# Effects of Habitat Diversity on Fire Regimes in El Malpais National Monument, New Mexico

Henri D. Grissino-Mayer
Thomas W. Swetnam

El Malpais National Monument, located south of Grants, New Mexico, encompasses a highly diverse landscape that provides a unique research opportunity for investigating the fire ecology of southwestern ponderosa pine (*Pinus ponderosa* Laws.) forests in habitats of varying size, isolation, and land-use history. These habitats consist of steep-sided cinder cones, low-lying shield volcanoes, highly weathered early-Pleistocene basalt flows, younger mid-Pleistocene and late-Holocene basalt flows, and isolated "islands" (kipukas) completely surrounded by lava (Lindsey 1951; Maxwell 1982, 1986; Laughlin and others 1993). This landscape heterogeneity suggests that fire ignition probabilities and spread are highly variable, depending on the physical and vegetative characteristics of the individual habitat. Hence, the development of a fire management policy is complicated, because no single fire regime characterizes the fire history of all habitats within the Monument.

In addition, all habitats have been disturbed by human activities to some degree within the last 100 years (Mangum 1990). Large-scale sheep herding began in the malpais area in the early 1880's soon after the subjugation of the Navajo and Apache Indian tribes. The community of San Rafael, adjacent to the Monument, became the center for sheep herding, with tens of thousands of sheep grazing within and adjacent to the Monument by 1885 (Bailey 1980; Mangum 1990). A thriving timber industry began in the early 1890's. Ponderosa pine forests within the Monument and in the Zuni Mountains to the north were heavily logged until the early 1950's (Bureau of Land Management 1981; Mangum 1990). Fire suppression most likely began in the area sometime after the Cibola National Forest was established in the Zuni Mountains in 1931. No change in the fire suppression policy is expected until new fire management plans, currently in development, are implemented.

The purpose of this research is to:

- Determine the history of fire occurrence over the past 300 to 600 years in various habitat types using dendroecological techniques.
- Investigate spatial differences in fire regimes between sites, and propose possible historical and ecological explanations for these differences.
- Investigate temporal differences in fire occurrence within sites and propose possible explanations for these differences.
- Suggest preliminary recommendations for implementing a fire management policy that considers the complexity of the landscape and the historical perspective of human land-use patterns.

## HABITAT TYPE SITE DESCRIPTIONS

Habitat type designations currently in use by the U.S. Department of Agriculture, Forest Service are usually based on the potential climax association that an area can support (Daubenmire and Daubenmire 1964; Alexander and others 1987). In the malpais area, geology is the dominant factor that influences vegetation characteristics and associations, because the different periods of volcanism in the area create unique habitats in different successional stages. For this reason, habitat type designations for this study are based on geologic characteristics, such as those used by Smathers and Mueller-Dombois (1974) for volcanic areas in Hawaii, rather than potential climax associations.

### Ponderosa Pine Forests on Cinder Cones and Shield Volcanoes

This habitat type consists of ponderosa pine forests located on the two types of volcanic vents in the malpais area. We collected samples at: Cerro Rendija, a highly eroded, low-lying shield volcano; Cerro Bandera East, located on a slightly eroded cinder cone; and Lost Woman, a cinder cone completely surrounded by the Twin Craters lava field (Laughlin and others 1993). All three vents are steep-sided and have well-developed soils that support ponderosa pine forests on their northern and northeastern flanks, and a pinyon-juniper forest on their southern and western sides (Lindsey 1951). All three sites are adjacent to surrounding grasslands with a long history of grazing (Mangum 1990). The ponderosa forests at these sites have been logged of many of their larger trees, and the numerous stumps contain well-preserved fire-scarred catfaces. Occasional dense thickets of young ponderosa pine occur on the slopes of these vents, perhaps as a result of fire suppression activities.

### Ponderosa Pine Forests on Ancient Basalt Flows

We collected samples at three sites that typify the open ponderosa pine forests and grasslands on ancient,

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Henri D. Grissino-Mayer is Graduate Research Associate and Thomas W. Swetnam is Associate Professor of Dendrochronology, Laboratory of Tree-Ring Research, University of Arizona, Tucson, AZ 85721.

highly-eroded basalts that surround the malpais: Cerro Bandera North, La Marchanita, and Candelaria. Soils at all three sites are more highly developed and deeper than soils on younger basalt flows, and support abundant grasses, herbaceous cover, and an open ponderosa pine forest. Extensive logging has left numerous stumps with well-preserved catfaces at all three sites. Intense grazing and fire suppression have probably occurred at all three sites because of their proximity to springs, major roadways, trails, and rail systems.

