettlement conditions, then surface fires must be re-introduced. Presettlement fires were usually low-intensity surface burns that crept through grassy understories of ponderosa pine and mixed-conifer forests, consuming fuels that accumulated since the last fire. These fires maintained forests in open, park-like conditions observed by the many pioneers that first entered the Southwest (Cooper, 1960; Savage, 1991; Covington and Moore, 1994). An excellent modern-day analog to these park-like conditions can be seen on the northern and northeastern slopes of the Lost Woman cinder cone, where the 1976 fire removed dense fuels, shrubs, and most understory trees.

The malpais fire histories revealed two major changes in fire frequency, the first around 1880 and the second around 1940. After 1880 fire frequency decreased at most sites, resulting in the longest fire-free intervals in the past 600 years. This decrease was coincident with the onset of widespread livestock grazing in the malpais area in the early 1880s following the subjugation of the Navajos and the arrival of railroads in 1881. By 1885 the nearby community of San Rafael became the center of sheepherding with tens of thousands of sheep grazing within and adjacent to the monument (Bailey, 1980; Mangum, 1990, this volume). Grazing reduced grasses and herbaceous cover required for spreading of surface fires (Cooper, 1960; Wright and Bailey, 1982; Savage and Swetnam, 1990; Touchan et al., 1995), thus lowering both frequency and areal extent following 1880.

The change in fire frequency around 1940 was most likely due to an increase in the efficiency of fire suppression. After 1945, aerial handling of wildfires using modified surplus warplanes became common, smoke jumping was perfected, fire-detection methods became more advanced, and the number of roads and trails increased to allow quicker access. Following these improvements, numerous pine thickets became established throughout the monument, especially on the western side. Tree-ring dating of these young ponderosa pines on the eastern slopes of Cerro Bandera confirmed that these dense "doghair" thickets appeared immediately after the 1939 fire.

Different fire histories of the various sites correspond with the heterogeneity of the landscape. Before

TABLE 1—Fire-history information for the nine sites collected for this study over the period 1700–1880.

| Habitat type/ site name | Number of samples | Minimum interval (years) | Maximum interval (years) | WMPI[1] (years) | Fire[2] freq. |
|---|---|---|---|---|---|
| Cinder cones and volcanoes | | | | | |
| Cerro Bandera East | 32 | 1 | 12 | 5.2 | 0.192 |
| Cerro Rendija | 11 | 1 | 25 | 7.8 | 0.128 |
| Lost Woman | 20 | 2 | 30 | 7.7 | 0.130 |
| Composite | 63 | 1 | 10 | 3.2 | 0.317 |
| Ancient basalt flows | | | | | |
| La Marchanita | 37 | 2 | 21 | 6.8 | 0.147 |
| Candelaria | 20 | 2 | 17 | 6.9 | 0.144 |
| Cerro Bandera North | 35 | 1 | 13 | 4.9 | 0.202 |
| Composite | 92 | 1 | 13 | 3.1 | 0.324 |
| Kipukas | | | | | |
| Mesita Blanca | 26 | 2 | 22 | 8.6 | 0.116 |
| Hidden Kipuka | 13 | 3 | 55 | 13.3 | 0.075 |
| Composite | 39 | 2 | 22 | 6.8 | 0.147 |
| Younger basalt flow | | | | | |
| Hoya de Cibola flow | 23 | 2 | 31 | 10.8 | 0.092 |
| El Malpais National Monument | | | | | |
| Composite, all fires | 217 | 1 | 8 | 2.1 | 0.489 |
| Composite, 25% scarred | 217 | 1 | 13 | 2.6 | 0.391 |

[1]Weibull Median Probability Interval, see text for definition.
[2]Fire frequency (x 100) is the probability (in %) of fire occurring in any given year.

1880 fire was a common phenomenon on the highly weathered basalt flows, cinder cones, and shield volcanoes, occurring approximately once every five to eight years. However, at the two kipuka sites fires occurred in 9–13 year intervals. Because both the kipuka sites are small, fires most likely spread to them from the surrounding forests on the Hoya de Cibola lava flow, where they occurred approximately once every 11 years. These results confirm that El Malpais forests have different regimes that the Park Service should consider when developing a fire management plan.

