CHAPTER 5

LOTS OF LIGHTNING AND PLENTY OF PEOPLE: AN ECOLOGICAL HISTORY OF FIRE IN THE UPLAND SOUTHWEST

Craig D. Allen

Was the pre-European Southwest a region of wild landscapes, shaped primarily by natural processes like lightning-ignited fire, or did people substantially mold these lands into regional-scale artifacts through their use of fire and other means? Perspectives on this question have varied markedly through time and between scholars, as evident from the quotes interspersed through this chapter (see Box 5.1). As the American frontier closed around the turn of the nineteenth century, lightning was rarely considered a primary cause of fire, with most fires in western forests assumed to be human-ignited. Native Americans were thought to have been the primary source of burning in the Southwest until Euro-Americans usurped that role after ca. 1850. Today, lightning-ignited fire is widely acknowledged to be an ancient and essential ecological process in the American Southwest (Pyne 1995a:282–283; Swetnam and Baisan 1996a; Bogan et al. 1998), for millennia structuring landscapes from low-elevation desert grasslands to montane forests. However, because the Southwest has been home to people for more than 12,000 years, with large human populations for over 1,000 years (Plog et al. 1988), some scholars continue to assert the dominance of aboriginal burning in the fire regimes of this region (Dobyns 1981; Pyne 1995a, 1996, 1997). This essay focuses on the roles of lightning versus human ignitions in pre-1900 fire regimes of the upland forests and woodlands of the Southwest. Given the regional abundance of long-term paleoecological and archaeological information, the Southwest provides unique opportunities to assess the relative importance of both natural and cultural factors in the ecological history of fire (Swetnam et al. 1999).

The American Southwest as discussed here is centered on Arizona and New Mexico, extending into adjoining portions of Mexico, the Colorado Plateau in Utah and Colorado, and western Texas. The emphasis of this chapter is on upland settings in the mountains and plateaus of this region, ranging from isolated mountain "sky islands" in the deserts of northern Sonora to the extensive subalpine forests of the southern Rocky Mountains in New Mexico. The forests and woodlands that cloak the Southwestern uplands provide the most extensive and detailed regional-scale network of fire history data available in the world (Swetnam and Baisan 1996a; Swetnam et al. 1999). I will give particular attention to the Jemez Mountains area in northern New Mexico (Figure 5.1), as this landscape exemplifies one of the most humanized portions of the prehistoric Southwest, with abundant fire history and land use information available. It is also the landscape I know and love best.

Multiple lines of evidence contribute to the southwestern fire and land use histories used here (Allen et al. 1998; Swetnam et al. 1999):

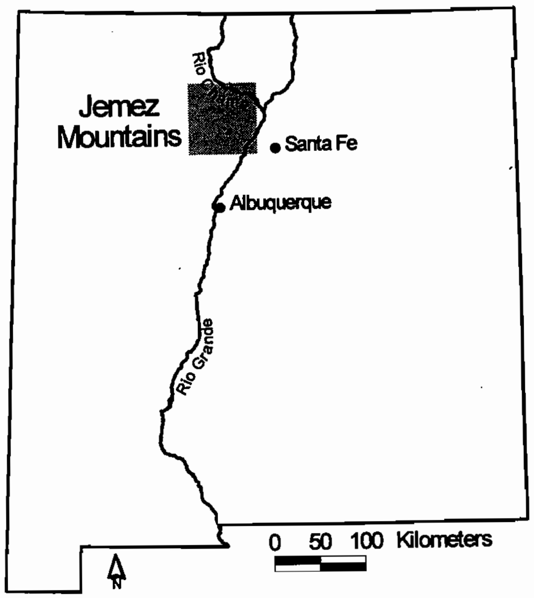

Figure 5.1. Location of the Jemez Mountains in New Mexico. The box outlines the area displayed in Figures 5.2, 5.4, and 5.5.

dendrochronological reconstructions of fire history, forest age structures, and climate; charcoal from bogs and other sedimentary records; repeat photography; modern observations of lightning and fire activity; documentary archives; and a variety of data from archeological surveys and excavations. This review begins with a consideration of the natural history of fire in the Southwest, then addresses the role of humans in modifying the fire regimes of this region's landscapes. I assert that frequent fire is an intrinsic, natural feature of the uplands of the Southwest, primarily driven by nonhuman factors such as climate, availability of surface fuels, and lightning ignitions. Modern claims of extensive aboriginal burning of southwestern landscapes are shown to be based upon broad overgeneralizations and uncritical extrapolations from a few historical reports of localized fire use. Yet within the overall regional context of generally natural fire regimes, people have significantly modified patterns of fire during particular times and in particular places. Since the ecological history of southwestern fire involves interactions among both natural and cultural histories, generalizations about "pristine" versus "humanized" landscape conditions need to consider the particulars of variation in the relative effects of people through time and space.

The Natural History of Fire in the Southwest

> Fire belongs in the mountain Southwest, and unless the peaks flatten, the monsoon evaporates, the seasons homogenize, or the biota vanishes, those fires will continue. (Pyne 1995a:295)

The paleoecology of the southwestern United States, including records of fire occurrence, is documented as well as for any region on Earth (Betancourt et al. 1990; Swetnam et al. 1999). Packrat middens (Van Devender and Spaulding 1979; Betancourt et al. 1990) and pollen deposits (R. S. Anderson 1993; Weng and Jackson 1999) show that modern climate/vegetation patterns basically developed in the Southwest during the early Holocene, ca. 11,000 to 8,000 years ago. Substantial fire activity apparently emerged in the Southwest during that time, as evidenced by the contemporaneous and rapid spread of fire-adapted ponderosa pine forests across the region (Anderson 1989) and by the abundant charcoal deposits found in lake and bog sediments (Petersen 1988; Brunner-Jass 1999; Weng and Jackson 1999). For example, Weng and Jackson (1999) link increases in fire activity to the establishment of ponderosa pine forests on the Kaibab Plateau between about 10,000 and 11,000 years ago, while charcoal sediments from Alamo Bog in the Jemez Mountains indicate essentially continuous fire activity extending back to at least 8,000 years ago (Brunner-Jass 1999). Other evidence includes a regional network of dendrochronologically dated fire-scar chronologies that documents the patterns of frequent and extensive fire which have characterized most southwestern forests over at least the past 300 to 500 years (Swetnam and Baisan 1996a; Swetnam et al. 1999), while the fire suppression records of land management agencies provide a direct record of abundant fire activity during the twentieth century (Barrows 1978; Snyderman and Allen 1997; Rollins et al. 1999). It is apparent that the uplands of the Southwest have experienced widespread and recurrent fires for thousands of years. Although fire-using people were present in the Southwest throughout this time period, the dominant view among fire ecologists is that most of the regional patterns of fire occurrence across the prehistoric and historic Southwest are adequately explained by natural factors (Swetnam and Baisan 1996a), including an abundance of lightning ignitions (Barrows 1978) and receptive climate/fuel conditions (Swetnam and Betancourt 1998).

A key feature of the southwestern environment that naturally fosters the occurrence of fire is a plentiful source of fire ignitions through high levels of lightning activity (Barrows 1978; Orville and Silver 1997). Convectional thunderstorms that generate lightning occur frequently in the Southwest, particularly during the summer monsoon season when warm temperatures and influxes of moist maritime air trigger near-daily cloud buildups over mountain areas. For example, 62 thunderstorm-days per year are observed in the Jemez Mountains at Los Alamos (U.S. DOE 1979), generating large numbers of lightning strikes. An automated lightning detection system (Krider et al. 1980) recorded 165,117 cloud-to-ground lightning strikes over a 775,554 ha area centered on the Jemez Mountains during the period 1985–1994. The annual number of recorded lightning strikes varied between 9,410 and 23,317 (see Figure 5.2). Although lightning activity clearly peaks during the summer monsoon (Figure 5.3), strikes were recorded in every month. Particularly important for fire ignitions is the substantial lightning activity during the warm, dry, foresummer months of April through June (Figure 5.3), when many lightning strikes occur from sporadic storms or clouds generating only virga (rain that evaporates while falling and thus fails to reach the Earth's surface). These strikes are the most significant sources of fire ignition because lightning is much more likely to start a spreading fire if it strikes dry fuels. Because lightning ignitions are so frequent and ubiquitous in the Southwest (Barrows 1978), climate and fuel conditions are the main drivers of fire regime dynamics in this region (Swetnam and Betancourt 1990, 1998; Swetnam and Baisan 1996a).

Patterns of precipitation variability in the Southwest favor frequent and extensive fire activity. The generally dry climate of this interior conti-

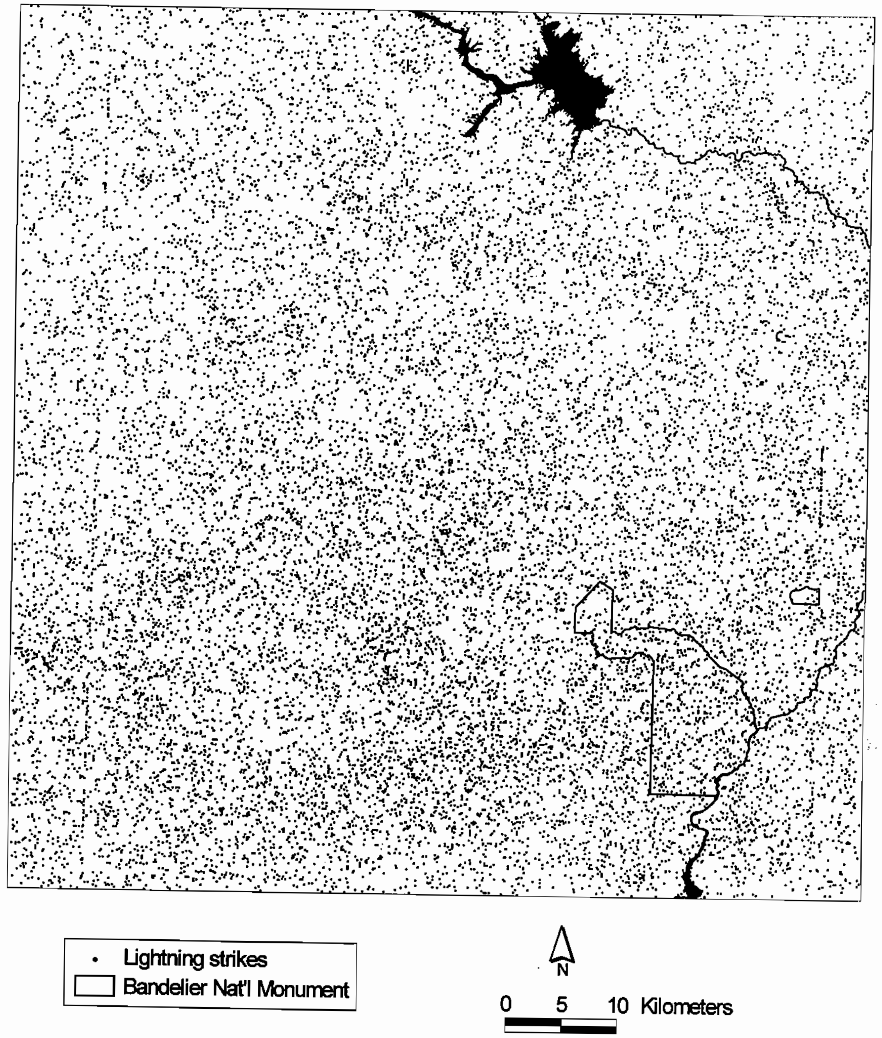

Figure 5.2. Lightning strikes in the Jemez Mountains, 1986. Map of 23,317 lightning strikes recorded across 775,554 ha in the Jemez Mountains area during 1986 by the national automated lightning detection system. The nominal resolution of the locational data is approximately 2 km. Surprisingly little difference in lightning strike frequencies is evident across the 1,800-meter elevational gradient present in this field of view, which is also the same in Figures 5.4 and 5.5.

nental region permits fuels to burn readily much of the year, especially during the warmer months of April through October (Barrows 1978). Dry seasons typically occur in the spring and fall between the winter period of cyclonic storms and the summer monsoon, with most precipitation received during the monsoon (Figure 5.3). The spring dry season

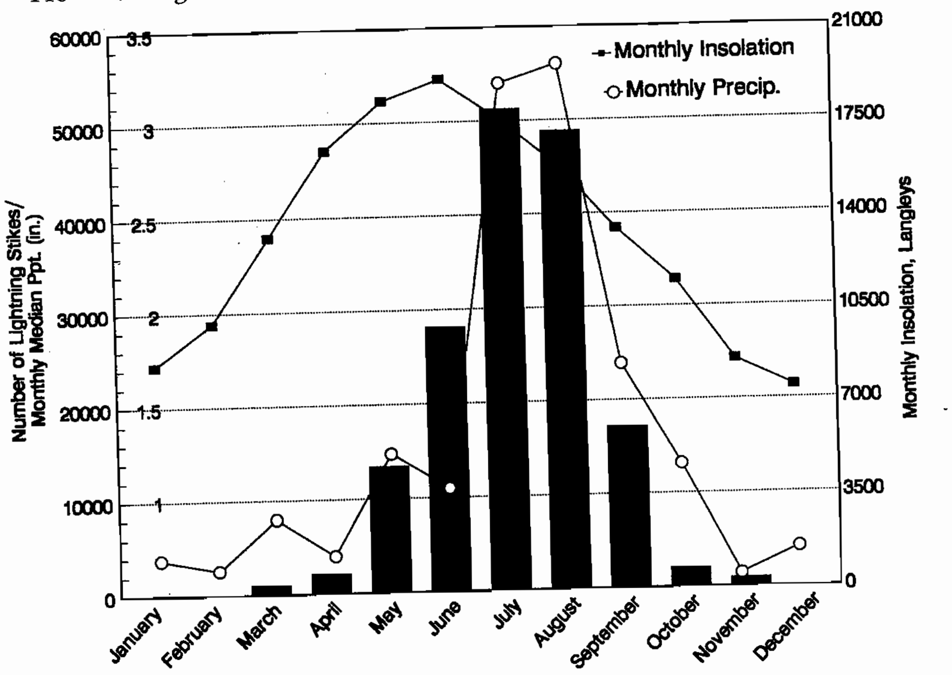

Figure 5.3. Monthly patterns of lightning strikes, insolation, and precipitation in the Jemez Mountains area. Lightning data from 165,117 cloud-to-ground strikes during 1985–1994 over 775,554 ha centered on the Jemez Mountains (Figure 5.2). Insolation and precipitation data for Los Alamos, New Mexico, from Bowen (1990).

(April through June) is particularly conducive to fire activity due to the common persistence of drought throughout much of this period, the long and warm days of this high-sun period, and the occurrence of lightning. While dry conditions are also common for multiweek periods in the fall, few natural ignitions occur at this time due to low levels of lighting activity. Fall burning conditions are also constrained by the shorter day lengths, the cooler temperatures, and the interruption of dry spells by cyclonic storms. In addition, substantial variability in regional precipitation happens at annual and decadal time scales due to the El Niño–Southern Oscillation phenomenon and other factors. This regionalized precipitation variability tends to synchronize fire activity and other disturbances across the Southwest, with the highest levels of fire activity occurring after dry winters (Swetnam and Betancourt 1990, 1998). Dendrochronological reconstructions of climate show that these patterns of substantial precipitation variability, including severe and sustained droughts, have characterized the Southwest for at least the past 2,000 years (Dean and Funkhouser 1995; Meko et al. 1995; Grissino-Mayer 1996). Overall, the climatic regime of recurrent dryness in the Southwest provides frequent

and extended opportunities for the ignition and spread of fires. To the north, into southern Colorado and Utah, the distinctive climate of the Southwest grades into a colder and more continental pattern dominated by fall-to-spring moisture from cyclonic storms embedded in the polar front jet stream, without pronounced spring drought and with less lightning activity (as a result, fire occurrence begins to shift from spring to midsummer, and natural fire frequencies decrease [Brown et al. 1999]). To the south, down the continental spine of the Sierra Madre Occidental into Durango (Mexico), key fire-enhancing features of the southwestern climate remain evident, including the pattern of warm, dry spring conditions broken by the influx of lightning-yielding summer moisture from the tropics (Fulé and Covington 1999).

