FIRE HISTORY AT THE SOUTHWESTERN GREAT PLAINS MARGIN, CAPULIN VOLCANO NATIONAL MONUMENT

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ABSTRACT—This study documents historic fire events at Capulin Volcano National Monument over the last four centuries using dendrochronologically dated fire scars at two sites: the lower volcano lava flows (the Boca) and the adjacent canyon slopes (Morrow Ranch). The mean fire interval (MFI) was 12 years at the Boca site (before 1890) and 5.4 years (1600-1750) and 19.1 years (1751-1890) at the Morrow Ranch site. Data from the Boca and Morrow Ranch sites combined with the extremely pyrogenic landscape position of the volcano slopes indicate that the volcano slopes likely burned more frequently (e.g., MFI <5 yr). Around 1750, the fire regime appeared to transition to longer fire intervals, greater temporal synchrony among fire-scarred trees, and a higher proportion of trees scarred in fire years. Temporal variability in the fire regime at Capulin Volcano may reflect changes in human populations, climate, and land use.

Key Words: dendrochronology, fire scars, New Mexico, Pinus edulis, Pinus ponderosa

INTRODUCTION

Quantitative fire history and disturbance information underlies many land management decisions, natural resource policies, and concepts of ecosystem processes. Long-term patterns of disturbance influence patterns of species composition and the function of natural communities. Determining condition classes for fire management plans requires information on reference conditions (Floyd et al. 2004). Studies at sites throughout North America have provided information about how fire frequency changes over long time periods and by physical features of the site, such as slope, aspect, elevation, and topographic roughness (e.g., Swetnam and Baisan 1996; Sieg 1997; Taylor and Skinner 1998; Guyette and Spetich 2003). Fire-history studies are increasingly used to guide prescribed burning practices and to develop specific prescribed burning management objectives (Parsons and Botti 1996; USDA Forest Service 2003).

In much of North America there is limited potential for documenting the long-term role of fire because historic fire evidence is unavailable, fire-scarred materials have been removed, or forest stand age and composition are too complex for extraction of reliable historic information. In New Mexico, nearly 70 fire histories have been cataloged in the International Multiproxy Paleofire Database (IMPD) (http://www.ncdc.noaa.gov/paleo/impd/). Although this is a relatively abundant number of fire-history records compared to other states, none exists for the Southwest Plateau and Plains Dry Steppe and Shrub Province (Bailey 1998), a 416,000 km² area of eastern New Mexico and northwestern Texas. The Cerro Pedernal fire-history site on the Santa Fe National Forest (Touchan et al. 2003) is one of the nearest (~100 miles southwest) to Capulin Volcano National Monument (CVNM); however, high between-site variability can exist in fire frequency due to elevation, aspect, geographic location, and historic human occupancy (Baker and Shinneman 2004). Such variability often precludes the use of information from other study sites and emphasizes the importance of site-specific fire-history information.

Historic fire-frequency information is needed for the Great Plains for several reasons. In an ecosystem that developed over thousands of years of cyclical grazing and fire (Higgins 1986), modern disruption of natural disturbance patterns has seriously affected the biodiversity of native plant and animal species. Natural communities are changing in response to factors such as the spread of exotic species, land-use change, landscape fragmentation, grazing pressure, and fire suppression (Sieg 1997). In addition, the potential for increased wildfire risk as a result of shifting vegetation and fuel characteristics is largely unknown.
Whether managers are interested in restoring or preserving natural biodiversity or reducing wildfire risk, historic fire-frequency information provides a scientific basis for management activities.

The objectives of this study were to (1) construct a chronology of fire-scar occurrence spanning several centuries, (2) present summary statistics on the frequency and occurrence of fire at various temporal periods and spatial extents, and (3) identify factors controlling the frequency and intensity (percentage of trees scarred) of historic fires by landscape type.