## Recommendations

In some areas the fuel structure of malpais forests should be restored before processes such as fire can be expected to behave naturally (i.e. within the range of historic natural variability). Large fuels, such as logs and snags, are abundant because extensive logging occurred in some parts of the monument early in this century, namely around El Calderon and the Lava Wall northeast of Cerro Rendija. Fire suppression has further altered fuel loadings primarily by allowing dense "doghair" thickets of young ponderosa pines to get established, creating ladder fuels that increase the probability of crown fires. Specific recommendations include: (1) using management-ignited prescribed burns to reduce high fuel loadings; (2) allowing natural, lightning-caused wildfires to burn as long as they occur within prescribed conditions and do not threaten developed areas, structures, or human lives; (3) thinning thickets of "doghair" ponderosa pines using either manual techniques (i.e. chainsaws) or carefully managed controlled burns; and (4) reducing or eliminating domestic grazing. Once the fire regime has been restored, management plans must consider the complexity of the malpais landscape which results in diverse conditions. Our knowledge of how to restore natural structures and processes is very limited. Re-introduced fire may not produce the desired presettlement conditions because ecosystems may be pervasively altered due to human factors (Allen, 1994).

We believe the malpais kipukas are extremely important for understanding the dynamics of ecological processes, especially fire. Kaufmann et al. (1994) stated "... we would like to have undisturbed ecosystems available for direct evaluation of natural ecosystem structure, composition, and function." The two kipukas sampled in this study revealed fire histories that were essentially uninterrupted (Fig. 11), indicating that human disturbances had little or no effect on fire regimes at these sites. Such sites are extremely rare in the western U.S. The kipukas are therefore suited to serve as control sites for (1) establishing the role of ecological processes that functioned during the presettlement period, and (2) establishing reference conditions to evaluate changes in fire over both time and space, especially those changes attributed to human disturbances. El Malpais National Monument has many kipukas with varied histories of land use, and these areas should be targeted for future fire-history and ecological research.

The fire histories show that fires were widespread throughout much of the malpais during certain years, e.g. in 1824 when fire was recorded as far south as the Hoya de Cibola site and as far north as the Paxton Springs cinder cone in the Zuni Mountains (H. D. Grissino-Mayer and C. H. Baisan, unpublished data). Such fires were probably tens of thousands or even