Fuel conditions in the Southwest also promote fire activity. The buildup of herbaceous and woody plant materials through plant growth and slow decay processes provides sufficient fuel periodically to support spreading fires in most Southwestern ecosystems. However, fuel types (e.g., grass versus logs), quantities (tons/ha), flammabilities, and rates of buildup depend upon patterns of vegetation structure, productivity, and species composition—these vary considerably across the major topographic, elevational, and ecological gradients that characterize southwestern landscapes (cf. Bogan et al. 1998). General zonational patterns can be discerned (Merriam 1890; Brown 1982): low-elevation grasslands grade upslope into woodlands of pinyon (*Pinus edulis*) and juniper (*Juniperus*) species, then into open ponderosa pine (*Pinus ponderosa*) forests, then become denser forests of mixed-conifer species (including *Pseudotsuga menziessi* and *Abies concolor*), ending with the high, cold, wet forests of spruce (*Picea engelmanni*) and corkbarkfir (*Abies lasiocarpa* var. *arizonica*), which in turn grade into subalpine and alpine vegetation on the highest peaks. The high frequency of spreading surface fires observed in the fire-scar record (Swetnam and Baisan 1996a) indicates that fine fuels (grasses and needle litter) have long been primary fuels in many southwestern ecosystems. Prior to changes initiated by the heavy grazing of introduced sheep and cattle (Leopold 1924; Cooper 1960; Baisan and Swetnam 1997; Bogan et al. 1998), herbaceous understories dominated by perennial grasses were present from valley grasslands up through ponderosa pine forests and into many highland mixed-conifer forests. Herbaceous plants create fine-textured surface fuels that dry out quickly (hours to days), particularly when exposed to sun and wind in open forest settings; as a result such fuels are often in suitable condition to burn. Since fire-adapted perennial grasses and herbs regenerate rapidly after fire, fuel quantities and continuities can often recover sufficiently to allow fire to recur in just a few years. Similarly, the needle litter from long-needled ponderosa pine trees dries out quickly, contains highly flammable terpenoid compounds, and rebuilds a surface litter cover within 3 to 7 years of removal as senescent needles drop from the trees—all characteristics that support high-frequency surface fires.

The factors of ignition, climate, and fuels combine to create a regional pattern where fire frequencies are greatest at the middle elevations along montane topographic gradients in the upper ponderosa pine zone (Swetnam and Baisan 1996a). Since high fire frequencies feed back to maintain relatively open forest structures that favor persistent herbaceous ground cover and long-needled ponderosa pines, these conditions generally co-occurred in the Southwest. At lower elevations (e.g., pinyon-juniper woodlands) herbaceous productivity declines due to drier conditions, thereby reducing fuel continuities and increasing the time needed for fuels to recover between fires. In contrast, vegetation productivity is enhanced at higher elevations, but the cooler, moister climate is only suitable for burning during shorter time windows, resulting in less frequent and patchier fires, denser mixed-conifer and spruce-fir forests, stifled herbaceous understories, and the dominance of slower-drying woody fuels (including the more compacted and less flammable litter of these shorter-needled conifers).

Twentieth-century records of fire suppression efforts illustrate the fire-prone nature of southwestern ecosystems. During the period 1960–1975, 80 percent of the fires on the national forests of Arizona and New Mexico were ignited by lightning, averaging 1,873 lightning fires per year (ranging from 1,184 to 2,841) for the highest rate of lightning fire ignition in the United States (Barrows 1978); for all protected private, state, and federal lands the regional average was 2,371 lightning fires per year. In southwestern national forests between 1940 and 1975, more than 1,000 lightning fires occurred during all but two fire seasons, 1941 and 1955; 187 lightning fires were ignited on the Gila National Forest alone in a 7-day period in 1974 (Barrows 1978:34). Area burned by lightning-caused wildfires peaks in June before the onset of the summer rains, although lightning ignitions are at a maximum in July (Barrows 1978). Southwestern fire activity is generally enhanced by drought (Barrows 1978; Rollins et al. 1999), with higher levels of regionally synchronized fire activity occurring in dry La Niña years (Swetnam and Betancourt 1990, 1998). Fires would have repeatedly burned across widespread portions of the Southwest during the twentieth century if these numerous lightning-ignited fires had not been vigorously suppressed by fire-fighting actions. Fuel availability has become less of a limiting factor in recent decades due to the landscape-wide buildups of woody fuels associated with a century of fire suppression (Covington et al. 1997; Bogan et al. 1998). As a result the frequency and severity of wildfire activity (including lightning-ignited fires) has been escalating despite increasing human suppression efforts, as the mean number of lightning fires per year in the Southwest grew by more than 50 percent from 1940 to 1975 (Barrows

1978); the mean annual acreage burned in the Southwest has increased continuously since ca. 1960 (Swetnam and Betancourt 1998); and unnatural stand-replacing conflagrations like the 1977 La Mesa Fire (Allen 1996a) and the 2000 Cerro Grande Fire are occurring more often in overdense ponderosa pine forests (Covington and Moore 1994).

These regional patterns of twentieth-century fire activity are also apparent in the suppression records from the Jemez Mountains (Figure 5.4). The point locations of 4,487 wildfires recorded between 1909 and 1996

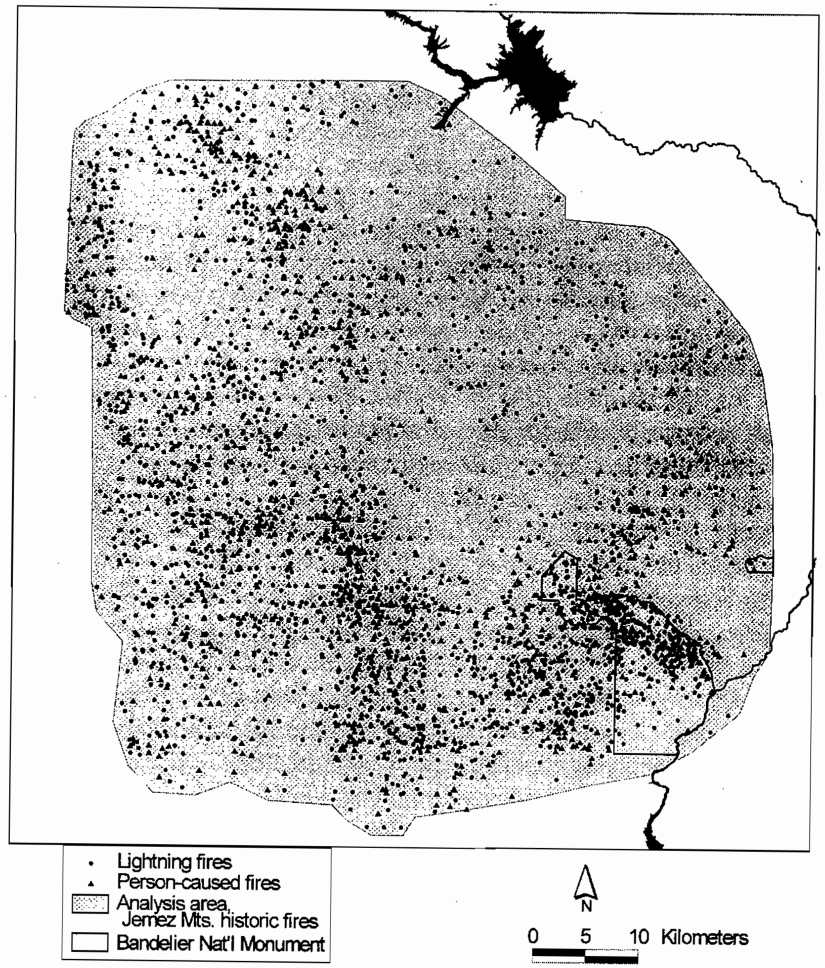

Figure 5.4. Point locations of historic fires in the Jemez Mountains, 1909–1996. Point locations of 4,487 historic wildfires in the Jemez Mountains, 1909–1996, compiled from the administrative records of land management agencies (Snyderman and Allen 1997). The shaded analysis area covers 380,691 ha. The gridlike pattern results from a subset of the data that were recorded only to the nearest section corner. Person-caused fires cluster near major roadways, campgrounds, habitations, and other human use areas.

across a 380,691 ha area in the Jemez Mountains, compiled from an array of administrative records (Snyderman and Allen 1997), suggest a high frequency of lightning fires in the most flammable vegetation types. Lightning caused 68 percent of the fires, with human ignitions clustered about roadways, campgrounds, habitations, and other human use areas. Area burned is greatest in June, while July records the most lightning-fire ignitions, consistent with local lightning occurrence and precipitation data (Figure 5.3). In contrast, area burned by management-ignited "prescribed" fires is greatest in the fall after the end of the summer monsoon, when conditions are often dry enough to sustain fire but controllability is greater than in the spring. Note that this record of modern fire occurrence in the Jemez Mountains is certainly conservative and substantially underestimates the actual occurrence of fire during this time period, as many small fires were likely never reported (especially prior to ca. 1945) and the database is riddled with multiple large gaps where data are obviously incomplete or missing (Snyderman and Allen 1997). For example, it is visually apparent that the greatest concentration of lightning fires is recorded in the southeastern flank of the Jemez Mountains at Bandelier National Monument (Figure 5.4), where a more complete administrative record of fires since 1934 has survived (yet even the Bandelier record lacks any data for 9 years since 1941). The Bandelier fire record indicates a per ha rate of lightning fire ignitions five times greater than the Jemez Mountains–wide data, reflecting the incompleteness of the overall Jemez record. Still, consistent patterns emerge from the large total number of fires in these records. From 1934 to 1997, lightning caused 341 fires at Bandelier (86 percent of all wildfires), with ignitions peaking in July and higher levels of fire activity occurring in dry years (Foxx and Potter 1978). Lightning ignited at least one fire per 2,134 ha per year during this period at Bandelier, with the greatest frequency of fires occurring in ponderosa pine forests at mid-elevations. Many of these fires would have spread widely in the absence of suppression efforts. The data from Bandelier, moreover, are not unique: despite a variety of problems with the completeness of fire suppression records, high levels of lightning-ignited fire are clearly observed in the modern landscapes of the Southwest (Barrows 1978; Snyderman and Allen 1997).

The extensive regional network of fire-scar chronologies (Fulé and Covington 1996; Swetnam and Baisan 1996a, 1996b; Touchan et al. 1996; Abolt 1997; Baisan and Swetnam 1997; Fulé et al. 1997; Allen et al. 1998; Kaib 1998; Kaufmann et al. 1998; Morino et al. 1998; Wolf and Mast 1998; Fulé et al. 2000; Swetnam et al. 2001) provides a precisely dated, multicentury perspective on fire regimes in the Southwest that is strikingly consistent with modern observations of lightning-caused wildfire activity. While substantial variability existed in pre-1900

fire regimes (Swetnam and Baisan 1996a), high-frequency, low-intensity surface fires were common in the Southwest, with the shortest intervals between fires found in mid-elevation ponderosa pine forests. Extensive fire activity was often recorded in the same year across landscape and regional scales, indicating that fires spread widely in the absence of active human suppression and artificial fuelbreaks like livestock trails and road networks (Allen et al. 1998; see also *http://biology.usgs.gov/luhna/chap9.html*). The absence of spreading fires in consecutive years from stand-scale fire histories in the Southwest indicates that rates of fuel recovery were one constraint on maximum fire frequencies. The landscape context of topographic and fuel conditions could enhance or inhibit the spread of fire into particular stands (Swetnam and Baisan 1996b).

Climate variability acted to synchronize regional fire activity, as major fire years were clearly associated with drought conditions, while wet periods recorded little fire activity (Swetnam and Betancourt 1990). The most extensive fire activity in ponderosa pine forests occurred in dry years that followed within 1 to 3 years of wet conditions; this pattern of major fire years suggests the importance of both fuel production and fuel moisture in these fire regimes, with antecedent wet conditions stimulating the buildup of continuous fuels and subsequent drought conditions enabling the fuels to burn widely. The common occurrence of persistent drought conditions in the Southwest likely allowed some fires to burn for months, potentially allowing even a few ignitions to cause extensive fire activity. The importance of climate in determining southwestern fire regimes is highlighted by evidence from fire-scar chronologies of responses to climate variations at annual, decadal, and centennial time scales (Swetnam and Baisan 1996a; Swetnam and Betancourt 1998; Grissino-Mayer and Swetnam 2000).

In most cases the seasonality of fire occurrence can be inferred by the relative position of a fire scar within the annual growth rings (Baisan and Swetnam 1990). The regional patterns of fire seasonality developed from prehistoric fire scars and modern fire records are generally indistinguishable (Swetnam et al. 2001), indicating that prehistoric fires occurred during the same seasons as modern lightning-ignited fires—predominantly in the spring and summer (Grissino-Mayer and Swetnam 2000). Unusual patterns of "excess" fall fires have been found in fire-scar histories only for brief time periods at a few localities (e.g., Secklecki et al. 1996).

Overall, regional fire-scar chronologies show that pre-1900 fire regimes in upland forests were characterized by frequent, widespread fires that favored the open forest stand structures and abundant herbaceous vegetation that have been well documented across the Southwest by early photographs, historical writings, early land surveys, and dendrochronological reconstructions of stand conditions (Weaver 1951; Cooper 1960; Bahre 1991; Covington and Moore 1994; Fulé et al. 1997; Allen et al. 1998; Kaufmann et al. 1998; Swetnam et al. 1999). At higher elevations and in more mesic forests, surface fire regimes became patchier and increasingly mixed with more intense fires occurring at longer return intervals (Grissino-Mayer et al. 1995; Touchan et al. 1996; Romme et al. 1999b), eventually grading into the (little-studied) stand-replacing fire regimes that apparently characterized subalpine spruce-fir forests in the absence of spreading surface fires. Historic records, synchronous fire-scar dates from canyon forest stringers linked by semi-desert grasslands, and ecological inferences suggest a substantial role for fire prior to the late 1800s in some lowland ecosystems in the Southwest (e.g., Humphrey 1974; Bahre 1991; Archer 1994; Swetnam et al. 2001). In contrast, ecosystems where fires were apparently scarce include deserts and some subalpine and alpine communities.