## Ponderosa Pine Forests on Younger Basalt Flows

We sampled one site that typifies the ponderosa pine forest habitats located on moderately-eroded basalt flows. The Hoya de Cibola volcano and its lava flow are considered geologically younger than most vents in the Zuni-Bandera lava field (Ander and others 1981; Maxwell 1986). The lava flow on which the samples were collected is predominantly pahoehoe lava that creates a broken topography with numerous fissures. Forest litter, which facilitates fire spread, tends to accumulate in these fissures. The lava flow supports a low-density, open ponderosa pine forest on shallow soil with patchy grass cover. This site is immediately adjacent to grasslands and may have been impacted by grazing, despite its broken topography. Fires have been suppressed in this area up to the present because of its easily accessible location (U.S. Department of the Interior, National Park Service). We found no evidence of logging at this site.

## Ponderosa Pine Forests on Isolated Kipukas

Kipukas are "islands" of original substrate material (sandstone, limestone, or older lava) that have been completely surrounded by relatively recent lava flows (Lindsey 1951). We collected samples from two isolated kipukas: Mesita Blanca, completely surrounded by the Hoya de Cibola lava flow; and Hidden Kipuka, located one km to the northeast of Mesita Blanca and bounded by the Hoya de Cibola flow to the west and by the Bandera Crater flow to the east. In this study, the fire histories from both kipukas will be combined because of their small size, similar land-use histories, and close proximity to each other. Both kipukas support an open ponderosa pine forest around their perimeter and a pinyon-juniper forest on the higher elevations. The kipukas support excellent grass cover, while shrub cover is negligible. Because of their inaccessibility, logging has not occurred at either site, and fire suppression has been minimal. While limited grazing may have occurred on these kipukas, the impact was probably minimal compared to surrounding areas.

# METHODS

At each site, we collected cross-sections from stumps, logs, and snags with evidence of repeated scarring by fire (catfaces). Small wedges were obtained from a few living trees at each site to determine the most recent fire years (Arno and Sneck 1977). Samples were fine-sanded and all fire scars were crossdated to their exact year of occurrence using dendrochronological techniques (Stokes and Smiley 1968; Swetnam and others 1985). We determined the intra-annual seasonality of fires by noting the position of the fire scar within the annual ring (Baisan and Swetnam 1990). Fire-scar positions and their seasonal designations include:

- Between previous year's latewood and current year's earlywood—dormant season fire (before May)
- Early portion of the earlywood (early May to mid-June)
- Middle portion of the earlywood (mid-June to mid-July)
- Late portion of the earlywood (mid-July to mid-August)
- Within the latewood (after mid-August).

Indirect evidence of fire occurrence (such as traumatic resin ducts) was also noted.

The period chosen for compilation and comparison of results among sites is 1600 to 1880. This period was chosen because sample depth drops to low levels before 1600; 1880 marks the beginning of extensive Anglo settlement and large-scale sheep grazing in the malpais area (Mangum 1990). To evaluate both the history of fire ignitions and fire spread, fire years were quantified by the number of samples scarred for that year. At least ten percent of the samples at each site must have been scarred in any given year for that fire year to be included in the analyses. This ten percent cutoff emphasizes only major, widespread fires while de-emphasizing the smaller "spot" fires. We quantified fire intervals for each site by calculating the maximum, the minimum, and the mean fire interval (Romme 1980) and its associated standard deviation and coefficient of variation for various percentage scarred classes. The coefficient of variation (standard deviation/mean) is used in this study as a measure of the homogeneity of fire frequency over time. For each site, a master fire chart was constructed that displayed the spatial and temporal aspects of fire occurrence (Dieterich 1980). We describe differences in these aspects between sites based on substrate parent material type, fuel types and amounts, and local topography and its effect upon fire history. Finally, the dominant season of fire occurrence for individual sites was obtained by compiling frequency distributions of the intra-annual positions of fire scars.