METHODS

Study Sites

The 792-acre Capulin Volcano National Monument lies in Union County, northeastern New Mexico (36°47′N, 103°57′W), at the edge of the Great Plains and approximately 60 miles east of the southern end of the Rocky Mountains (Parent et al. 1999). The national monument is located in the transition zone between the Southwest Plateau and Plains Dry Steppe and Shrub Province and the Great Plains Palouse Dry Steppe Province (Bailey 1998). Capulin Volcano (elevation: 2494 m) rises from the Raton-Clayton volcanic field, which has had periodic volcanic activity for the past 9 million years (Parent et al. 1999). It is an extremely well-preserved, recently extinct cinder-cone volcano formed between 56,000 and 62,000 years ago, and was designated a national monument in 1916 by President Wilson (Parent et al. 1999; NPS 2004). The surrounding landscape includes mesa, canyon, and arroyo features but is predominantly heavily grazed arid grassland plains. The dominant vegetation associations at CVNM are Plains-Mesa Grassland and Pinyon-Juniper woodlands. The area of approximately 0.1 km², and the dominant tree species at the Morrow Ranch site is ponderosa pine (P. ponderosa Douglas ex C. Lawson); also present are Douglas-fir [Pseudotsuga menziesii (Mirbel) Franco] and oak (Quercus spp.).

We exhaustively searched both study areas for trees that exhibited both numerous tree rings (longevity) and presence of fire scars. Cross-sections were collected from the base of trees using a chainsaw. Samples were collected primarily from ponderosa and pinyon pine remnants (dead trees), and a limited number (n = 4) of wedges were collected from live and recently dead trees to capture the fire history of the 20th and 21st centuries. Twenty-two ponderosa pine cross-sections from CVNM (Boca and cinder cone) and 25 cross-sections from the Morrow Ranch site were used in the final fire-history analysis. Cross-sections of three dead pinyon pines were collected from the upper slopes of Capulin cinder cone, but no datable fire scars were found. The location of each sample was geographically referenced using a GPS unit (Fig. 1). In addition to cross-sections, tree-core samples (n = 54) were collected from the base of trees using an increment borer. Core samples were collected non-randomly from the oldest pinyon pines on the upper slopes of the cinder cone of Capulin Volcano in an effort to determine past recruitment and age cohorts.

Field Methods

In October 2004 we collected tree cross-sections, wedges, and cores at Capulin Volcano National Monument and the adjacent Morrow Ranch (Fig. 1). Historic fire regimes were likely highly variable across this landscape due to differences in physical (landform) and vegetative characteristics (Table 1). Samples were initially collected from the upper portion of the cinder cone of Capulin Volcano, where steep, smooth slopes support a mosaic of pinyon-juniper-oak woodland and grassland. However, these samples had limited fire-history potential because of age (too young), the abundance of porcupine scarring, and the lack of fire scars on trees. Therefore, many of the CVNM samples came from the Boca area, where we exhaustively sampled dead remnant wood. The Boca area, located on the western side of the volcano base (Fig. 1), is an extremely rough basaltic lava field with an area of approximately 0.1 km². Vegetation at the Boca site is currently a patchy mosaic of pinyon-juniper-oak woodlands and grassland, with many completely barren areas consisting of broken basalt. Vegetation establishes in lava rock fissures and is sustained by moisture trapped in the porous rock (Grissino-Mayer et al. 1997). The Morrow Ranch site is privately owned and located on a north-facing lower slope of an east-facing box canyon adjacent to the monument. The area is approximately 0.1 km², and the dominant tree species at the Morrow Ranch site is ponderosa pine (P. ponderosa Douglas ex C. Lawson); also present are Douglas-fir [Pseudotsuga menziesii (Mirbel) Franco] and oak (Quercus spp.).