The fire-scar record from the Jemez Mountains (Allen 1989; Allen et al. 1996; Touchan et al. 1996; Morino et al. 1998) is consistent with regional patterns. Dendrochronologically dated fire-scar collections have been made from forty-two localities in and adjoining the Jemez Mountains (Figure 5.5), with more than 4,000 pre-1900 fire-scar dates determined from more than 600 sampled trees, snags, logs, and stumps. Fire dates extend back to A.D. 1422. Sampled forest types and landscape settings range from low-elevation stands of ponderosa pine intermixed with semiarid pinyon and juniper woodlands up to high-elevation montane forests dominated by Engelmann spruce. The Jemez Mountains fire-scar chronologies show that high-frequency fire (with mean return intervals of 6 to 15 years) characterized the pre-1900 fire regimes at most sites (Touchan et al. 1996), with maximum frequencies found in upper-elevation ponderosa pine stands (e.g., Figure 5.6). Fire activity commonly occurred over extensive areas (Figure 5.5; Allen et al. 1998); for example, watershed-wide fires occurred approximately every 16 years across the 15-km-long Frijoles watershed in Bandelier (Allen 1989). Stand-level fire frequencies were affected by topographic features that would inhibit or enhance the spread of fires into the site from the larger surrounding landscape (e.g., reduced frequencies where rocky cliffs act as isolating barriers, versus greater frequencies on the upper portions of a large smooth plateau slope), indicative of natural controls on fire regimes (Allen and Snyderman 1997). Years with extensive fire activity were tied to dry conditions in all forest types, with lagged relationships to wet years in ponderosa pine forests (Touchan et al. 1996). The fire-scar seasonality data show that most prehistoric fire scars in the Jemez Mountains formed during the dry spring and early summer months (about 94

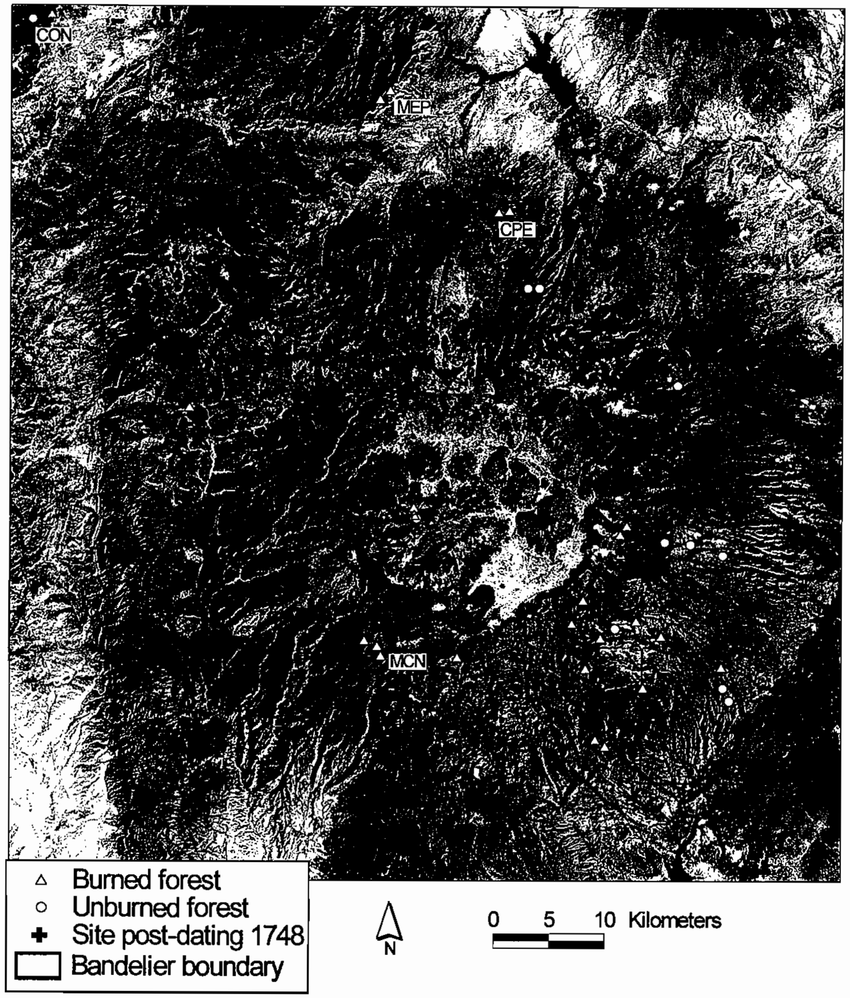

Figure 5.5. Jemez Mountains, extent of fires in 1748. Map of fire-scar sample site locations in the Jemez Mountains, showing the extent of widespread fires in 1748. Sites where at least 10 percent of the sampled trees recorded a fire in 1748 are shown as burned. Three clusters of sites in the northern Jemez Mountains area are labeled: CON (Continental Divide), MEP (Mesa Prieta), and CPE (Cerro Pedernal). Also marked is Monument Canyon (MCN) in the south.

percent formed by July), and fall fires were rare (Allen 1989 and unpublished data; Touchan and Swetnam 1995). Abundant fire activity clearly was a major determinant of ecosystem patterns and processes in the pre-1990 landscape of the Jemez Mountains (Allen 1989; Touchan et al. 1996; Morino et al. 1998). As elsewhere in the Southwest, the surface fire regimes collapsed by ca. 1900 at most sites in the Jemez area (Fig-

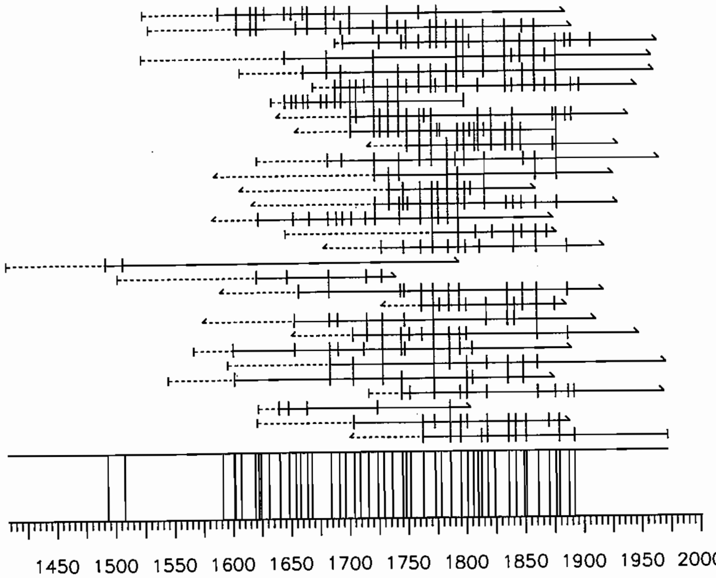

Figure 5.6. Fire-scar chronology, Monument Canyon Research Natural Area. Horizontal lines represent the life spans of individual trees, whereas fire-scar events are shown by short vertical bars. The longer vertical lines at the bottom of each chronology indicate the years in which at least 10 percent of the recording trees (i.e., previously scarred trees) recorded a fire.

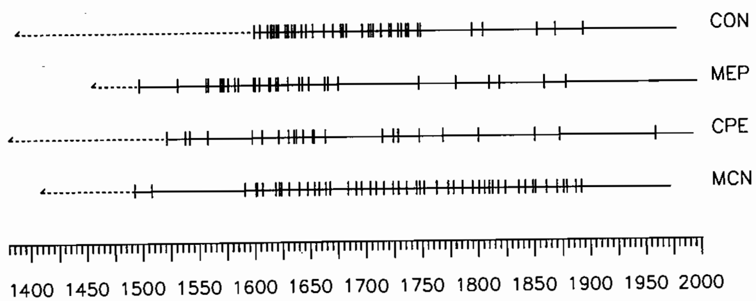

Figure 5.7. Composite fire-scar chronologies from four sites, Jemez Mountains. Each of the four labeled horizontal lines represents the composite fire chronology from a different site (labels match Figure 5.5), and the vertical bars are the fire dates recorded by at least 10 percent of the fire-scarred trees within that site. Fire frequency patterns before ca. 1600 are reduced by small sample sizes (cf. Figure 5.6).

ures 5.6 and 5.7), due to the effects of domestic grazing on fuel availability and human suppression activities (described below in the section titled Historic Human Effects on Southwestern Fire Regimes).

Overall, the patterns of lightning-ignited fire observed in the modern landscapes of the Southwest are strikingly consistent with, and generally sufficient to explain, the prehistoric and historic fire regimes indicated by the fire-scar record. This natural history of frequent lightning-ignited fires in most upland ecosystems, modulated by climate and fuel conditions, provides the context against which potential human alteration of southwestern fire regimes though time and space must be assessed.

The Cultural History of Fire in the Southwest

The natural history of southwestern fires overlaps with a history of human occupancy. The two worlds of nature and people interact to give a history of southwestern landscapes.

Prehistoric Human Effects on Southwestern Fire Regimes (11,000 B.C.–A.D. 1600)

> That extraordinary fire load is not simply a product of natural processes. For millennia humans have busily restructured the geography and seasonality of Southwestern fire—sometimes complementing and sometimes countering the natural order. Lightning had to compete not only with rain but with aboriginal firesticks. Human inhabitants added other sources of ignition in the service of hunting, raiding, foraging, and horticulture, and as an inadvertent by-product of a seasonal nomadism whose routes became trails of smoke from camp fires, signal fires, and escaped fires of diverse origins. (Pyne 1995a:284)

The American Southwest has a long record of occupation by humans (Cordell 1997), the fire-using species (Pyne 1995a), extending back to the Clovis Paleoindian sites that document Native American presence here for more than 11,000 years. These first known people of the Southwest were apparently big-game hunters who likely moved frequently as they pursued their primary food resources. Their small populations and mobile way of life likely caused few lasting changes to regional ecosystems, although it is possible that these early hunters contributed to the extinction of the "Pleistocene megafauna" through overhunting (Martin and Klein 1984), which indirectly had substantial ecological effects. Paleoindian use of fire to manipulate southwestern landscapes is possible (e.g., as a hunting method), but entirely speculative at this point. "It is difficult to reconstruct the impact of early humans, whose firesticks coincided with the colossal climatic fluctuations that ended the last ice age" (Pyne 1995a:294).

With the development of foraging lifeways during the Archaic period (ca. 5500 to 500 B.C.), hunting and gathering by small, mobile groups of people became the norm. The primary ecological effects of these people were likely localized, with frequent movements allowing any overharvested resources to recover. Based upon cross-cultural surveys of fire use by hunting and gathering societies in the western United States and the rest of the world, Fish (1996) has suggested that Archaic peoples of the Southwest may have made substantial use of fire to modify vegetation, although direct supporting evidence is absent.

By ca. 2000 B.C., cultigens from Mexico (e.g., maize) initially appear in the Southwest, beginning the slow transition toward sedentary agricultural societies with higher populations. With increasing reliance on agriculture, human populations and societal complexity increased, as did their ability to modify landscapes to support their growing resource demands. By ca. A.D. 800, substantial human populations had developed across much of the Southwest; population growth in the Colorado Plateau area accelerated (Euler 1988); and evidence of human effects on at least local environments can be discerned in various paleorecords (Plog et al. 1988), such as in the Dolores River Valley of southwestern Colorado (Kohler and Mathews 1988). By ca. A.D. 1100, large populations of sedentary agriculturalists were found across the Southwest, including the Hohokam irrigators of the Arizona desert river valleys, the Mogollon of the Mogollon Rim uplands (e.g., Mimbres), and the Anasazi of the Colorado Plateau (e.g., the Chaco region and Mesa Verde). Anasazi (ancestral Puebloan) occupations were focussed on pinyon-juniper ecosystems, which occur widely across the upland mesas, plateaus, and mountain footslopes of the Four Corners region. With the decline of the Chacoan system in the 1100s and the general abandonment of the Colorado Plateau by the late 1200s, these ancestral Puebloan populations largely shifted toward the northern Rio Grande valley, including the Jemez Mountains. Throughout the late prehistoric period (A.D. 1200–1600) the northern Rio Grande region was the center of large Puebloan populations; at the time of European settlement in A.D. 1598, the Pueblo world consisted of about 100,000 people associated with about 100 communities (Schroeder 1992). While greatly reduced over the next several centuries by diseases and other impacts of the Spanish Entrada, their descendants are the modern Puebloan peoples who continue to live in this region (Hopi, Zuni, and the numerous pueblos of the northern Rio Grande watershed). Most of these contemporary communities have been occupied since before European contact. In addition, unknown numbers of more nomadic peoples were present in the Southwest by the 1400s, including the ancestors of the modern Utes, Paiutes, Navajos, and Apaches (Towner 1997).

The Jemez Mountains contain much evidence of large Anasazi populations. For example, Bandelier National Monument (Figure 5.5) may have the highest density of cultural resource sites in the entire National Park Service system, with over 2,400 archeological sites recorded from the approximately 6,500 hectares inventoried to date (Powers and Orcutt 1999, unpublished data at Bandelier National Monument). Site densities are greatest in the pinyon-juniper and lower ponderosa pine zones. Intensive utilization of the Bandelier landscape by ancestral Puebloans occurred during the period A.D. 1150–1550, with estimated populations of between 1,000 and 3,500 people across some 10,000 ha during the period A.D. 1225–1450 (Bracker 1996; Orcutt 1999). Similar densities of late prehistoric archeological sites are found around much of the Jemez country, including several dozen huge communal pueblos (1,000–3,000 rooms) in the Chama and Jemez River drainages (Elliott 1993; Anschuetz 1998).

Human populations of this magnitude and extent could substantially modify their environment in many ways (Butzer 1990; Denevan 1992; Spoerl and Ravesloot 1995; Fish 1996), including through the use of fire. Since southwestern agriculturalists like the Anasazi utilized about 0.5 ha per person per year to raise staple foods (Kohler et al. 1996; Trierweiler 1990), large areas were farmed to raise staple foods, with abundant archeological evidence still visible today of agricultural terraces, cobble mulch gardens, and even irrigation infrastructure (Doolittle 1992; Periman 1996; Anschuetz 1998). The broad extent of prehistoric agricultural influence in landscapes like the Pajarito Plateau (on the eastern flank of the Jemez Mountains) is also indicated by the abundance of "field houses" found dispersed across potential agricultural areas, as these small structures (one to ten rooms) were probably used seasonally for purposes that included tending crops. Wood scarcities likely developed over extensive areas as the Anasazi and other farmers overharvested pinyon-juniper woodlands to meet their substantial needs for cleared agricultural land, firewood for cooking and winter heating, and building materials. Evidence of deforestation has been detected from such areas as Mesa Verde (Wyckoff 1977) and Dolores in southwestern Colorado (Kohler and Matthews 1988), Chaco Canyon (Samuels and Betancourt 1982; Betancourt et al. 1986), and Bandelier (Huber and Kohler 1993; Allen, in review). The shifting of agricultural field locations through time, and the frequent relocations of human populations at local and regional scales (Euler 1988), amplified the total area affected by these cultural activities.

While significant land-altering activities surely occurred near human settlements, anthropogenic effects at more expansive landscape and regional scales are less certain, particularly in mountain areas remote from permanent habitations. We know that aboriginal southwesterners certainly were capable of utilizing remote resources, such as transporting thousands of logs more than 75 km from mountain source areas to "great houses" in Chaco Canyon (Betancourt et al. 1986). Another indication of extensive human influence is the evidence that populations of large mammals, particularly elk, may have been depleted over broad areas by prehistoric southwestern hunters (Lang and Harris 1984; Osborn 1993; Allen 1996b; cf. Kay 1994; Martin and Szuter 1999).

How might the various aboriginal peoples of the Southwest have modified fire regimes in the late prehistoric period (ca. A.D. 1200–1600)? Since prehistoric documentation of specific burning practices does not exist, most of our perspectives about the effects of early Indian burning in the Southwest must be inferred from indirect lines of evidence ranging from archeological and paleoecological information to historic accounts of aboriginal fire use (cf. Fish 1996; Kaib 1998). Although an extensive ethnographic literature describes cultural uses of fire by Native Americans from many regions of North America (Hough 1926; Stewart 1951, 1955, 1956, 1963; Day 1953; Lewis 1973, 1985; Sauer 1975; Barrett and Arno 1982; Boyd 1986; M. K. Anderson 1993, 1996; Gottesfeld 1994; Clark and Royall 1995; Pyne 1997; Williams 1997, 2000; Delcourt and Delcourt 1998; Bonnicksen 2000), relatively little information exists for the Southwest (but see the thorough review of fire use in Apacheria by Kaib [1998]). General reasons given for Indian burning in North America (Pyne 1997; Kaib 1998; Williams 2000) include hunting, crop management, improvement of plant growth and yield, insect collection, pest management, fireproofing areas, warfare and signaling, clearing areas for travel, and felling trees. The substantial Native American populations of the prehistoric Southwest may have used fire for all these purposes, (Dobyns 1981; Bahre 1991; Pyne 1997), but a paucity of region-specific data renders speculative most of our conclusions about the effects of aboriginal burning at landscape scales (areas at least several kilometers in extent).

Yet some scholars have painted a region-wide picture of substantial aboriginal burning effects by extrapolating broadly from a few historical anecdotes and statements of questionable authority or accuracy (cf. Forman and Russell 1983). For example, influential overviews by Cooper (1960:138) and Pyne (1995a:284–285, 1987:519) extensively quote Holsinger (1902) (see Box 5.1) as important evidence for widespread Indian burning in the Southwest, even though the Holsinger article (1) cites no evidence for its assertions of Native Americans as primary sources of fire ignition; (2) clearly views fire as a negative influence that degraded forest cover and thereby worked against a utilitarian vision of preserving desired watershed conditions; (3) emphasized fire as unnatural and thus preventable, displaying an obvious bias toward blaming all fires, past and present, on people, particularly Indians; and (4) primarily, though loosely, focuses on undocumented ancient burning practices of southwestern Native Americans who left obvious architectural ruins (e.g., the Anasazi), rather than Apaches or other contemporary historic tribes. Cooper (1960:138) indicates that "There is abundant evidence that Indians were responsible for many fires," but the sources that he cites convey largely hearsay claims of Indian burning in the Southwest. Pyne's footnotes (1995a:359–360, 1997:615) indicate only a few other anecdotal sources that hardly provide solid support for his assertions that prehistoric Native American burning was important in the Southwest. The fact is that archaeological, anthropological, and historic sources con-

BOX 5.1. Varied perspectives on the cause of early fires in the Southwest.