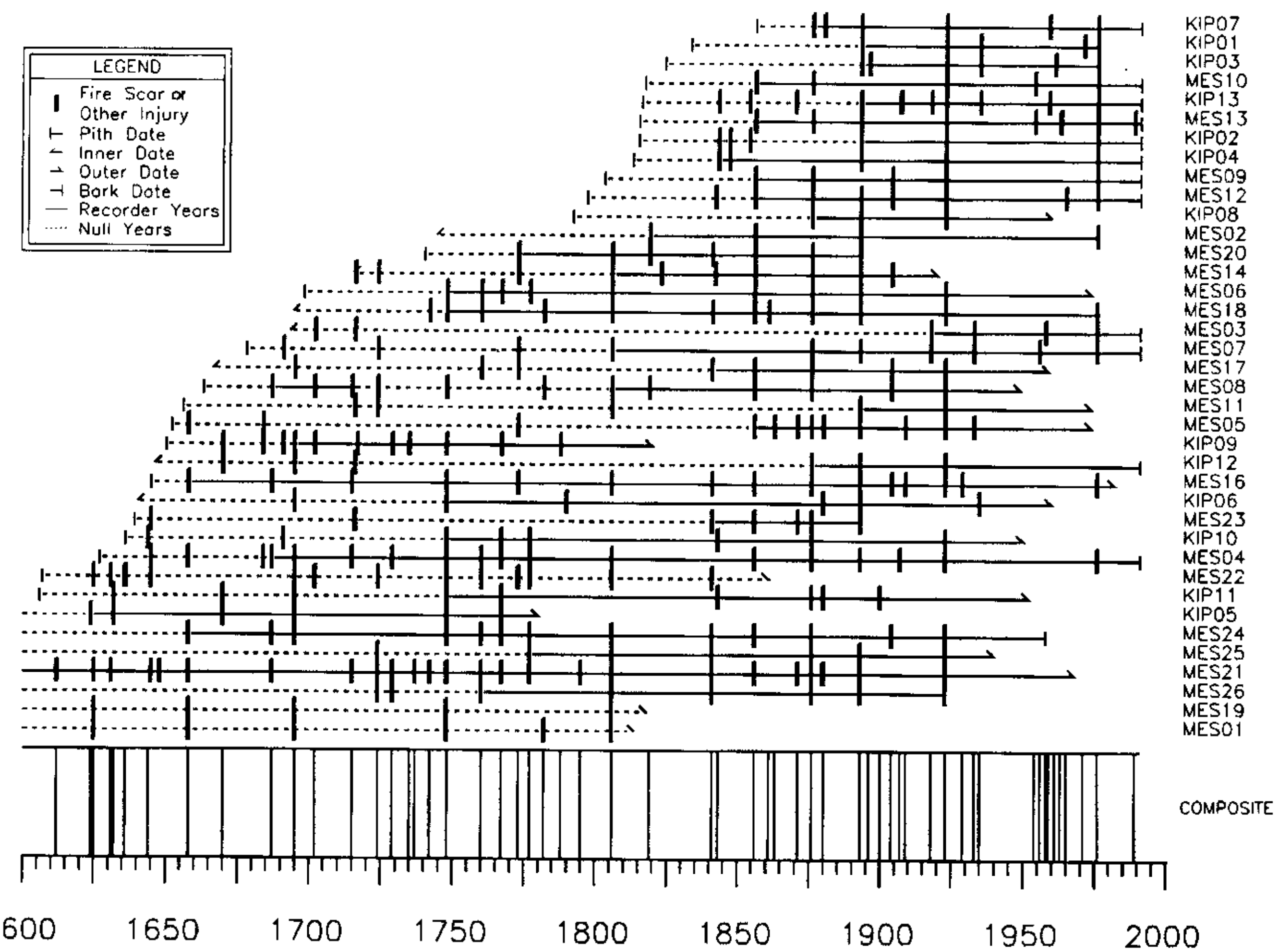


FIGURE 11—Combined fire history for the two kipuka sites, Mesita Blanca and Hidden Kipuka, illustrating uninterrupted fire occurrence into the 20th century. All other sites in the malpais showed changes in the temporal pattern of fires beginning approximately at 1880.

hundreds of thousands of hectares in size. These regional-scale fire years were a natural and recurrent phenomenon over much of the Southwest for many centuries (Swetnam and Baisan, 1996). In the 20th century, however, such regional-scale fire years are almost uniformly high-intensity, destructive burns in forest types where such fires did not previously occur. Such catastrophic fires could alter the successional pathways for malpais habitats (Connell and Slatyer, 1977). The question is not *if* such a fire occurs, but *when*. Effects of such fires on the environment will be more beneficial if fuel loadings and vegetative characteristics are restored to levels that existed prior to 1880.

## Acknowledgments

This research was made possible by a grant from the U.S. Department of the Interior National Park Service, and we are grateful to Doug Eury, Ken Mabery, and Kent Carlton for their enthusiastic support. We thank Dave and Reddy Candelaria who granted us permission to sample on their property. We also thank those who helped in this immense fire history project: Rex Adams, Dave Bleakly, Tony Caprio, Dennis Dixon, Ikuo Furukawa, Andrew Hand, Robbie Heckman, Douglas Henio, Emily Heyerdahl, John Maingi, Guy McPherson, Wolfgang Ortloff, Joe Perry, James Riser, Paul Sheppard, Denise Slama, Ramzi Touchan, and Ed Wright. We thank Chris Baisan and Ramzi Touchan who read, commented upon, and improved early drafts of this paper.

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