Laboratory Methods

Cross-sections and wedges were surfaced with an electric hand planer, and the cellular detail of annual rings and fire-scar injuries were revealed by sanding with progressively finer sandpaper (80 to 1200 grit) (Fig. 2). Cores were mounted on wooden planks and sanded in the same manner. For each core sample, the number of rings to the pith was counted. When the pith was absent
Figure 1. Maps of study area (top), samples collected from Capulin Volcano National Monument (A) and samples collected from Morrow Ranch (B).
TABLE 1
SITE AND FIRE-REGIME CHARACTERISTICS OF THE STUDY AREAS
OF CAPULIN VOLCANO NATIONAL MONUMENT

<table>
<thead>
<tr>
<th></th>
<th>Boca</th>
<th>Morrow Ranch</th>
<th>Capulin Volcano</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elevation (m)</td>
<td>2225-2274</td>
<td>2164-2210</td>
<td>2164-2500</td>
</tr>
<tr>
<td>Site area (km²)</td>
<td>0.5</td>
<td>0.1</td>
<td>Not available</td>
</tr>
<tr>
<td>Landform</td>
<td>Lava flow</td>
<td>Lower canyon slope</td>
<td>Volcano cone</td>
</tr>
<tr>
<td>Vegetation type</td>
<td>Pinyon-juniper-oak-grassland</td>
<td>Ponderosa pine forest-woodland</td>
<td>Pinyon-juniper-oak-grassland</td>
</tr>
<tr>
<td>Number of positive fire characteristics</td>
<td>2</td>
<td>3</td>
<td>6</td>
</tr>
</tbody>
</table>

Figure 2. Cross-section of a preserved, previously cut stump (sample MOR013) showing the annual rings, charcoal-covered exterior surface, fire-scar injuries, and their associated dates.

the number of missing rings was estimated by dividing the estimated distance to pith by the average ring width of the innermost three rings present on the core.

Only ponderosa pine samples were used in the fire-scar chronology. A radius (pith-to-bark tree-ring series) of each cross-section or wedge with the least amount of ring-width variability due to fire injuries was chosen for tree-ring width measurement and cross-dating. All tree-rings were measured to 0.01 mm precision using a binocular microscope and a moving stage fixed to an
electronic transducer. Tree-ring-width series from each sample were visually cross-dated using ring-width plots (Stokes and Smiley 1968; Baillie 1982), and dates were statistically verified using standard dendrochronological techniques. The computer program COFECHA (Grissino-Mayer 2001) was used to ensure accurate dating of samples, and it facilitated identification of false and missing rings (Stokes and Smiley 1968). Ponderosa pine samples were also cross-dated with two nearby ponderosa pine chronologies from the International Tree-Ring Database (NM574, NM575) (Woodhouse and Brown 2001). Missing and false rings were identified on multiple samples.

Fire scars were identified by the presence of callus tissue, charcoal, traumatic resin canals, liquefaction of resin, and cambial injury. Fire-scar dates were assigned to the first year of response to cambial injury. The season of each fire event was also identified using the location of the injury within or between rings. The location of injuries within a ring allows for identification of the fire-event season (i.e., earlywood indicates approximately April to July; latewood, approximately July to October; and between rings, approximately October to April) (see Kaye and Swetnam 1999). We used FHX2 software (Grissino-Mayer 1995; Grissino-Mayer 1996) to construct the fire chronology, analyze fire-scar years, and graph individual tree and composite fire intervals. Mean fire intervals (MFI) and summary statistics were computed for the composite (site-level) mean fire intervals.

**Analysis**

Kolmogorov-Smirnov goodness-of-fit (K-S) tests were conducted on the frequency distribution of fire intervals to determine whether a Weibull distribution modeled the interval data better than a normal distribution. Weibull median fire intervals were recorded. Due to limited sample availability, fire-regime characteristics of the upper volcanic slopes (i.e., above Boca area) are inferred based on the number of positive fire characteristics (see Table 1), land use, and the fire-history site’s MFIs.