"These prehistoric aborignes [sic] must have exerted a marked influence upon the vegetation of the country. Their fires, and those of the historic races, unquestionably account for the open condition of the forests. . . . From Puget Sound to the Gulf of California these strange people rambled at will, but their abiding place was . . . in the southwest. The extensive ruins indicate that they inhabited the fringe, so to speak, of the forests which, like vanguards, were working their way down from the mountain tops to the plains. The most potent and powerful weapon in the hands of these aborigines was the firebrand. It was alike used to capture the deer, the elk, and the antelope, and also to rout or vanquish the enemy. It cleared their mountain trail and destroyed the cover in which their quarry took refuge. . . . How far the occupancy of the prehistoric and historic tribes has retarded the progress of foresting it is impossible to say, but it must have been no small factor. . . . Were it not for the long Indian occupancy and the ravages of fire incident to their habitancy, vast territories now barren desert wastes might be covered with a forest growth." (Holsinger 1902:23, 24)

"Given the high incidence of lightning-caused fires, reliably documented by modern data, the relative importance of fires set by Indians is probably moot." (Bahre 1991:128)

"Under aboriginal rule, fine fuels blossomed, and the Southwest burned easily and often. Lightning and firestick competed to see which would burn a particular site or in what season." (Pyne 1995a:285) tain little evidence for widespread anthropogenic alteration of prehistoric fire regimes in the Southwest.

For example, consider the use of fire for prehistoric agricultural purposes in the Southwest, where new plots were likely cleared and prepared using fire (Wyckoff 1977). Indians also may have burned to enhance the productivity of a variety of favored wild resources (M. K. Anderson 1993, 1996), such as herbs with edible seeds in pinyon-juniper woodlands (Sullivan 1992). These probable uses of fire represent the potential for abundant wildfire starts to have occurred from human ignitions, given the dependence of large prehistoric human populations on agriculture in this region, the shifting nature of their enterprises, and the probability that some fires escaped from human control. Petersen (1988:101) suggests that high charcoal concentrations dating to about A.D. 900 in a bog at 3,060 m elevation in the La Plata Mountains of southwestern Colorado are due to charcoal influx from Anasazi land uses (presumably agriculture-related fire in the adjoining valleys), although natural forest fires might be a more plausible explanation. Fish (1996) suggests that prehistoric agriculturalists in southeastern Arizona would have carefully controlled or avoided burning practices in their zones of intensive settlement, agriculture, and fuelwood procurement in order to protect residences, crops, and fuel supplies. These rationales to constrain the application of fire are equally valid elsewhere in the Southwest. Localized burning by agriculturalists may have caused little change in the natural fire regimes of extensive upland areas.

Similarly, the use of fire as a hunting strategy is commonly presented as a potential means by which fire regimes could have been altered across broad areas by aboriginal peoples (Stewart 1956), including prehistoric southwesterners (Holsinger 1902; Cooper 1960; Dobyns 1981). Cabeza de Vaca's early description of Indian fire use from southeastern Texas in the 1520s is often quoted in support of this idea: "[They] fire the plains and forests within reach with brands, both to drive the mosquitoes away and at the same time drive lizards and like things from the earth to eat. They also kill deer [antelope] by encircling fires; deprived of pasturage, the animals are forced to seek it where the Indians may trap them" (Cabeza de Vaca, in Covey 1993). The idea that western Indians extensively used fire in hunting has been widely asserted by many influential people, ranging from John Wesley Powell (1890, "Before the white man came the natives systematically burned over the forest lands with each recurrent year as one of their great hunting economies") and Aldo Leopold (1920, "As is well known to all old-timers, the Indian fired the forests with the deliberate intent of confusing and concentrating the game so as to make hunting easier") to Stephen Pyne (1987:74, "Of all Indian uses for fire, the most widespread was probably the most ancient: fire for hunting"). However, in the Southwest the idea of landscape-scale hunting fires is based upon an insubstantial foundation of minimal documentation. For example, although Pyne (1987:519) specifically propagates the view of extensive Apache fire use in the Southwest for purposes that included hunting, an extremely thorough review of Apache fire use in the U.S./Mexico-borderlands portion of the Southwest finds only evidence for localized fire use for small game drives, not widespread fire-drive hunting (Kaib 1998:140). While Kaib's review documents that historic-era Apaches certainly used fire for a variety of other purposes (most significantly warfare), he emphasizes that they had good reasons and sufficient skills to control the spread of most fires. Fish (1996) also downplays the idea of extensive burning by prehistoric southwestern hunters, as it would work against "attracting and concentrating game in a precise, predictable location for hunters," defeating the supposed aboriginal purpose. Primary evidence for landscape-scale burning for hunting purposes is nearly nonexistent in the Southwest, and supporting rationales are weak.

A lack of archeological or ethnographic evidence on aboriginal use of fire is similarly apparent in the Jemez Mountains area, despite an overall wealth of archaeological information (e.g., Powers and Orcutt 1999) and the continuity of relatively intact native Puebloan cultural traditions since prehistoric times (Henderson and Harrington 1914; Harrington 1916; Robbins et al. 1916). For example, a detailed "Ethnographic Literature Search and Consultation" to document traditional Indian uses of the cultural and natural resources of Bandelier National Monument uncovered no information on fire use (Levine and Merlan 1997). Surprisingly little information is available on cultural uses of fire by ancestral Puebloan peoples (cf. Hough 1926).

Overall, the archeological and ethnographic evidence in the Southwest supports the notion that human-set fires likely enhanced prehistoric fire frequencies in localized areas, as fire-using people were present throughout the region. However, there is little evidence of landscape-scale burning practices in the Southwest, as aboriginal peoples likely emphasized "controlled rather than comprehensive [i.e., broadcast] uses of fire" (Fish 1996). There are severe limitations on our ability to reliably infer the prehistoric ecological effects of cultural fire use from anthropological information sources alone in a region where the rate of natural fire occurrence is so high. Assertions that emphasize aboriginal burning as a major ecological process in the Southwest are largely based upon overgeneralized amplifications of anecdotal information or biased and unsubstantiated statements in historical writings.

However, another emerging source of evidence exists—the detailed temporal and spatial records of past fire activity contained in dendrochronologically dated fire-scar chronologies may provide indications of aboriginal burning during certain periods in particular southwestern localities. Although relatively few fire-scar chronologies have been developed that overlap documented prehistoric human use areas in both time and space, those that exist provide opportunities to test some hypotheses about prehistoric Indian burning, to see if a signal of human burning can be distinguished. For example, Fish (1996) suggests that "cultural practices could have accelerated vegetational responses by introducing fire in seasons of low natural ignition and by increasing frequencies to the extent that fuel buildups allowed," while Pyne (2000) asserts that "Anthropogenic (human-caused) fire comes with a different seasonal signature and frequency than natural fire." Clues of human influences on the fire regime recorded in a fire-scar chronology might include periods with unusual patterns of fire frequency, stand-level fire synchroneity, fire seasonality, or decreased correlation with climatic conditions (Baisan and Swetnam 1997; Swetnam et al. 2001), providing the potential for linkages to documented patterns of human land use. For example, fire-scar chronologies from two sites in the mountains near Albuquerque display early periods (1500s to 1680) with frequent, patchy fires and inconsistent fire-climate relationships that indicate the possibility that local Native Americans were starting fires in these areas during this time (Baisan and Swetnam 1997). In the Jemez Mountains area, chronologies from the three northernmost clusters of sites display patchy, frequent fires in the late 1500s and early 1600s that may reflect enhanced ignition rates by protohistoric people (Figure 5.7). For example, the Continental Divide cluster of sites (Figure 5.5) shows high fire frequencies and less synchronous fire dates in the period prior to 1750 (Figure 5.7), and fire-climate relationships are weaker here than at any other site sampled so far in the Jemez Mountains (Touchan et al. 1995; Allen et al., unpublished data). Perhaps these fire scars record excess ignitions by early Navajos around this area before their acquisition of substantial numbers of sheep disrupted surface fire frequencies in this dry ponderosa pine/pinyon-juniper transition area (Touchan et al. 1995, 1996). In these cases the fire-scar record does provide limited evidence of possible aboriginal alteration of southwestern fire regimes in the late prehistoric to early historic period.

Still, these unusual site histories belie the consistency of the general patterns found in fire-scar chronologies at all scales across the Southwest (Swetnam and Baisan 1996a; Swetnam et al. 1999). Climate relationships are strong and persistent at most fire-scar chronology sites. Although pre-1900 fire regimes were dynamic, most chronologies are like Monument Canyon (Figure 5.6), showing no obvious fire frequency changes across the late prehistoric to early historic divide despite the continued occupation of Jemez Puebloan peoples near this forested highland site until as late as ca. 1620, when the Spanish forcibly resettled them in the adjoining Jemez Valley (Elliott 1993). Similarly, early fire-scar chronologies from other areas near prehistoric or historic Puebloan communities (e.g., the Frijoles watershed in Bandelier, near Cochiti and San Ildefonso Pueblos, and Gallina Mesa near Santa Clara and San Juan Pueblos) also do not show higher fire frequencies in the late prehistoric or early historic eras (Touchan et al. 1996; Allen et al., unpublished data). Although fire-scar sample sizes are generally small for prehistoric time periods, in the Jemez Mountains alone there are currently six fire-scar chronologies with earliest fire dates in the 1400s and six more with initial dates between A.D. 1503 and 1601. If human burning was an important ignition source, one would expect to see declines in fire frequencies in the early historic period with decreased Puebloan use of the mountains, but most fire chronologies in the Jemez Mountains show no sustained decline in fire frequencies from ca. 1600 to 1850 (although perhaps increased use of the mountains by Navajo and Apaches added a compensatory set of new aboriginal ignition sources).

The fire-scar record can be used to directly test some claims about Indian burning practices. For example, Lewis (1985:76) expansively asserts that "there are four general considerations used by hunter-gatherers that distinguish their fire regimes from natural ones: the seasonality of burning, the frequency with which fires are set, the intensity of fires, and the selection of preferred sites. These . . . considerations are shown from North American Indians across a broad range of habitats . . ." (see also Bonnicksen et al. 1999:444). Overall, the extensive fire-scar record in the Southwest is strikingly consistent with modern patterns of lightning fire ignition, revealing few indications of early human modification to natural fire-regime patterns of seasonality, frequency, intensity, or locality. For example, Stevenson (1881) "stated that Indians set fire to the timber on the mountain ranges of New Mexico each fall in order to drive deer down into the canyons" (in Cooper 1960:138). However, this claim is not supported by the abundant fire-scar seasonality data from New Mexico's mountains, as fall fire scars were rarely recorded in the pre-1900 period, and the proportion of late-season fire scars actually declines in the 1800s relative to preceding centuries (Allen 1989:91–94; Grissino-Mayer 1995:199–201), likely due to a shift in regional climate (Grissino-Mayer and Swetnam 2000). Indeed, the fire-scar record across the Southwest shows that prehistoric fires generally occurred in the same April to July window as modern fires (Baisan and Swetnam 1990; Touchan and Swetnam 1995; Swetnam and Baisan 1996a; Grissino-Mayer and Swetnam 2000; Swetnam et al. 2001). Given the suitability of fall conditions for human-ignited burning, the near absence of fall fires in the fire-scar record suggests that aboriginal ignitions were unimportant in the Southwest, or that for unknown reasons they restricted their burning to the same spring-to-early summer period as natural lightning ignitions.

Tree-ring fire reconstructions cannot directly determine the cause of ignition for recorded fires. So it is possible that prehistoric people set spring fires that spread widely when fuels and climatic conditions allowed, leaving fire scars and ecological outcomes indistinguishable from the natural lightning fires that otherwise would have occurred. Thus, while the simplest explanation of the available data is that lightning started essentially all extensive prehistoric fires in the uplands of the Southwest, Indian-set fires could have been substituting for some natural ignitions to varying degrees through time and space without altering natural fire regimes.

Overall, the notion of landscape-scale burning by prehistoric Indians in the Southwest lacks archaeological and ethnographic support, and the regional network of fire-scar chronologies generally records patterns of prehistoric fire that are consistent with natural control of fire regimes by climate and fuels. Although long-term use by large populations of prehistoric Native Americans likely had substantial impacts on pinyon-juniper woodlands and lowland riverine environments in many areas, the available evidence indicates that Indians likely had minimal effects on the fire regimes of most upland ecosystems in the Southwest prior to European contact.

Historic Human Effects on Southwestern Fire Regimes (Since A.D. 1600)

> The character of Southwestern fire reflects the changing character of its human occupation. (Pyne 1995a:294)
>
> The region boasts an ideal formula for natural fires. Its dramatic terrain and well-defined wet-dry cycles, both annular and secular, have long established it as an epicenter for lightning fires. But the real narrative of Southwest fire history belongs to its human firebrands, who have co-existed, if not co-evolved, with the regional biota throughout the Holocene. Different waves of human colonization have shaped distinctive fire regimes. (Pyne 1996)

The American Southwest has one of the longest histories of European exploration and settlement of any part of the United States. Prehistoric and historic eras and land uses grade into one another here, with sporadic Spanish exploration from the 1530s onward (e.g., Cabeza de Vaca, Coronado, Espejo), culminating in Oñate's colonizing settlement at the foot of the Jemez Mountains in 1598 and the establishment of Santa Fe in 1610. For the purposes of this overview, A.D. 1600 will be used to mark the approximate divide between the prehistoric and historic eras when Euro-Americans began markedly reshaping the Southwest, even though their Old World diseases, livestock, and cultures likely started to affect the region during the 1500s. Still, large portions of this region remained outside Euro-American control (and written documentation) until the last half of the nineteenth century, and some prehistoric land use patterns persisted among the diverse Indian lifeways of the historic Southwest. For example, although the subjugated Puebloan farmers were greatly reduced in numbers, concentrated in river valleys, and incorporated into the colonial Spanish economy of farming and livestock husbandry, they also maintained much of their indigenous culture and undoubtedly continued to utilize adjoining upland areas for resource procurement (medicinal plants, game) and other traditional uses (Henderson and Harrington 1914; Harrington 1916; Robbins et al. 1916; Levine and Merlan 1997). At the other extreme, some nomadic peoples (e.g., Apaches and Utes) held onto their independence and many aspects of their prehistoric hunter-gatherer-raider lifeways through the middle to late 1800s, while enhancing their mobility with horses. Navajo hunters and farmers developed along a somewhat intermediate path, also maintaining their freedom through mobility and warfare, while adding sheep husbandry and raiding to their economies. There was also a blending of land use practices here at the frontier of the Spanish Empire—by trade and warfare among these groups, including commerce in captive slaves; by Spanish settlement of Europeanized Indians in peripheral genizaro communities as buffers against warring tribes; and by intermarriage between Euro-Americans and Native Americans (Meinig 1971; deBuys 1985; Scurlock 1998). The presence of such diverse cultures suggests that fire use likely varied markedly through time and space across the historic Southwest.

Given the 400-year duration of the historic period here, it is conceivable that intermingled Native American and Euro-American impacts on southwestern fire regimes have been going on long enough to appear natural to many modern observers. However, assertions of landscape-scale burning by southwestern peoples during the historic era are subject to the same criticisms as the prehistoric claims reviewed above. Overall these claims are largely speculative due to the paucity of firm information on this topic found in archaeological, anthropological, and historic sources (with some exceptions reviewed here). Eyewitness accounts of broadcast burning by Indians are quite rare in the Southwest (Kaib

1998). In addition, the regional network of fire-scar chronologies shows relatively consistent patterns of pre-1900 fire occurrence through time and space, indicating that the fire regimes at most sampled sites were primarily driven by natural and synoptic climatic factors rather than by local and ephemeral cultural burning practices. However, unique local fire histories that differ markedly from regional patterns provide some indications of probable human interactions with southwestern surface fire regimes during the historic period.