# RESULTS AND DISCUSSION

## Fire Intervals

Information on fire intervals at all nine sites in the four habitat types is summarized in Table 1. During the period 1600 to 1880, the ponderosa pine forests occupying the low-lying grasslands within and around the malpais had the shortest mean fire interval, ranging from 5.7 years at Cerro Bandera North to 9.0 years at the Candelaria site. The mean fire interval for forests on the steeper sided cinder cones and shield volcanoes is only slightly longer at 6.9 and 8.3 years for Cerro Bandera East and Cerro Rendija, respectively. The longer mean fire interval for the Lost Woman site (11.6 years) is perhaps due to the surrounding topography. Cerro Bandera and Cerro Rendija are surrounded by forests and grasslands on well-developed soil in relatively

**Table 1**—Summary of mean fire intervals (more than 10% of samples were scarred) found for four representative habitats in El Malpais National Monument, 1600 to 1880

| Habitat type site | Fire interval summary | | | | |
|---|---|---|---|---|---|
| | *Mean* | *Stan Dev** | *Coef Var** | *Min* | *Max* |
| Ancient Basalt Flows | | | | | |
| La Marchanita | 7.5 | 5.1 | 0.68 | 1 | 21 |
| Cerro Bandera North | 5.7 | 3.1 | 0.54 | 2 | 16 |
| Candelaria | 9.0 | 4.9 | 0.54 | 2 | 23 |
| Cinder Cones and Volcanoes | | | | | |
| Cerro Bandera East | 6.9 | 3.0 | 0.44 | 2 | 13 |
| Cerro Rendija | 8.3 | 5.4 | 0.65 | 2 | 25 |
| Lost Woman | 11.6 | 7.6 | 0.66 | 3 | 30 |
| Isolated Kipukas | | | | | |
| Mesita Blanca | 11.4 | 6.4 | 0.56 | 4 | 29 |
| Hidden Kipuka | 14.8 | 11.5 | 0.78 | 2 | 33 |
| Combined | 11.4 | 8.5 | 0.75 | 2 | 41 |
| Younger Basalt Flow | | | | | |
| Hoya de Cibola | 14.0 | 8.0 | 0.57 | 2 | 31 |

*Stan Dev = Standard Deviation; *Coef Var = Coefficient of Variation.

unbroken topography that may facilitate fire spread to the cinder cone. Lost Woman is surrounded by a younger lava flow in broken topography that may hinder fire spread to this site.

The longest mean fire interval values exist in the ponderosa forests at the kipuka sites (11.4 years), Lost Woman (11.6 years), and Hoya de Cibola (14 years). These relatively long intervals are probably due to the location and surrounding topography at each site. We expected fires to occur at the Hoya site with lower frequency because of the open, low-density ponderosa forest and patchy grass cover, and because greater time is needed to accumulate fuels, especially within the lava fissures. Because of the small size of the two kipukas, fire occurrence may predominantly spread from the surrounding lava flows and would therefore be dependent upon the same factors affecting fire ignition and spread at the Hoya de Cibola site. In addition, the synchrony of fire years at both Mesita Blanca and Hidden Kipuka indicates that the intervening Hoya de Cibola lava flow hinders fire spread only minimally across the lava surface.

An equal and perhaps more important aspect of fire regimes is the variability of intervals between fires. The coefficient of variation (CV) is used in this study to describe this variability because it combines both the mean and standard deviation into one statistic and allows comparisons between sample populations with different means (Barber 1988). The lower the coefficient of variation, the lower the variability of intervals about the mean fire interval and the more homogeneous the intervals are between fires. The site with the most homogeneous fire intervals is Cerro Bandera East (CV = 0.44) indicating little variability about the mean fire interval of 6.9 years. Conversely, the Lost Woman, La Marchanita, and kipuka sites have the highest variabilities about their respective mean fire interval. These three sites represent three different habitat types, suggesting that the level of heterogeneity of fire occurrence is not dependent on habitat type.

## Grazing Impacts

We expect intense widespread sheep grazing to have a greater effect on the occurrence of large, widespread fires because grazing removes grass cover that provides the finer fuels necessary for fire to spread to adjacent areas (Pearson 1923; Madany and West 1980; Savage and Swetnam 1990; Bahre 1991). Therefore, while we expect to see little change in fire occurrence after 1880, we do expect to see a decrease in widespread fires beginning around 1880.