**Results**

The tree-ring record from both the Capulin Volcano National Monument and Morrow Ranch sites spanned the period from about 1600 to the late 20th century (Table 2).
The total number of years (tree rings) analyzed was 9,358. We identified and dated 152 fire scars that occurred from 47 fire-event years. No datable fire scars were found on samples from the upper slopes of the Capulin cinder cone. Fire-scar dates ranged in calendar years from 1601 to 1966 (Figs. 3, 4). Fire-scar synchrony between sites occurred for six events and suggests that landscape-scale fires occurred periodically in the vicinity of CVNM (Table 2). The greatest number of fire scars on a single tree was nine at CVNM and 11 at Morrow Ranch. Mean fire intervals (MFIs) prior to 1750 varied by site and ranged from 5.4 at Morrow Ranch to 12 years at Boca. Between 1751 and 1890, the MFI was longer at Morrow Ranch (19.1 years) than at the Boca (12 years). Annual burning was rare, occurring only three times and only at the Morrow Ranch site. The MFI for the total record was 11.3 years at the Boca site and 9.9 years at Morrow Ranch. Over the common period of record, the Morrow Ranch site had over twice the number of fire events than the Boca site. The current fire interval at CVNM is the longest on record, with 146 years since the last fire (Fig. 3). The longest fire interval at Morrow Ranch for the period of record was 57 years (1886-1943) (Fig. 4). For the entire record, composite mean fire intervals were 11.3 years at Capulin Volcano and 9.9 years at Morrow Ranch. Mean individual tree-scar fire intervals were 21.4 years at Capulin Volcano and 23.4 years at Morrow Ranch (Fig. 5).

Fire severity (percentage of trees scarred) was temporally variable at both the Boca and Morrow Ranch sites. At both sites the percentage of trees scarred during fire events increased after about 1750. Prior to 1750, mean percentage of trees scarred was 14% at the Boca site and 13% at Morrow Ranch. After 1750, mean percentage of trees scarred increased slightly at the Boca site to 19% and increased dramatically at the Morrow Ranch site to 55%. The three most severe fire years (i.e., highest percentage of trees scarred) for the combined site records were 1770 (incipient dry), 1815 (incipient wet), and 1851 (severe drought) (Fig. 6). The percentage of trees scarred and drought (Palmer drought severity index) were not significantly correlated ($r = -0.08, p = 0.62$).
Season of burning transitioned in the mid-18th century from primarily growing season to dormant season (Table 3). At the Boca site there were no growing-season fires after 1753. Three of seven fires prior to 1753 occurred during the growing season; one in the early growing season (e.g., May-June), one in the mid-growing season (e.g., June-July), and one in the late growing season (e.g., July-September). At Morrow Ranch at least 21 of 29 fires (72%) before 1771 occurred during the growing season, but only 3% of fires occurred during the growing season after 1771. No growing-season fires occurred at Morrow Ranch between 1771 and 1940.

Core samples indicated that the oldest pinyon pines (485+ years) present on the volcano slopes were on the most barren and erosive landscape positions, where the lack of fuel possibly protected them from severe fires. Many of these trees are located above the volcano-rim access road on the east and south aspects. Pinyon pine recruitment has been relatively continuous over the past 300 years, and between 1700 and 1890, pinyon pine recruitment on the volcano slopes occurred in three pulses (circa 1750, 1820, and 1880) that were associated with long fire-free intervals (Fig. 7).

**CONCLUSIONS**

The overall fire history of Capulin Volcano National Monument is the result of spatially and temporally complex interactions among regional climate, topography, fuels, ignitions, and humans—each of which we attempt to put into a specific context relative to one another.

Differences in historic fire-regime characteristics among the Boca site, Morrow Ranch site, and upper volcano slopes can be attributed primarily to differences in landscape position and fuels (Table 1). In the early portion of the record (prior to the influences of fire suppression
and widespread livestock grazing), fire was more common at the Morrow Ranch than at the Boca site. While the landscape position and continuous fuels at Morrow Ranch and the cinder cone made them conducive to fire spreading, the discontinuity of fuels on the Boca likely meant that more years of fuel accumulation were required between fire events for fire propagation. Fire frequency at the Boca site likely represents a minimum fire frequency for the Capulin Volcano National Monument for this reason. Although the lower frequency of fire at the Boca (in comparison to the Morrow Ranch) may be attributable to sample size, particularly prior to about 1675, the well-replicated portions of the record also show a reduced frequency.