As noted above, some southwestern fire-scar chronologies (e.g., Figure 5.7) hint that human ignitions were raising fire frequencies above natural levels during the transition between late prehistoric times and the early historic era (Baisan and Swetnam 1997). Interestingly, the abrupt end of the higher fire-frequency period at several sites in New Mexico is roughly coincident with the Pueblo Revolt of 1680 (Baisan and Swetnam 1997; Figure 5.7). The 1600s were a tumultuous time in New Mexico, likely with lots of undocumented Indian use of upland areas around the Spanish-dominated valley settlements, perhaps including use of fire. On the other hand, the 1600s and 1700s were generally a time of relatively high frequency and less well synchronized fires across the Southwest, and after ca. 1800 increased synchronization and lower frequencies are regionally evident, regardless of local Indian site histories (Grissino-Mayer and Swetnam 2000).

One of the strongest cases for extensive aboriginal burning in the Southwest is associated with the use of fire during historic warfare periods by Apachean peoples, or their enemies, in the U.S./Mexico borderlands region. Several recent fire-scar studies document enhanced fire frequencies or partially altered fire seasonalities, in concert with weaker fire/climate relationships, suggesting anthropogenic ignitions in particular localities frequented by Apaches during documented times of raiding and warfare. At Fillmore Canyon in the Organ Mountains, Morino (1996) found high fire frequencies and weak correlations with climate during the 1700s, a time of known Apache use and warfare in this area. Kaye and Swetnam (1999) interpret atypical occurrences of late-season fires, in concert with tree peel scars, as clues of probable Apache war-related fires near Dog Canyon in the Sacramento Mountains during the late 1700s, although they note that alternative explanations exist. Seckleck et al. (1996) suggested that an unusually large proportion of late winter or early spring fires, in concert with a high fire frequency during the period 1760–1786, may indicate Apache burning in a high-elevation portion of the Chiricahua Mountains during this brief time of local warfare. Kaib (1998) more broadly reviews fire histories for several mountain ranges in Apacheria along the U.S./Mexico border, finding evidence for warfare-related burning in parts of the Chiricahua Mountains during two historical warfare periods (1748–1790 and 1831–1886). Kaib (1998) also found indications of Apache burning from the Animas Mountains and Sierra de los Ajos during the later warfare period (1831–1886). Kaib (1998:145) concludes: "Common and indiscriminate burning practices that influenced extensive areas were associated with documented raiding and wartime periods."

Although burning related to warfare between historic Apaches and their enemies has apparently left a fire history signal in some localities, the regional fire-scar record indicates that such burning had limited overall effect on southwestern fire regimes. Evidence of warfare fire use cited above is constrained to a narrow set of particular times and places. The anthropogenic signal noted at some fire history sites is often lacking from adjoining sites within the same mountain range, indicative of the restricted geographic scope of the possible human burning. The fire-scar and documentary evidences are primarily linked to brief periods of historic conflict between the Apaches and European settlers, both relative newcomers to the Southwest.

The most vigorous and best documented claims for widespread aboriginal use of fire in the Southwest are related to various Apache groups in the historic period: "The Apaches worked to create and perpetuate a grassland environment. . . . The uses of broadcast fire by the Apaches were those typical of grassland tribes" (Pyne 1997:519). While there is more evidence of Apache burning practices than for other regional Indian cultures (Hough 1926; Kaib 1998; Kaye and Swetnam 1999; Swetnam et al. 2001), assertions of widespread ("broadcast") fire use are weakly supported overall. The extent of warfare burning was limited to particular times and places, and there is little tangible support for the idea that Apaches or other historic southwestern Indians burned at landscape scales for hunting purposes (as reviewed in the prehistory section above). Kaib believes that the Chiricahua Apaches applied controlled fires on fine scales, particularly for hunting small game in localized grassland settings (Kaib 1998 and personal communication). However,

> Overall, the documentary and ethnoecological evidence suggests that neither widespread nor local burning practices were used to promote forest or grassland resources. . . . Non-warfare burning practices were also more likely controlled spatially and limited in use because of (a) enemy detection, (b) inherent problems with fire control, (c) threats to life and property. And (d) because increasing fire frequencies beyond the normal fire regimes would probably have been detrimental to the majority of important ethnobotanical resources including fuelwood. (Kaib 1998: 144–145)

Historic Euro-Americans and Fire

How did historic Euro-Americans influence southwestern fire regimes? The best evidence for ecologically significant enhanced ignition rates comes from the period of initial Anglo-American rule during the last half of the 1800s, a time of Euro-American-set conflagrations elsewhere in the United States (e.g., Veblen and Lorenz 1991:25; Agee 1993; Pyne 1997). Some historical evidence suggests that large even-aged forests of aspen, mixed conifer, and spruce-fir may have regenerated after crown fires dating to this period throughout the southern Rocky Mountains and farther into the Southwest (Personal Communication, W. de Buys). Anglo settlement and exploitation of the Southwest in the last half of the 1800s likely contributed to higher frequencies of large stand-replacing fires in high-elevation mixed-conifer and spruce-fir forests, where the availability of ignitions during brief dry periods may have been a limiting factor (Box 5.2). However, fire history and age structure studies in aspen and spruce-fir forests by Romme et al. (1996, 1999a, 1999b) do not show anomalously high rates of disturbance for this period in the San Juan Mountains of southwestern Colorado, and Baker (in review) has found frequent lightning ignitions (but infrequent weather-controlled fire spread) in Rocky Mountain spruce-fir forests farther north.

In an odd twist, Kay (1997) broadly asserts that western aspen is "doomed" due to the European suppression of earlier fire regimes that he attributes to Indians ("The very presence of aspen, for instance, indicates that aboriginal burning was once widespread. . . . Unlike lightning fires, which tend to be infrequent, high-intensity infernos, native burning produced a higher frequency of lower-intensity fires."). However, Kay's paradigm is historically and ecologically incorrect in the Southwest, where lightning ignitions are frequent and aspen stands generally develop by resprouting from clonal rootstocks after high-intensity crown fires free them from the competition of more shade-tolerant conifers.

The apparent pulse of careless burning by early Euro-Americans in the late nineteenth and early twentieth centuries notwithstanding, there appears to have been a substantial bias among Anglo observers at that time toward a belief in human ignition as the primary cause of fire in the western United States, including the Southwest (Box 5.3). Fire was generally considered to be an unnatural agent of destruction that wasted timber resources, degraded the ability of forests to regenerate and protect essential watersheds, and threatened the ability of foresters to exert management control over the newly created forest reserves. Human-caused fires were considered preventable, and pressure was building to protect forests from purposeful underburning as well as wildfire conflagrations. Perhaps the late-1800s prejudice that Indians set many fires was also related to a "Manifest Destiny" mind-set that sought to justify removing some tribes from their native forest lands. These biases affected even many of the most perceptive and knowledgeable observers of the time (Box 5.4), from utilitarian conservationist Gifford Pinchot to the aesthetic-minded preservationist John Muir (Pyne 1997).

Sheep grazing was one of the economic mainstays of the historic Southwest (Denevan 1967; Baxter 1987). During the long period of

BOX 5.2. John Wesley Powell (1890:919) provides a confessional description of a Colorado crown fire in a plea to protect western forests from human-set burns.

"More than two decades ago I was camped in a forest of the Rocky Mountains. The night was arched with the gloom of snow-cloud: so I kindled a fire at the trunk of a great pine, and in the chill of the evening gazed at its welcome flame. Soon I saw it mount, climbing the trunk, crawling out along the branches, igniting the rough bark, kindling the cones, and setting fire to the needles, until in a few minutes the great forest pine was all one pyramid of flame, which illumined a temple in the wilderness domed by a starless night. Sparks and flakes of fire were borne by the wind to other trees, and the forest was ablaze. On it spread, and the lingering storm came not to extinguish it. Gradually the crackling and roaring of the fire became terrific. Limbs fell with a crash, trees tottered and were thrown prostrate; the noise of falling timber was echoed from rocks and cliffs; and here, there everywhere, rolling clouds of smoke were starred with burning cinders. On it swept for miles and scores of miles, from day to day, until more timber was destroyed than has been used by the people of Colorado for the last ten years.

"I have witnessed more than a dozen fires in Colorado, each one of which was like that described. Compared with the trees destroyed by fire, those used by man sink into insignificance. Some years ago I mapped the forests of Utah, and found that about one-half had been thus consumed since the occupation of the country by civilized man. So the fires rage, now here now there, throughout the Rocky Mountains and through the Sierras and the Cascades. They are so frequent and of such vast proportions that the surveyors of the land who extend the system of triangulation over the mountains often find their work impeded or wholly obstructed by clouds of smoke. A haze of gloom envelops the mountain land and conceals from the eye every distant feature. Through it the rays of the sun can scarcely penetrate, and its dull red orb is powerless to illumine the landscape."

BOX 5.3. Selected historical references on fire causation in the western United States (emphasis added to first quote).

1897: "Fires are particularly destructive to the forests of western North America. . . . Fires in western forests are started by careless or ignorant hunters and campers, who often leave their camp fires burning or, in utter wantonness, ignite coniferous trees to enjoy the excitement of the conflagration. **They can be occasionally traced to the effects of lightning, which locally is held responsible for many forest fires, although in reality fires set in this way are very rare**, as lightning is usually accompanied or followed by copious rains, which extinguish them before they can gain headway; **and very rarely they are produced by the rubbing together of adjacent trees swayed by the wind**. The right of way of every railroad crossing the Rocky Mountains and the other interior ranges of the continent is marked by broad zones of devastation due to fires which have started from the camps of construction gangs or the sparks of locomotives; and thousands of acres of timber are destroyed annually by the spread of fires lighted by settlers to clear their farms.

"Prospectors in search of valuable minerals frequently set fires in wooded regions to uncover the rocks and facilitate their operations; and the shepherds who drive their flocks to pasture during the summer months in the mountain forests . . . make fires in the autumn to clear the ground and improve the growth of forage plants the following year.

". . . Such conflagrations have occurred in the West since it was settled, and they will always menace the prosperity of that part of the country." (National Academy of Sciences 1897:44)

1898: "It has often been claimed that many forest fires are due to lightning. Little credence was at first given to this. . . . It is possible that lightning fires may be much more frequent in the Cascades than has been supposed, and the subject is certainly one worthy of further investigation." (Coville 1898:32, 33, Cascade Forest Reserve, Ore.)

1900: "The origin of the oldest fires is unknown. They are not even accredited, as in the White River region, to the Ute Indians. . . . While the general belief among settlers that most fires are due to careless campers is true in the main, there are also other agencies. The extensive coal mining carried on at various points in and near the reserve, with the constantly burning 'slag piles,' can not fail to be a prolific source of ignition. . . . Sheep men are charged with starting fires to improve the pasture. Hunters, cattlemen, sheep herders, sawmill operators, logging crews, ranchmen, settlers, and transient travelers are the people responsible for fires originating in the reserve. Doubtless some are blameless, while others are guilty of neglecting camp fires. . . . Circumstantial evidence, at least, points to these parties as the most likely perpetrators, as recent fires of greater or lesser extent were found in close connection with their work. It is reasonable, therefore, to conclude that the greatest danger from fire lies in the presence of these people." (Sudworth 1900:228–231, Battlement Mesa Forest Reserve, Colo. [today's Grand Mesa National Forest])

1900: "Of all the reserves established by the federal government, the three under consideration have probably been the most damaged by fire. . . . Probably at least 75 per cent of the total area of the reserves clearly shows damage by fire, much of it within the last half century or since the advent of white settlers in the region." (Jackson 1900:43, 44, Pike's Peak, Plum Creek, and South Platte Forest Reserves, Colo. [today's Pike National Forest])

1900: "It (the large fire) was said to have originated from the burning of a heap of brush by one of the early settlers; but other information placed the responsibility for the fire upon the Indians, who probably are charged with more than their share of such occurrences." (Jackson 1900:97, South Platte Forest Reserve, Colo. [today's Pike National Forest])

1900: "Several cases of fires started by lightning were reported." (Jackson 1900:77, Plum Creek Forest Reserve, Colo. [today's Pike National Forest])

1900: "The early fires which devastated a great part of the forest land are said to have taken place when the country was first explored, about half a century ago; and it is claimed that they were started by Indians, who thus attempted to drive out the game before them when they were compelled to leave this region for more distant reserves." (Jackson 1900:69, Pike's Peak Forest Reserve, Colo. [today's Pike National Forest])

1900: "The fires which burned during Indian occupancy and soon after the arrival of the present settlers in the region were far more widespread and destructive than those of recent years. . . .

"The origin of fires in recent years may, in part, be ascribed to carelessness of sheep herders, in part to sparks from the engines on the Atchison, Topeka and Santa Fe Railroad. The region is not good hunting or camping ground and few fires originate from the camps of hunting parties. But by far the larger number of fires are due to lightning strokes, and this cause has, of course, always operated. Electric storms are very numerous in this region during July and August. . . . While most of the thunder showers are accompanied by rain, some are not and when a tree is struck by lightning during a storm of this sort, a fire of more or less severity is sure to follow." (Leiberg et al. 1904:266–268, San Francisco Mountains Forest Reserve, Ariz. [today's Coconino National Forest])

continues

BOX 5.3. *Continued*

1910: "It is probably unjust, however, to attribute all the fires to man. During two summers' work nearly a dozen fires were noted which were due to lightning." (Clements 1910:8, Estes Park, Colo.).

1912: "That lightning is one of the chief causes of forest fires is now an established fact. Careful observations on the National Forests have shown that there it ranks second only to sparks from locomotives as a source of conflagration. . . . Lightning may bring about a forest fire by igniting the tree itself, or the humus at its base. Most forest fires caused by lightning probably start in the humus." (Plummer 1912b:5, 36)

1912: "In order of their importance, the following are the chief known causes of fires on the National Forests: ([R])ailroads; lightning; campers; brush burning; incendiary; sawmills. Lightning is responsible for about 17.5 per cent of the fires." (Plummer 1912a:9).

1955: "Almost all of the forests of California, Oregon, and Washington have indicators, either in the scars on living trees or in the subclimax nature of the types of trees, showing that fires set by Indians have frequently run through them.

"Many foresters and plant ecologists have been reluctant to attribute to the aborigines the amount of vegetation burning evident from the record in the trees. They seem to prefer a natural cause, lightning, rather than human cause for such widespread conflagrations. . . . In a few sections of the mountains, lightning starts dozens of fires each year, but over the major part of the west fires started by lightning are unknown. Thus, there are millions of acres of forest, brushland, and grassland on which Indian fires were the factor determining what kind of vegetation survived or dominated." (Stewart 1955:6)

1978: "Lightning is the leading cause of fires in southwestern forests. On all protected private, state and federal lands in Arizona and New Mexico, nearly 80 percent of the forest, brush and range fires are ignited by lightning. The Southwestern region leads all other regions of the United States both in total number of lightning fires and in the area burned by these fires. Lightning fires are an important factor in the management of wildland resources in all of the western United States. . . . These fires are a natural element in wildland ecosystems." (Barrows 1978:1)

BOX 5.4. Historic views of fire in the Southwest by the U.S. Bureau of Biological Survey.

Vernon Bailey of the U.S. Bureau of Biological Survey spent major portions of at least nine field seasons between 1889 and 1908 conducting biological inventories in the Southwest, including efforts to synthetically describe these landscapes in the life-zone system developed by C. H. Merriam (1890). Bailey noticed the obvious signs of past fire occurrence in many southwestern landscapes, and he consistently attributed these to human causes, particularly to efforts to burn off forests to create better pastures during this era of peak livestock grazing intensities. In 1903, Bailey described extensive evidence of fire in the high elevation forests of today's Pecos Wilderness in the Sangre de Cristo Mountains, which he linked to the influence of people: "The forest (now included in the Pecos River Forest Reservation) has been sadly thinned by burning, fully three fourths of it having been burned over and a large part of the coniferous forest replaced by poplars [aspen] or kept open by repeated burning for grazing land" (Bailey 1903).