Figure 1 displays the years in which at least 10% of samples were scarred at sites representative of the four major habitat types in the malpais, and therefore displays only the largest widespread fires. At the Cerro Bandera East, La Marchanita, and Hoya de Cibola sites, major widespread fires decrease dramatically after about 1880. Between 1600 and 1880, fire intervals for widespread fires were 7.2, 7.5, and 12.5 years for the La Marchanita, Cerro Bandera East, and Hoya de Cibola sites, respectively. Between 1880 and 1940, these intervals increase to 14.8 years for the Cerro Bandera East site, and 33.0 years for the Hoya de Cibola site. The La Marchanita site records only one major widespread fire during this period (in 1900). In contrast, the mean fire interval for the kipuka sites was 9.1 years from 1600 to 1880, and showed little change during the period 1880 to 1940 (11.8 years), indicating grazing had little or no impact in these relatively inaccessible areas. However, after about 1940, wide-spread fires become rare in all sites sampled in all habitat types, perhaps as a result of fire suppression.

## Seasonality of Fires

Combining all nine sites, the season of fire occurrence could be determined on 1,493 fire scars. As seen in Table 2, the seasonality of fires is spread evenly throughout the growing season. This result differs from results of other studies in which the dominant season of fire typically occurs during

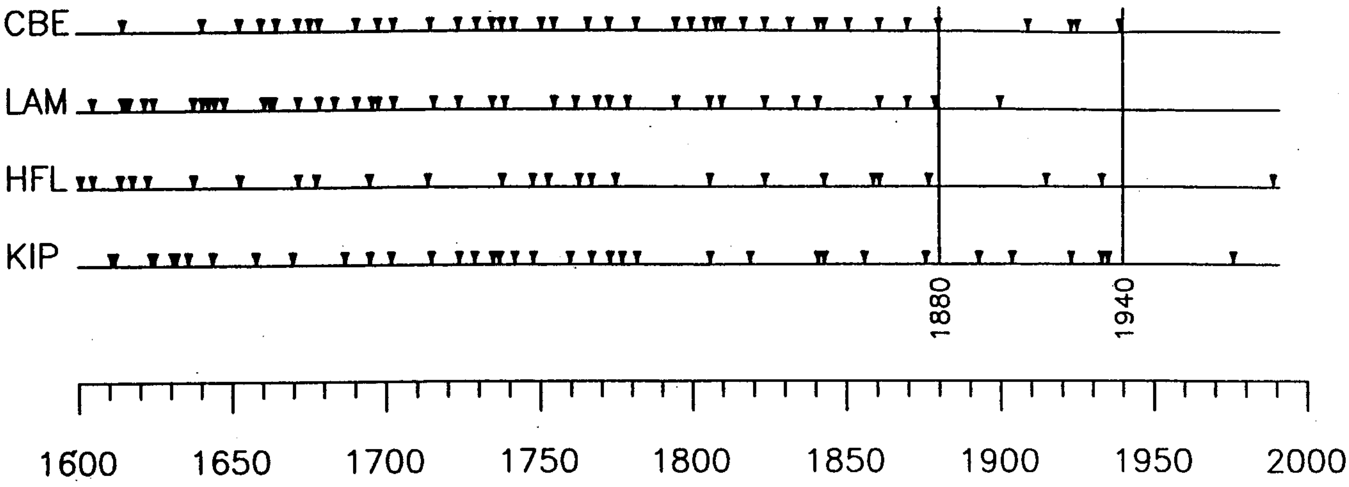


**Figure 1**—Composite fire chronologies for sites representative of the four major habitat types in the malpais area. Fire years are indicated by triangles. Only fires in which more than 10% of samples were scarred are plotted, indicating fires that were widespread. Study site abbreviations are: CBE (Cerro Bandera East), LAM (La Marchanita), HFL (Hoya de Cibola), and KIP (Kipuka sites).

**Table 2**—Summary of fire seasonality from all nine sites for 1,493 fire scars on which season could be determined

| Season | Total number | Percentage |
|---|---|---|
| Dormant Season | 331 | 22 |
| Early Growing Season | 376 | 25 |
| Middle Growing Season | 442 | 30 |
| Late Growing Season* | 344 | 23 |
| Total | 1,493 | 100 |

*Combines late earlywood scars and latewood scars.

the early or middle portion of the growing season, prior to the onset of summer monsoonal precipitation (Swetnam and others 1988; Baisan and Swetnam 1990; Grissino-Mayer and Swetnam 1992; Touchan and others, this proceedings). However, the dominant season of fire occurrence may be masked due to temporal changes in the seasonality of fire occurrence in the malpais area.