Due to the lack of fire-scar evidence, historic fire frequency was inferred for the upper volcanic slopes based on features of the site and adjacent fire-history data (Table 2). Several factors preclude fire-history reconstruction from the few older pinyon pines growing on the upper slopes, such as site erosion, excessive basal bole twisting, extensive porcupine scarring, and the general lack of fire scars. Despite these confounding factors, the inferred fire frequency (MFI ~5 yr) of the Capulin cinder cone is a best estimate, and interestingly, is similar to that found at volcanic sites at El Malpais National Monument in northwest New Mexico (Grissino-Mayer and Swetnam 1997).

In addition to topography, regional climate influences nearly every other aspect of the fire regime, including the nature and distribution of fuels, the number of natural ignitions, and occupancy of the site by humans. Although drought was not significantly correlated to percentage of trees scarred, it cannot be discounted as an important influence on regional fire occurrence (Swetnam and Baisan 1996). Three fires (1716, 1752, and 1851) were among the 20 largest fires recorded in the southwestern United States since 1700 (Swetnam and Baisan 1996). Drought-fire analyses using fire-history data commonly incorporate many sites to reduce site-scale “noise” and enhance the

Figure 5. A comparison of the frequency distributions of fire intervals at Capulin Volcano and Morrow Ranch, including intervals based on all scars found at each site (composite fire intervals, top) and individual tree-scar intervals at each site (bottom).
Frequent lightning strikes and high winds are characteristic features of the upper slopes and rim of Capulin and vicinity (Wagner et al. 2006). Natural ignitions were almost certainly supplemented by anthropogenic ignitions, as the area was widely occupied during this period by Jicarilla Apaches known to set fires for hunting and agricultural purposes (Thomas et al. 1974; Ross and Moore 1987). The short MFI at Morrow Ranch and the low percentage of trees scarred during this portion of the record suggests a fire regime dominated by relatively frequent, low-intensity surface fires.

During the mid-1700s a shift in the fire regime occurred, which was detected by changes in the mean fire interval, the percentage of trees scarred, and the seasonality of fires. Fires occurred less frequently than before, but a much higher percentage of trees scarred per fire event suggests an increase in fire severity. While not an exact measure, the synchrony of a higher percentage of trees scarred and a pulse in pinyon pine recruitment lends support to the idea that fires during this era were more severe and possibly stand-replacing events. A shift from primarily growing-season fires to dormant-season fires, particularly at the Morrow Ranch, also occurred during this period. These changes in the fire regime may reflect the effects of an increasing local human population or changes in regional climate.

Fire-history studies in other Southwest locations have revealed a pattern of shifting fire-regime characteristics concurrent with those found in this study (e.g., Baisan and Swetnam 1997; Kaye and Swetnam 1999; Grissino-Mayer et al. 2004). Grissino-Mayer et al. (2004), for example, found a substantial gap in fire occurrence from 1750 to 1770 in the San Juan Mountains of southwestern Colorado, followed by increased fire frequency and extent. The authors speculated that a cooling trend in regional climate, possibly related to the Pacific Decadal Oscillation, led to

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**TABLE 3**

<table>
<thead>
<tr>
<th>SITE FIRE-SCAR CHARACTERISTICS BY TIME PERIOD</th>
</tr>
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<tbody>
<tr>
<td>Boca</td>
</tr>
<tr>
<td>Mean percentage of trees scarred in fire events (first year-1750)</td>
</tr>
<tr>
<td>Mean percentage of trees scarred in fire events (1751-1890)</td>
</tr>
<tr>
<td>Fire seasons (before 1751)</td>
</tr>
<tr>
<td>Fire seasons (1751-1890)</td>
</tr>
</tbody>
</table>

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The early period of the fire chronology (~1600-1750) reflects a relatively well-documented period of Native American occupation, and the numbers of natural and human ignitions were probably the primary factors controlling fire frequency and extent at the monument.
the gap in fire events and the subsequently altered fire-regime characteristics. While no substantial hiatus in fire occurrence was found at Capulin, we found less frequent and arguably more widespread fire events after 1750, along with the shifts in fire seasonality.