In 1904 Bailey spent over two weeks reconnoitering the "Gallinas Mountains" (actually, the northwest portion of the Jemez Mountains, including the San Pedro Parks plateau), noting: "Canadian Zone covers the tops and upper slopes of the mountains and is marked by both dense forests and extensive grassy parks. Its timber . . . has been burned over as far as possible & replaced to a great extent by Populus tremuloides." (Bailey 1904a). On this trip Bailey provided a classic description of widespread fire-structured ponderosa pine forests: "Transition Zone is the most extensive in the mountains and includes the most extensive and perfect yellow pine (Pinus ponderosa) forest that I have ever seen. It covers the broad basal slopes of the range from 8,000 to 9,700 feet on S.W. slopes or 7,000 to 9,000 on N.E. slopes and is generally an open park like forest with well spaced trees and clean grama turf beneath. The trees are large and symmetrical, often 5 feet in diameter and 80 to 100 feet high with beautifully smooth trunks. . . . Fire has left little havoc in this open forest" (Bailey 1904a).

Yet Bailey's field notes for this same expedition show that he viewed fire to be a relatively recent anthropogenic intrusion rather than a long-term natural disturbance process in these mountain forests: "The timber has been burnt off as far as possible, but fortunately the yellow pines stand burning pretty well and have not been injured much while much of the higher spruce forest will not burn. This leaves much of the forest in good condition" (Bailey 1904b). In contrast, dendrochronological fire histories developed in the past decade from this northern portion of the Jemez Mountains provide evidence of frequent surface fires extending back into the late 1400s at Mesita del Cañoncito Seco, into the mid-1500s at three other sites, and back to ca. A.D. 1600 at four additional sites (Touchan et al. 1996). These early fires precede the Spanish colonization and introduction of livestock into this region, and thus were not set by people to create grazing lands.

Spanish and Mexican rule there is very little documentation of fire use, although burning to improve pasturage for livestock seems likely given Spanish traditions (Pyne 1997:137). By 1890 there were more than 5 million sheep in New Mexico alone (Wooton 1908); shepherds, like Indians, clearly became another favorite target of the late 1800s "establishment," which accused them of causing many uncontrolled resource and social problems, including setting destructive fires (National Academy of Sciences 1897). Third-generation shepherd Leandro Salazar recalled his father telling of fires set by shepherds to enlarge pastures in the northeastern Jemez Mountains in the late 1800s—fires that created meadows still present today (Allen 1984:131–132). But since one might expect shepherds to burn in fall as they retreated from the mountains toward the valleys, to improve next year's grazing without damage to the current year's potential, the absence of fall fires in fire-scar chronologies from the Jemez Mountains (including from near the area described by Salazar) fails to support claims of shepherd ignitions. However, perhaps efforts to convert southwestern forests into grass would have been focused on the natural spring burning window, when higher fire intensities can occur.

If shepherd burning had been important, pressure on the sheep industry to improve its image and the imposition of severe penalties against even accidental ignition of wildland fires must have reduced the frequency of human-set fires by ca. 1900 (Allen 1984:130–132). Consider this report by Coville (1898:34, 36), who was sent to inspect for shepherd impacts in the Cascade Forest Reserve in Oregon:

> It has been alleged that sheep herders systematically set fire to the forest in order to burn off the timber so that a growth of weeds and grass will spring up to furnish grazing in succeeding years. . . . It is clear that the extent of the practice among sheepmen of systematically setting forest fires has been overestimated. It is interesting to note that during the progress of the season's investigation, while no fires were found that could be traced by positive evidence to sheepmen, camp fires were seen abandoned by travelers, by campers and by Indians, fires set by road builders and by lightning, and fires set for the purpose of creating smudges.

Similarly, there is no evidence that shepherds were more important than many other human causes of fire in the historic Southwest. Indeed, dendrochronological fire histories show precipitous declines in fire frequencies concurrent with the introduction of extensive sheep herds—not an increase. Although early fire suppression records on the Santa Fe

National Forest (1910–1920) occasionally noted "goatherders" and "brushburning" as causes of fire, Leandro Salazar told me that shepherds certainly no longer set fires by 1922, when he began herding sheep in the Jemez Mountains (Allen 1984:131).

Associated with the late-1800s emphasis on the human role in setting destructive fires (cf. Agee 1993) was the downplaying of a natural role for lightning ignitions (Box 5.4). Although many people knew that lightning started fires, they did not recognize the commonness of lightning ignitions. The turn-of-the-twentieth-century references that are cited today as evidence for the importance of human ignitions in southwestern fire regimes are tainted by the prevailing bias that people started almost all fires. However, evidence regarding the importance of lightning-caused fires was eventually assembled, especially after the establishment of the U.S. Forest Service (in 1905), which quickly developed a firefighting organization that systematically collected data on fire causes (Plummer 1912a, 1912b). Improvements in fire-detection methodologies during the 1930s and 1940s (Swetnam 1990) also increased the incidence of reported lightning fires by picking up many small lightning-strike ignitions in remote locations. Eventually, over the course of several decades, the discussion of fire as a natural disturbance process in the Southwest began to emerge above the insistent utilitarian mantra of universal fire control (Leopold 1937; Weaver 1951; Pyne 1997). The evolution of perspectives on fire causation, from emphasis on human ignitions to recognition of lightning as a dominant source, is evident from a review of written accounts through time (Box 5.4). It is now apparent that lightning is the leading cause of fires throughout the West, igniting more than 64 percent of all recorded fires (an average of 6,253 lightning fires per year) in western national forests from 1960 to 1975 (Barrows 1978:5).

The relative importance of lightning fires in the pre-1900 Southwest is further confirmed by the observation that surface fire frequencies in ponderosa pine and many mixed-conifer forests generally declined somewhat by ca. 1840 (Grissino-Mayer and Swetnam 2000), decades before the onset of suppression, despite the turn-of-the-nineteenth-century perception that Anglo ignitions were the main cause of fires after ca. 1850. This suggests that Euro-American ignitions were insignificant relative to background levels of lightning-ignited surface fires in these ecosystems even during this "Wild West" period of fire use.

Further, cessation of spreading surface fires occurred at most southwestern fire-scar sites between ca. 1880 and 1900 (Swetnam et al. 1999), despite continued Euro-American fire sources and a general lack of organized suppression activities until ca. 1910 (Pyne 1997). Indeed, the greatest impacts of historic people on southwestern fire patterns have involved suppression rather than ignition of fires. The region-wide collapse of surface-fire regimes by ca. 1900 (e.g., Figures 5.6 and 5.7) is closely linked to major reductions in fuel quantities and continuities due to intense overgrazing and trailing effects by livestock, especially sheep in the mountains. Livestock numbers soared in the uplands of the Southwest with the pacification of the mobile raiding tribes (Apache, Navajo, and Ute) and the entry of railroads into the region by ca. 1880. The fire-suppressing effects of overgrazing were well recognized by some contemporary observers (Leopold 1924)—consider this description by Powell (1890):

> There is a practical method by which the forests can be preserved. All of the forest areas that are not dense have some value for pasturage purposes. Grasses grow well in the open grounds, and to some extent among the trees. If herds and flocks crop these grasses, and trample the leaves and cones into the ground, and make many trails through the woods, they destroy the conditions most favorable to the spread of fire.

Early interruptions in fire regimes, likely due to localized livestock grazing by Indians or Hispanics, are evident in some fire-scar chronologies from the Chuska Mountains (Savage and Swetnam 1990; Savage 1991) and the Sandia and Manzano Mountains (Baisan and Swetnam 1997). Fire-scar histories from the northern Jemez area (Figure 5.5) tend to show early gaps or interruptions in fire regimes that follow an initial period of highest fire frequency (Figure 5.7). Grazing by Navajo and Puebloan peoples likely occurred at these sites, which include Continental Divide and Cerro Pedernal (Touchan et al. 1995, 1996), and Mesa Prieta along an old "Navajo Trail" (Figure 5.7; Allen and Riser, unpublished data). Some Indians adopted sheep husbandry early on (Puebloans in the 1600s and Navajo by ca. 1700 [Bailey 1980; Baxter 1987:13, 25])—the Puebloans even kept sheep through the Pueblo Revolt of 1680–1696 when many other aspects of Spanish culture were violently rejected (e.g., "During the April 1694 battle for the heights above Cochití, Spanish forces captured nine hundred sheep" [Baxter 1987:13]). Old Spanish documents record non-Navajo sheep/goat numbers in New Mexico of 112,000 in 1757, with 58 percent of those owned by Pueblo and Hopi Indians (Baxter 1987:42), and at least localized overgrazing of ranges noted in the 1730s and 1810s (Baxter 1987:24, 92). As a result, it is hard to confidently attribute grazing suppression effects in fire-scar chronologies to Indian, Hispanic, or even later Anglo cultures without firm knowledge of local land use histories.

By the 1880s millions of sheep and cattle grazed across the Southwest

(Wooton 1908; Bogan et al. 1998; Frederickson et al. 1998), and surface fire regimes collapsed in most places (Swetnam et al. 1999). In the Jemez Mountains area, spreading surface fires cease earliest near the encircling river valleys and latest in the most interior portions (Allen, unpublished data), consistent with the spread of livestock from valley settlements up into more remote and dangerous uplands. Fire cessation dates at particular sites correspond to the local initiation of intense livestock grazing, not to the cessation of human ignitions associated with local declines in Indian activities. For example, fire activity (and thus ignitions) continued for decades in many mountain ranges of the U.S./Mexico borderlands region after Apache removals, with subsequent declines associated with either overgrazing impacts on fine fuels or the start of active fire suppression (Swetnam et al. 2001). In contrast, relatively natural fire regimes persisted in the few areas of the Southwest where heavy livestock grazing and active fire suppression were excluded by topography or land use history, such as forested kipuka islands amidst forbidding lava-flow seas at El Malpais National Monument (Grissino-Mayer 1995), an inaccessible butte summit at Zion National Park (Madany and West 1983), isolated plateaus in the Grand Canyon (Fulé et al. 2000), portions of the rugged and remote Animas Mountains of the New Mexico bootheel (Swetnam et al. 2001), and the Sierra de los Ajos and other isolated mountains in northern Mexico (Swetnam et al. 2001). These unique local situations show that natural lightning ignitions can sustain surface fire regimes even where human ignitions have been inconsequential, particularly where Indians and their potential firesticks are long gone.

Inadvertent disruption of fire regimes by livestock graded into active fire suppression across the American Southwest in the early 1900s (Pyne 1997), with suppression methods becoming increasingly effective through ca. 1950 (Swetnam 1990). The resultant fuel buildups have promoted increased numbers of large and intense fires (Swetnam and Betancourt 1998), while the negative ecological effects of long-term fire suppression have become ever more apparent across the Southwest (Weaver 1951; Cooper 1960; Covington and Moore 1994; Bogan et al. 1998). In recent decades a consensus has emerged among federal wildland managers that the strategy of suppressing all fires has become counterproductive and that "wildland fire use" has many benefits (USDI/USDA 1995). Powell would likely grant himself a smile at the current popularity of prescribed burning, taking it as confirmation of his once maverick position in support of "Pauite forestry" (Powell 1890; Pyne 1997). However, vigorous debate persists over the notion that fire can be used to restore more natural conditions in wilderness areas (Pyne 1995b; Swetnam et al. 1999).

Conclusion: How Important Was Native American Burning in Shaping the Upland Ecosystems of the Southwest?

> How can anyone dismiss anthropogenic fire as inconsequential or indistinguishable from lightning fire? Biotas are adapted not just to fire but to fire regimes, and all the regimes of Holocene America have emerged within the context of anthropogenic burning or that negotiated matrix between lightning and humans. . . . Together lightning and people made the elastic matrix that defined the fire regime. (Pyne 1995b:16, 21)

> It is unnecessary in most cases to invoke human-set fires as an explanation or cause of fire regime patterns in the Southwest. We contend that, even if humans had never crossed the land bridge from Asia to North America, historical fire regimes in most Southwestern forests would still have been similar in most respects to the fire regimes that we have documented. (Swetnam and Baisan 1996a:29)

It is possible to believe and appreciate the eloquent scholarship of Sauer (1975), Stewart (1956), and Pyne (1995a) regarding aboriginal modification of *many* landscapes through fire use without accepting the premise that *all* landscapes are artifacts of ancient human burning practices. Indeed, it is appropriate to "dismiss anthropogenic fire as inconsequential or indistinguishable from lightning fire" in most times and places in the uplands of the American Southwest. Multiple lines of evidence from this region overwhelmingly suggest that in A.D. 1850, as in A.D. 1580, most mountain landscapes were "natural" and "wild" with regard to fire regimes and associated vegetation patterns. Evidence of landscape-scale fire use by aboriginal people in the Southwest is scanty to nonexistent, and most assertions of aboriginal burning are based upon anecdotal accounts or sources subject to substantial historical bias. The high levels of lightning-ignited fire observed today in the Southwest are easily sufficient to generate the frequent return intervals indicated for many forest types by the fire-scar record, given pre-1900 landscapes where fires would have spread widely in dry years through continuous and quick-regenerating fine fuels in the absence of active human suppression and artificial fuelbreaks. The strong consistencies between the multicentury fire-scar record of prehistoric fire regimes and modern observations of lightning-caused wildfire activity suggest that pre-1900 fire regimes can largely, if not wholly, be attributed to natural factors. Since ignitions are generally not a limiting factor in this region, the factors of climate and fuels are magnified as the primary drivers of southwestern fire regimes—it is unnecessary to invoke human agency. Mid-elevation wild lands in the Southwest naturally included frequent fires, regardless of human burning practices.

Proponents of aboriginal modification of North America through fire use are generally well aware of the age-old importance of lightning fires in the American Southwest: "It is more difficult to interpret fire in the Southwest, where lightning, not humans, normally supplies ignition" (Pyne 1995a:295). Yet some would cast a humanistic perspective across the entire continent, transposing a global view of the dominance of landscape-scale aboriginal burning to the Southwest, despite much contrary evidence and only meager support from a few historic documents about localized fire use.

Still, anthropogenic effects on fire regimes are discernable in particular times and places in the southwestern uplands. Human-set fires likely enhanced natural fire frequencies in local areas over the already high levels initiated by lightning. Yet, even during these limited time periods only a few localities show irregularities consistent with possible anthropogenic enhancement of fire frequencies, such as periods with unusually high fire frequencies, less within-stand synchrony of fire dates, weaker fire-climate relationships, aberrant patterns of fire seasonality, or drastic changes in fire regime through time. As summarized by Swetnam et al. (2001) for the Apacheria Borderlands situation: "quantitative fire history studies in the region . . . all conclude that, if Apaches or Europeans influenced pre-1900 fire regime patterns, these influences were probably very time and place specific, and not generalizable across broader temporal and spatial scales." Native American burning practices, by Apaches or other Indians, had little regional effect on pre-1900 fire regimes in the Southwest. Overall, the most profound anthropogenic effects on southwestern fire regimes are the pervasive but relatively modern impacts of fire suppression.

Of course, it is possible that prehistoric Native Americans used fire widely in the Southwest, but little evidence has survived to our current day due to the "fading record" problem (Swetnam et al. 1999). This presumption has likely contributed to the casually documented claims about the essential role of aboriginal burning in the Southwest and elsewhere (e.g., Bonnicksen et al. 1999:443; Krech 1999:113; Bonnicksen 2000:355; Pyne 2000; Williams 2000). Yet even if we assume that substantial, undocumented aboriginal fire use occurred, the potential ecological effects of prehistoric Indian burning in the Southwest are greatly diminished by the intrinsic natural background of frequent lightning fires.

The role of people in southwestern fire regimes relates to a larger question: Were the pre-European landscapes of the Southwest in the 1500s pristine wildernesses or humanized culturescapes? The relative effects of people upon wild nature in the Southwest were contingent upon the particulars of time and place and culture, with spatial gradients of impacts associated with the varying intensities of human occupation and use. For example, the extensive portions of the Pajarito Plateau on the eastern flank of the Jemez Mountains that sustained large Anasazi populations into the mid-1500s are likely still in recovery from prehistoric land uses that cleared mesatops for agriculture and consumed large quantities of wood, suggested by the modern lack of old-growth pinyon-juniper woodland in the area. In general, prehistoric aboriginal impacts in the Southwest were greater at lower elevations, in woodland and valley settings where many people lived year-round (and where a dendrochronological record of human land uses is usually poorly preserved due to centuries of human wood use). Still, despite a variety of early human land uses, most mountains in the Southwest retained a dominantly wilderness character until the advent of Anglo-American exploitation in the late nineteenth century, as evidenced by the persistence of natural fire regimes until this time.