Figure 2 plots running percentages of early season fires (dormant season scars and scars in the early portion of the earlywood) versus late season fires (scars in the middle and late portions of the earlywood, and in the latewood) for all fire years from 1600 to 1991. Three dominant modes of fire seasonality are clearly displayed. From about 1630 to 1740, the majority of fires occurred during the early portion of the growing season. From about 1740 to 1840, fires predominantly occurred during the latter portion of the growing season. After about 1840, the fire season shifted back to the early portion of the growing season. Because seasonality of fire is probably coupled with Southwestern climate, these shifts may be due to shifts in regional-scale climate, in particular the seasonality and/or intensity of the bimodal precipitation regime in the Southwest. The temporal stability of the seasonality and intensity of Southwestern precipitation has already been questioned and investigated (Bryan 1940; Hastings and Turner 1965; Leopold 1951, 1976; Dean 1988). Future research should determine whether the temporal changes in fire seasonality are related to temporal changes in the precipitation regime of the Southwest. To help investigate this relationship, a 2,000 year tree-ring chronology is currently being developed to reconstruct climate for the malpais area.

## CONCLUSIONS AND RECOMMENDATIONS

We hypothesize that fire regimes in the malpais area are significantly influenced by the following factors and their interactions: degree of erosion of lava surfaces, subsequent soil development and supported vegetation, topography, size of area considered, and land-use history. These factors created highly variable pre-settlement fire regimes. The two habitats consisting of ponderosa pine

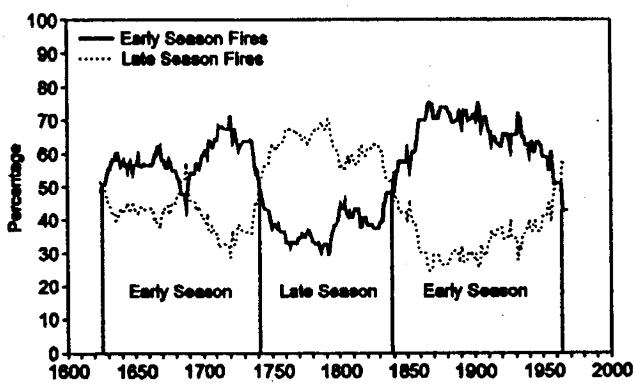


**Figure 2**—Running percentage plot of early season fires versus late season fires for successive 51-year overlapping periods, showing temporal shifts in the dominant season of fire occurrence in the malpais region.

forests on the steep-sided cinder cones and shield volcanoes and surrounding areas of the malpais on more ancient, weathered basalt flows had the highest occurrence of fire prior to 1880, with an average mean fire interval of about seven years. Ponderosa forests in the kipuka habitat and on moderately eroded basalt flows had the lowest occurrence of fire with mean fire intervals between 12 and 14 years. The coefficient of variation indicates that no specific habitat type had the most homogeneous occurrence of fire over time.

Widespread fires cease in accessible areas at about 1880 when intensive sheep grazing became widespread in the malpais area. This finding supports the hypothesis that grazing reduces the finer fuel classes and therefore reduces the ability of a habitat to carry fire. However, fires continued to occur into the 20th century at nearly all sites, but were not capable of spreading to adjacent areas. The two kipukas sampled for this study appear to have fire histories only minimally impacted by human disturbances. All fires recorded by fire scars abruptly cease at about 1940. This reduction in fires may reflect greater success in fire suppression. It may also be due to logging operations that significantly reduced the number of trees that could record fire occurrence with fire scars.

Combining all sites, we found no dominant season of fire occurrence; fires were distributed relatively evenly throughout the growing season. However, we did note that the seasonality of fires has shifted between a fire season dominated by early season fires (1600 to around 1740), to one dominated by late season fires (around 1740 to 1840), back to one dominated by early season fires (after about 1840).

To fully restore natural fire processes within El Malpais National Monument, it will be necessary to restore the present condition of forest stand structure and fuel loads to approximately the conditions that existed before human disturbance. To accomplish this, park personnel should consider the following alternatives:

- Domestic grazing should be reduced and ultimately excluded from the Monument to restore grass cover and fine fuels that would allow fire to spread
- Carefully implemented controlled burns should be conducted in small compartments to reduce the abnormally high levels of both live and dead fuels that have accumulated over time due to fire suppression and logging. Manual thinning of overstocked thickets of young ponderosa pine trees may be required prior to burning to reduce the hazard of fires "crowning" in the remaining overstory, old-growth trees
- Once forest and fuel conditions have been restored to approximately the natural conditions, naturally occurring fires should be suppressed within the Monument only when there is hazard to humans or private property.

These recommendations are solely the opinion of the authors and do not necessarily reflect the opinions of, or endorsement by, the National Park Service.

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