While climate patterns may be at least partially responsible for the changes in the fire regime at Capulin during this period, the influence of humans and land-use change almost certainly contributed as well. Up until the beginning of the 19th century, northeastern New Mexico was considered the “wild east” or the frontier for the Spanish explorers coming from the south. The Louisiana Purchase changed this, opening the territory up to American explorers and traders (Thomas et al. 1974), and after Mexico gained independence from Spain in 1821, the first trading party established the Santa Fe Trail. The Cimarron Cutoff portion of the trail passed less than a mile from Capulin Volcano, which was an important landmark and resting point for travelers on the long journey to Santa Fe (Centennial Book Committee 1988).

Longer fire intervals at both sites after 1860 coincide with heavy use of the Santa Fe Trail, the advent of widespread livestock grazing, the founding and settlement of nearby communities, the relocation of Jicarilla Apaches to a reservation, and the arrival of railroads (Thomas et al. 1974; Centennial Book Committee 1988). Cattle ranching was intensive on lands surrounding Capulin, and the Goodnight Trail, an important cattle-drive route, passed over toe-slopes of the volcano. Widespread grazing at this site and throughout the southern Great Plains reduced abundance and heterogeneity of fine fuels, impacting the frequency and extent of surface fires (Covington and Moore 1994). Reduced fire frequency coincident with widespread livestock grazing has been found at sites throughout the southwestern United States (Savage and Swetnam 1990; Touchan et al. 1995; Swetnam and Baisan 1996; Grissino-Mayer and Swetnam 1997) and as early as the mid-1700s (Baisan and Swetnam 1997).

The more recent portion of the record (~1890-present) appears to be largely controlled by land use and ignition suppression. The fire-history record shows no fires occurring at Capulin Volcano National Monument since 1860, though at least one fire has been recorded at the monument since then: the 0.1 acre Cable Fire in 1981 (NPS 2004). Many of the undesirable current conditions identified at the monument (i.e., juniper and pinyon encroachment of grasslands, increased tree and shrub density in woodlands, hazardous levels of large woody fuels, and displacement of native grasses and forbs) (NPS 2004) are likely the result of both decreased fire occurrence and widespread livestock grazing during this period. Fire suppression and decreased grazing continue to affect vegetation-community composition and the types and arrangement of fine fuels. Continued fire suppression will likely result in further increases in forested area and fuel accumulation, likely impacting the behavior and increase the severity of future fires at the monument.

The location of this fire-history study at the southwestern edge of the Great Plains prompts the question as to how this study increases our understanding of the fire history of the Great Plains—a poorly understood ecosystem in terms of the historic role of fire disturbance. Although there is abundant fire-history information from the intermountain west and the southwestern regions,
the applicability of such information to the Great Plains is unknown, particularly considering that the many key components of the fire regime (e.g., topography, vegetation, climate, and land use) are different. At this time, most available information on the historic fire regimes of the Great Plains is derived from studies of charcoal in lake sediments (e.g., Camill et al. 2003; Brown et al. 2005), modern fires (e.g., Higgins 1984), and written documents (e.g., Higgins 1986). Fire-scar histories based on tree rings are relatively limited and primarily located on the periphery of the region. Additional tree-ring studies targeting underrepresented portions of the Great Plains would increase our understanding of both the spatial and temporal variability in historic fires. Additional fire-history studies have many practical applications as well, such as guiding prescribed burning and putting the fire-history results from Capulin Volcano National Monument into a broader context.

**ACKNOWLEDGMENTS**

The authors thank Bruce Robinson for assistance in locating study sites, sample collection, and providing meaningful information about the ecology of the Capulin Volcano National Monument and vicinity. We thank Jill Morrow for graciously making her ranch and forests available for this study. We thank Jessie Bebb for assistance in locating and collecting fire-history samples and Adam Bale and Joe Marschall for their assistance with laboratory analysis. We also thank Gary Willson, Research Coordinator at the Great Plains Cooperative Ecosystem Studies Unit (CESU) and Acting Research Coordinator for the Upper and Middle Mississippi Valley Cooperative Ecosystem Studies Unit, for assistance with fieldwork and project reports. Funding for this study was provided by the Great Plains and Desert Southwest CESUs and the National Park Service.

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Manuscript received for review, July 2006; accepted for publication, September 2006.