While available evidence asserts the long-term primacy of lightning-ignited fires, we will never know for certain the varied roles of aboriginal Americans in the fire regimes of the prehistoric Southwest. However, precise determination of Indian burning effects is unnecessary to justify wildland fire programs in this region, for we can be sure that "lots of lightning" and frequent fire naturally characterize the mesas and mountains of the Southwest, even in the absence of burning by "plenty of people."

Acknowledgments

This chapter draws heavily on long-term collaborations with Tom Swetnam's fire history research group at the University of Arizona Laboratory of Tree-Ring Research, especially interactions with Tom, Chris Baisan, Kiyomi Morino, Ramzi Touchan, Henri Grissino-Mayer, and Tony Caprio. I thank Bill deBuys for historic reference materials and thoughtful discussions on this topic. James Riser, Dave Snyderman, and John Hogan of the USGS Jemez Mountains Field Station conducted essential fieldwork, tree-ring dating, and mapping of historic fires, while most figures were created by Kay Beeley. This research was supported by the U.S. Geological Survey (Biological Resources Division), the National Park Service (particularly Bandelier National Monument), and the Santa Fe National Forest. For helpful review comments I thank Tom O'Shea, Bill deBuys, Tom Swetnam, Tom Vale, and Mark Kaib. The

views expressed here are those of the author and do not represent an official position of the USGS.

Literature Cited

Abolt, R. A. P. 1997. Fire histories of upper elevation forests in the Gila Wilderness, New Mexico Via fire scar and stand age structure analyses. M.S. thesis, University of Arizona, Tucson.

Agee, J. K. 1993. *Fire ecology of Pacific Northwest forests.* Washington, D.C.: Island Press.

Allen, C. D. 1984. Montane grasslands in the landscape of the Jemez Mountains, New Mexico. Master's thesis, University of Wisconsin.

———. 1989. Changes in the landscape of the Jemez Mountains, New Mexico. Ph.D. diss., University of California, Berkeley.

———, tech. ed. 1996a. *Fire effects in southwestern forests: Proceedings of the second La Mesa fire symposium.* General technical report RM-286. Fort Collins, Colo.: USDA Forests Service.

———. 1996b. Elk response to the La Mesa fire and current status in the Jemez Mountains. Pp. 179–195 in *Fire effects in southwestern forests: Proceedings of the second La Mesa fire symposium*, ed. C. D. Allen. General technical report RM-286. Fort Collins, Colo.: USDA Forest Service.

———. 1998. Sensitivity of semiarid woodlands and forests to climate-induced disturbances in the southwestern U.S. Unpublished proposal to USGS Global Change Research Program on file at USGS Jemez Mts. Field Station.

———. In review. Ecological patterns and environmental change in the Bandelier landscape. Chapter 2 in *Village formation on the Pajarito Plateau, New Mexico: The archaeology of Bandelier National Monument*, ed. T. A. Kohler. Albuquerque: University of New Mexico Press.

Allen, C. D., J. L. Betancourt, and T. W. Swetnam. 1998. Landscape changes in the southwestern United States: Techniques, long-term datasets, and trends. Pp. 71–84 in *Perspectives on the land use history of North America: A context for understanding our changing environment*, ed. T. D. Sisk. U.S. Geological Survey, biological science report USGS/BRD/BSR-1998-0003.

Allen, C. D., and D. Snyderman. 1997. Spatial patterns of prehistoric and historic fires in the Jemez Mountains, New Mexico (abstract). Bulletin of the Ecological Society of America 78:44.

Allen, C. D., R. Touchan, and T. W. Swetnam. 1996. Overview of fire history in the Jemez Mountains, New Mexico. Pp. 35–36 in *New Mexico Geological Society guidebook, 47th field conference, Jemez Mtns. Region*, ed. F. Goff, B. S. Kues, M. A. Rogers, L. D. McFadden, and J. N. Gardner. New Mexico Geological Society.

Anderson, M. K. 1993. The mountains smell like fire. *Fremontia* 21:15–20.

———. 1996. Tending the wilderness. *Restoration and Management Notes* 14:154–166.

Anderson, R. S. 1989. Development of the southwestern ponderosa pine forests: What do we really know? Pp. 15–22 in General technical report RM-185. Fort Collins, Colo.: USDA Forest Service.

———. 1993. A 35,000 year vegetation and climate history from Potato Lake, Mogollon Rim, Arizona. *Quaternary Research* 40:351–359.
Anschuetz, K. F. 1998. Not waiting for the rain: Integrated systems of water management by pre-Columbian Pueblo farmers in north-central New Mexico. Ph.D. diss., University of Michigan, Ann Arbor.
Archer, S. 1994. Woody plant encroachment into southwestern grassland and savannas: Rates, patterns and proximate causes. Pp. 13–68 in *Ecological implications of livestock herbivory in the West*, ed. M. Vavra, W. A. Laycock, and R. D. Pieper. Denver, Colo.: Society for Range Management.
Bahre, C. J. 1991. A legacy of change: Historic human impact on vegetation in the Arizona borderlands. Tucson: University of Arizona Press.
Bailey, L. R. 1980. If you take my sheep: The evolution and conflicts of Navajo pastoralism, 1630–1868. Pasadena: Westernlore Publications.
Bailey, V. O. 1903. Unpublished physiography report—Pecos River Mountains. Transcribed and annotated by William deBuys, on file at USGS Jemez Mts. Field Station, Los Alamos, N. Mex.
———. 1904a. Unpublished physiography report—Gallinas Mountains. Transcribed and annotated by William deBuys, on file at USGS Jemez Mts. Field Station, Los Alamos, N. Mex.
———. 1904b. Unpublished field notes, Gallinas Mountains, October 4–20, 1904. Transcribed and annotated by William deBuys, on file at USGS Jemez Mts. Field Station, Los Alamos, N. Mex.
Baisan, C. H., and T. W. Swetnam. 1990. Fire history on a desert mountain range: Rincon Mountain Wilderness, Arizona, U.S.A. *Canadian Journal of Forest Research* 20:1559–1569.
———. 1997. *Interactions of fire regimes and land use in the central Rio Grande valley*. Research paper RM-330. Fort Collins, Colo.: USDA Forest Service.
Baker, W. L. (In review.) Fires and climate in forested landscapes of the Rocky Mountains. In *Fire and climatic change in the Americas*, ed. T. W. Swetnam, G. Mongenegro, and T. T. Veblen.
Barrett, S. W., and S. F. Arno. 1982. Indians fires as an ecological influence in the northern Rockies. *Journal of Forestry* 8:647–651.
Barrows, J. S. 1978. Lightning fires in southwestern forests. Final report to USDA Forest Service Intermountain Forest and Range Experiment Station. Fort Collins, Colo.
Baxter, J. O. 1987. Las carnerada: Sheep trade in New Mexico, 1700–1860. Albuquerque: University of New Mexico Press.
Betancourt, J. L., J. S. Dean, and H. M. Hull. 1986. Prehistoric long-distance transport of construction beams, Chaco Canyon, New Mexico. *American Antiquity* 5:370–375.
Betancourt, J. L., and T. R. Van Devender. 1981. Holocene vegetation in Chaco Canyon, New Mexico. *Science* 214(6):656–658.
Betancourt, J. L., T. R. Van Devender, and P. S. Martin, eds. 1990. *Packrat middens: The last 40,000 years of biotic change*. Tucson: University of Arizona Press.
Bogan, M. A., C. D. Allen, E. H. Muldavin, S. P. Platania, J. N. Stuart, G. H. Farley, P. Melhop, and J. Belnap. 1998. Southwest. Pp. 543–592 in *National status and trends report*, ed. M. J. Mac, P. A. Opler, and P. D. Doran. Washington, D.C.: U.S. Geological Survey.

Bonnicksen, T. M. 2000. *America's ancient forests*. New York: John Wiley.
Bonnicksen, T. M., M. K. Anderson, H. T. Lewis, C. E. Kay, and R. Knudson. 1999. Native American influences on the development of forest ecosystems. Pp. 439–470 in vol. 2 of *Ecological stewardship: A common reference for ecosystem management*, ed. R. C. Szaro, N. C. Johnson, W. T. Sexton, and A. J. Malk. Oxford: Elsevier Science Ltd.
Bowen, B. M. 1990. *Los Alamos climatology*. LA-11735-MS UC-902. Los Alamos: Los Alamos National Laboratory.
Boyd, R. 1986. Strategies of Indian burning in the Williamette Valley. *Canadian Journal of Anthropology* 5:65–96.
Bracker, S. B. 1996. How many people lived at Bandelier? Unpublished report on file at Bandelier National Monument, N. Mex.
Brown, D. E., ed. 1982. Biotic communities of the American Southwest—United States and Mexico. *Desert Plants* 4(1–4):1–342.
Brown, P. M., M. R. Kaufmann, and W. D. Shepperd. 1999. Long-term landscape patterns of past fire events in a montane ponderosa pine forest of central Colorado. *Landscape Ecology* 14:513–532.
Brunner-Jass, R. 1999. Fire occurrence and paleoecology at Alamo Bog and Chihuahueños Bog, Jemez Mountains, New Mexico, USA. Master's thesis, Northern Arizona University, Flagstaff.
Butzer, K. W. 1990. The Indian legacy in the American landscape. Pp. 27–50 in *The making of the American landscape*, ed. M. P. Conzen London: HarperCollins Academic.
Clark, J. C., and P. D. Royall. 1995. Transformation of a northern hardwood forest by aboriginal (Iroquois) fire: Charcoal evidence from Crawford Lake, Ontario, Canada. *The Holocene* 5:1–9.
Clements, F. E. 1910. *The life history of lodgepole burn forests*. USDA Forest Service Bulletin 79. Washington, D.C.: U.S. Government Printing Office.
Cooper, C. F. 1960. Changes in vegetation, structure, and growth of southwestern pine forests since white settlement. *Ecological Monographs* 30(2):129–164.
Cordell, L. S. 1997. *Archaeology of the Southwest*. San Diego: Academic Press.
Covey, C., ed. and trans. 1993. Cabeza de Vaca's "Adventures in the unknown interior of America." Albuquerque: University of New Mexico Press.
Coville, F. 1898. *Forest growth and sheep grazing in the Cascade Mountains of Oregon*. USDA Division of Forestry bulletin no. 15. Washington, D.C.: U.S. Government Printing Office.
Covington, W. W., P. Z. Fulé, M. M. Moore, S. C. Hart, T. E. Kolb, J. N. Mast, S. S. Sackett, and M. R. Wagner. 1997. Restoring ecosystem health in ponderosa pine forests of the Southwest. *Journal of Forestry* 95:23–29.
Covington, W. W., and M. M. Moore. 1994. Southwestern ponderosa pine forest structure: Changes since Euro-American settlement. *Journal of Forestry* 92:39–47.
Day, G. M. 1953. The Indian as an ecological factor in the northeastern forest. *Ecology* 34:329–346.

Dean, J. S. 1988. Dendrochronology and paleoenvironmental reconstruction on the Colorado Plateaus. Pp. 119–167 in *The Anasazi in a changing environment*, ed. G. J. Gummerman. Cambridge: Cambridge University Press.

Dean, J. S., and G. S. Funkhouser. 1995. Dendroclimatic reconstruction for the southern Colorado Plateau. Pp. 85–104 in *Climate change in the four corners and adjacent region: Implications for environmental restoration and land-use planning*, ed. W. J. Waugh. Grand Junction, Colo.: U.S. Department of Energy, Grand Junction Project Office.

DeBuys, W. 1985. *Enchantment and exploitation: The life and hard times of a New Mexico mountain range*. Albuquerque: University of New Mexico Press.

Delcourt, H. R., and P. A. Delcourt. 1998. Pre-Columbian Native American use of fire on southern Appalachian landscapes. *Conservation Biology* 11:1010–1014.

Denevan, W. M. 1967. Livestock numbers in nineteenth-century New Mexico and the problem of gullying in the Southwest. *Annals of the Association of American Geographers* 57(4):691–703.

———. 1992. The pristine myth: The landscape of the Americas in 1492. *Annals of the Association of American Geographers* 82:369–385.

Dobyns, H. E. 1981. *From fire to flood: Historic human destruction of Sonoran Desert riverine oases.* Ballena Press anthropology papers no. 20. Socorro, N. Mex.: Ballena.

Doolittle, W. E. 1992. Agriculture in North America on the eve of contact: A reassessment. *Annals of the Association of American Geographers* 82:386–401.

Elliott, M. L. 1993. *Jémez.* Santa Fe: Museum of New Mexico Press.

Euler, R. C. 1988. Demography and cultural dynamics on the Colorado Plateaus. Pp. 192–229 in *The Anasazi in a changing environment*, ed. G. J. Gummerman. New York: Cambridge University Press.

Fish, S. K. 1996. Modeling human impacts to the Borderlands environment from a fire ecology perspective. Pp. 125–134 in *Effects of fire on Madrean Province ecosystems: A symposium proceedings*, tech. coord. P. F. Ffolliott et al. General Technical Report RM-289. Fort Collins, Colo.: USDA Forest Service.

Forman, R. T. T., and E. W. B. Russell. 1983. Evaluation of historical data in ecology. *Bulletin of the Ecological Society of America* 64:5–7.

Foxx, T. S., and L. D. Potter. 1978. Fire ecology at Bandelier National Monument. Unpublished report on file at Bandelier National Monument.

Frederickson, E., K. M. Havstad, and R. Estelle. 1998. Perspectives on desertification: Southwestern United States. *Journal of Arid Environments* 39:191–207.

Fulé, P. Z., and W. W. Covington. 1996. Changing fire regimes in Mexican pine forests: Ecological and management implications. *Journal of Forestry* 94:33–38.

———. 1999. Fire regime changes in La Michilía Biosphere Reserve, Durango, Mexico. *Conservation Biology* 13:640–652.

Fulé, P. Z., W. W. Covington, and M. M. Moore. 1997. Determining reference conditions for ecosystem management of southwestern ponderosa pine. *Ecological Applications* 7:895–908.

Fulé, P. Z., T. A. Heinlein, W. W. Covington, and M. M. Moore. 2000. Continuing fire regimes in remote forests of Grand Canyon National Park. Pp. 242–248 in *Proceedings: Wilderness science in a time of change conference*, vol. 5: *Wilderness ecosystems, threats, and management, May 23–27, 1999, Missoula, Mont.*, comp. D. N. Cole, S. F. McCool, W. T. Borrie, and F. O'Loughlin. Ogden, Utah: USDA Forest Service, Rocky Mountain Research Station, Proceedings RMRS-P-15-VOL-5.

Gottesfeld, L. M. J. 1994. Aboriginal burning for vegetation management in northwest British Columbia. *Human Ecology* 22:171–188.

Grissino-Mayer, H. D. 1995. Tree-ring reconstructions of climate and fire history at El Malpais National Monument, New Mexico. Ph.D. diss., University of Arizona.

———. 1996. A 2129-year reconstruction of precipitation for northwestern New Mexico, USA. Pp. 191–204 in *Tree rings, environment and humanity*, ed. J. S. Dean, D. M. Meko, and T. W. Swetnam. Tucson, Ariz.: Radiocarbon.

Grissino-Mayer, H. D., C. H. Baisan, and T. W. Swetnam. 1995. Fire history in the Pinaleño Mountains of southeastern Arizona: Effects of human-related disturbances. Pp. 399–407 in *Biodiversity and management of the Madrean Archipelago: The sky islands of southwestern United States and northwestern Mexico*, tech. coord. L. F. DeBano et al. General technical report RM-264. Fort Collins, Colo.: USDA Forest Service.

Grissino-Mayer, H. D., and T. W. Swetnam. 2000. Century-scale climate forcing of fire regimes in the American Southwest. *The Holocene* 10(2):207–214.

Harrington, J. P. 1916. *The ethnogeography of the Tewa Indians.* The 29th annual report of the Bureau of American Ethnology—1907–1908. Washington, D.C.: U.S. Government Printing Office.

Henderson, J., and J. P. Harrington. 1914. *Ethnozoology of the Tewa Indians.* Washington, D.C.: Smithsonian Institution, Bureau of American Ethnology.

Holsinger, S. J. 1902. The boundary line between the desert and the forest. *American Forests* 8:21–27.

Hough, W. 1926. *Fire as an agent in human culture.* Smithsonian Institution, U.S. National Museum bulletin 139. Washington, D.C.: U.S. Government Printing Office.

Huber, E. K., and T. A. Kohler. 1993. Pollen Analysis, Kiva, Area 1, Burnt Mesa Pueblo (LA 60372). Pp. 121–129 in *Papers on the early classic period prehistory of the Pajarito Plateau, New Mexico.* Pullman: Department of Anthropology, Washington State University.

Humphrey, R. R. 1974. Fire in the deserts and desert grassland of North America. Pp. 365–400 in *Fire and Ecosystems*, ed. T. T. Kozlowski and C. E. Ahlgren. New York: Academic Press.

Jackson, J. G. 1900. Pikes Peak, Plum Creek, and South Platte forest reserves. Pp. 39–116 in *Twentieth annual report of the U.S. Geological Survey, 1898–1899*, part 5: *Forest Reserves.* Washington, D.C.: U.S. Government Printing Office.

Kaib, J. M. 1998. Fire history in the riparian canyon pine-oak forests and the intervening desert grasslands of the Southwest borderlands: A dendroecological, historical, and cultural inquiry. Master's thesis, University of Arizona, Tucson.

Kaufmann, M. R., L. S. Huckaby, C. M. Regan, and J. Popp. 1998. *Forest reference conditions for ecosystem management in the Sacramento Mountains, New Mexico.* General technical report RMRS-19. Fort Collins, Colo.: USDA Forest Service.

Kay, C. E. 1994. Aboriginal overkill: The role of North Americans in structuring western ecosystems. *Human Nature* 5:359–398.

———. 1997. Is aspen doomed? *Journal of Forestry* 95:4–11.

Kaye, M., and T. W. Swetnam. 1999. An assessment of fire, climate, and Apache history in the Sacramento Mountains, New Mexico. *Physical Geography* 20:305–330.

Kohler, T. A., and M. A. Matthews. 1988. Long-term Anasazi land use and forest reduction: A case study from southwest Colorado. *American Antiquity* 53(3):537–564.

Kohler, T. A., J. D. Orcutt, K. L. Petersen, and E. Blinman. 1986. Anasazi spreadsheets: The cost of doing agricultural business in prehistoric Dolores. Pp. 525–538 in *Dolores archaeological program: Final synthetic report*, comp. D. A. Breternitz, C. K. Robinson, and G. T. Gross Denver: Bureau of Reclamation.

Krech, S., III. 1999. *The ecological Indian: Myth and history.* New York: W. W. Norton.

Krider, E. P., R. C. Noggle, A. E. Pifer, and D. L. Vance. 1980. Lightning direction-finding systems for forest fire detection. *Bulletin of the American Meteorological Society* 61:980–986.

Lang, R. W., and A. H. Harris. 1984. *The faunal remains from Arroyo Hondo Pueblo, New Mexico: A study in short-term subsistence change.* Santa Fe: School of American Research Press.

Leiberg, J. B., T. F. Rixon, and A. Dodwell. 1904. Forest conditions in the San Francisco Mountains Forest Reserve, Arizona. U.S. Geological Survey Professional Paper No. 22, Series H, Forestry, 7. Washington, D.C.: U.S. Government Printing Office.

Leopold, A. 1920. "Piute forestry" vs. forest fire protection. *Southwestern Magazine* 2(3):12–13.

———. 1924. Grass, brush, timber and fire in southern Arizona. *Journal of Forestry* 22:1–10.

———. 1937. Conservationist in Mexico. *American Forests* 43 (3):118–120, 146.

Levine, F., and T. Merlan. 1997. Bandelier National Monument: Ethnographic literature search and consultation. Unpublished report on file at Bandelier National Monument.

Lewis, H. T. 1973. *Patterns of Indian burning in California: Ecology and ethnohistory.* Anthropological papers no. 1. Ramona, Calif.: Ballena.

———. 1985. Why Indians burned: Specific versus general reasons. Pp. 75–80 in *Proceedings—Symposium and workshop on wilderness fire*, tech. coord. J. E. Lotan et al. General technical report INT-182. Ogden, Utah: USDA Forest Service.

Madany, M. H., and N. W. West. 1983. Livestock grazing–fire regime interactions within montane forests of Zion National Park. *Ecology* 64:661–667.

Martin, P. S., and R. G. Klein, eds. 1984. *Quaternary extinctions: A prehistoric revolution.* Tucson: University of Arizona Press.

Martin, P. S., and C. R. Szuter. 1999. War zones and game sinks in Lewis and Clark's West. *Conservation Biology* 13:36–45.

Meinig, D. W. 1971. Southwest: Three peoples in geographical change 1600–1970. New York: Oxford University Press.

Meko, D. M., C. W. Stockton, and W. R. Boggess. 1995. The tree-ring record of severe sustained drought. *Water Resource Bulletin* 31:789–801.

Merriam, C. H. 1890. *Results of a biological survey of the San Francisco Mountains region and desert of the Little Colorado in Arizona.* North America fauna no. 3. Washington, D.C.: USDA

Morino, K., C. H. Baisan, and T. W. Swetnam. 1998. Expanded fire regime studies in the Jemez Mts., New Mexico. Unpublished report on file at USGS Jemez Mts. Field Station.

Morino, K. A. 1996. Reconstruction and interpretation of historical patterns of fire occurrence in the Organ Mountains, New Mexico. Master's thesis, University of Arizona, Tucson.

National Academy of Sciences. 1897. *Report of the commission appointed by the National Academy of Sciences upon a forest policy for the forested lands of the United States.* 55th U.S. Cong., 2d sess., S. Doc. 57, pp. 28–73.

Orcutt, J. D. 1999. Demography, settlement, and agriculture. Pp. 219–308 in *The Bandelier archeological survey* (vols. 1 and 2), ed. R. P. Powers and J. D. Orcutt. USDI National Park Service, Intermountain Cultural Resources Management professional paper no. 57.

Orville, R. E., and A. C. Silver. 1997. Lightning ground flash density in the contiguous United States: 1992–1995. *Monthly Weather Review* 125:631–638.

Osborn, A. J. 1993. Snowblind in the desert Southwest: Moisture islands, ungulate ecology, and alternative prehistoric overwintering strategies. *Journal of Anthropological Research* 49(2):135–164.

Periman, R. D. 1996. The influence of prehistoric Anasazi cobble-mulch agricultural features on northern Rio Grande landscapes. Pp. 181–188 in *Desired future conditions for southwestern riparian ecosystems*, tech. coord. D. Shaw and D. Finch. General technical report RM-272. Fort Collins, Colo.: USDA Forest Service.

Petersen, K. L. 1988. *Climate and the Dolores River Anasazi.* University of Utah anthropological papers no. 113. Salt Lake City: University of Utah Press.

Plog, F., G. J. Gummerman, R. C. Euler, J. S. Dean, R. H. Hevly, and T. N. V. Karlstrom. 1988. Anasazi adaptive strategies: The model, predictions, and results. Pp. 230–277 in *The Anasazi in a changing environment*, ed. G. J. Gummerman. New York: Cambridge University Press.

Plummer, F. G. 1912a. *Forest fires: Their causes, extent and effects, with a summary of recorded destruction and loss.* USDA Forest Service bulletin 117. Washington, D.C.: U.S. Government Printing Office.

———. 1912b. *Lightning in relation to forest fires.* USDA Forest Service bulletin 111. Washington, D.C.: U.S. Government Printing Office.

Powell, J. W. 1890. The non-irrigable lands of the arid region. *Century Magazine* (April 1, 1890):915–922.
Powers, R. P., and J. D. Orcutt, eds. 1999. *The Bandelier archeological survey* (vols. 1 and 2). USDI National Park Service, Intermountain Cultural Resources Management professional paper no. 57.
Pyne, S. J. 1995a. *World fire: The culture of fire on earth.* Seattle: University of Washington Press.
———. 1995b. Vestal fires and virgin lands: A reburn. Pp. 15–21 in *Proceedings: Symposium on fire in wilderness and park management,* tech. coord. J. K. Brown et al. General technical report INT-320. Ogden, Utah: USDA Forest Service.
———. 1996. Nouvelle Southwest. Pp. 10–16 in *Conference on adaptive ecosystem restoration and management: Restoration of cordilleran conifer landscapes of North America,* tech. coord. W. Covington and P. K. Wagner. General technical report RM-278. Fort Collins, Colo.: USDA Forest Service.
———. 1997. *Fire in America: A cultural history of wildland and rural fire.* Seattle: University of Washington Press.
———. 2000. Where have all the fires gone? *Fire Management Today* 60:4–6.
Robbins, W. W., J. P. Harrington, and B. Freire-Marreco. 1916. *Ethnobotany of the Tewa Indians.* Washington, D.C.: Smithsonian Institution, Bureau of American Ethnology.
Rollins, M. G., T. W. Swetnam, and P. Morgan. 1999. Twentieth-century fire patterns in the Selway-Bitterroot Wilderness Area in Idaho/Montana and the Gila/Aldo Leopold Wilderness Areas in New Mexico. Unpublished final report to Aldo Leopold Wilderness Research Institute, Missoula, Mont.
Romme, W. H., D. Hanna, L. Floyd-Hanna, and E. J. Bartlett. 1996. Fire history and successional status in aspen forests of the San Juan National Forest: Final report. Unpublished report on file at USGS Jemez Mts. Field Station.
Romme, W. H., L. Floyd-Hanna, D. Hanna, and E. J. Bartlett. 1999a. Chapter 5: Aspen forests. Landscape condition analysis for the south central highlands section, southwestern Colorado and northwestern New Mexico. Unpublished final report on file at USGS Jemez Mts. Field Station.
Romme, W. H., L. Floyd-Hanna, D. Hanna, J. S. Redders, K. McGarigal, and M. Crist. 1999b. Chapter 6: Spruce-fir forests. Landscape condition analysis for the south central highlands section, southwestern Colorado and northwestern New Mexico. Unpublished final report on file at USGS Jemez Mts. Field Station.
Samuels, M. L., and J. L. Betancourt. 1982. Modeling the long-term effects of fuelwood harvests on pinyon-juniper woodlands. *Environmental Management* 6:505–515.
Sauer, C. O. 1975. Man's dominance by use of fire. *Geoscience and Man* 10:1–13.
Savage, M. 1991. Structural dynamics of a southwestern pine forest under chronic human disturbance. *Annals of the Association of American Geographers* 81:271–289.
Savage, M., and T. W. Swetnam. 1990. Early and persistent fire decline in a Navajo ponderosa pine forest. *Ecology* 70(6):2374–2378.
Schroeder, A. H. 1992. Protohistoric Pueblo demographic changes. Pp. 29–35 in *Current research on the late prehistory and early history of New Mexico,* ed. B. J. Viera New Mexico Archaeological Council special publication 1. Albuquerque, N. Mex.

Scurlock, D. 1998. *From the rio to the sierra: An environmental history of the middle Rio Grande Basin.* General technical report RMRS-5. Fort Collins, Colo.: USDA Forest Service.
Seckdecki, M. T., H. D. Grissino-Mayer, and T. W. Swetnam. 1996. Fire history and the possible role of Apache-set fires in the Chiricahua Mountains of southeastern Arizona. Pp. 238–246 in *Effects of fire on Madrean Province ecosystems,* tech. coord. P. F. Ffolliott et al. General technical report RM-289. Fort Collins, Colo.: USDA Forest Service.
Snyderman, D., and C. D. Allen. 1997. Fire in the mountains: Analysis of historical fires for Bandelier National Monument, Santa Fe National Forest, and surrounding areas, 1909–1996. Unpublished report on file at USGS Jemez Mts. Field Station.
Spoerl, P. M., and J. C. Ravesloot. 1995. From Casas Grandes to Casa Grande: Prehistoric human impacts in the sky islands of southern Arizona and northwestern Mexico. Pp. 492–501 in *Biodiversity and management of the Madrean Archipelago: The sky islands of southwestern United States and northwestern Mexico,* tech. coord. L. F. DeBano et al. General technical report RM-264. Fort Collins, Colo.: USDA Forest Service.
Stevenson, J. J. 1881. Report upon geological examinations in southern Colorado and northern New Mexico, during years 1878 and 1879. U.S. Geographic Survey west of 100th Meridian Vol. 3 (supp.).
Stewart, O. C. 1951. Burning and natural vegetation in the United States. *Geographical Review* 41:317–320.
———. 1955. Forest and grass burning in the Mountain West. *Southwestern Lore* 21:5–9.
———. 1956. Fire as the first great force employed by man. Pp. 115–133 in *Man's role in changing the face of the earth,* ed. W. L. Thomas, Jr. Chicago: University of Chicago Press.
———. 1963. Barriers to understanding the influence of use of fire by aborigines on vegetation. *Proceedings of the Tall Timbers Fire Ecology Conference* 72:117–126.
Sudworth, G. B. 1900. Battlement Mesa Forest Reserve. Pp. 181–244 in *Twentieth Annual Report of the U.S. Geological Survey, 1898-1899,* part 5: *Forest Reserves.* Washington D.C.: U.S. Government Printing Office.
Sullivan, A. P., III. 1992. Pinyon nuts and other wild resources in Western Anasazi subsistence economies. *Research in Economic Anthropology* (supp.) 6:195–239.
Swetnam, T. W. 1990. Fire history and climate in the southwestern United States. Pp. 6–17 in *Effects of fire management of southwestern natural resources,* tech. coord. J. S. Krammes. General technical report RM-191. Fort Collins, Colo.: USDA Forest Service.
Swetnam, T. W., C. D. Allen, and J. L. Betancourt. 1999. Applied historical ecology: Using the past to manage for the future. *Ecological Applications* 9:1189–1206.

Swetnam, T. W., and C. H. Baisan. 1996a. Historical fire regime patterns in the southwestern United States since A.D. 1700. Pp. 11–32 in *Fire effects in southwestern forests: Proceedings of the second La Mesa fire symposium*, tech. ed. C. D. Allen. General technical report RM-286. Fort Collins, Colo.: USDA Forest Service.

———. 1996b. Histories of montane forests in the Madrean Borderlands. Pp. 15–36 in *Effects of fire on Madrean Province ecosystems*, tech. coord. P. F. Ffolliott et al., General technical report RM-289. Fort Collins, Colo.: USDA Forest Service.

Swetnam, T. W., C. H. Baisan, and J. M. Kaib. 2001. Forest fire histories of the sky islands of La Frontera. Pp. 95–119 chapter in *Changing Plant Life of La Frontera*, ed. G. Webster and C. J. Bahre. Albuquerque: University of New Mexico Press.

Swetnam, T. W., and J. L. Betancourt. 1990. Fire–southern oscillation relations in the southwestern United States. *Science* 249:1017–1020.

———. 1998. Mesoscale disturbance and ecological response to decadal climatic variability in the American Southwest *Journal of Climate* 11:3128–3147.

Touchan, R., C. D. Allen, and T. W. Swetnam. 1996. Fire history and climatic patterns in ponderosa pine and mixed-conifer forests of the Jemez Mountains, northern New Mexico. Pp. 33–46 in *Fire effects in southwestern forests: Proceedings of the second La Mesa fire symposium*, tech. ed. C. D. Allen. General technical report RM-286. Fort Collins, Colo.: USDA Forest Service.

Touchan, R., and T. W. Swetnam. 1992. Fire history of the Jemez Mountains: Fire scar chronologies from five locations. Unpublished report on file at Bandelier National Monument, N. Mex.

———. 1995. Fire history in ponderosa pine and mixed-conifer forests of the Jemez Mountains, Northern New Mexico. Unpublished report on file at Bandelier National Monument, N. Mex.

Touchan, R., T. W. Swetnam, and H. D. Grissino-Mayer. 1995. Effects of livestock grazing on pre-settlement fire regimes in New Mexico. Pp. 268–272 in *Proceedings: Symposium on fire in wilderness and park management*, tech. coord. J. K. Brown et al. General technical report INT-320. Ogden, Utah: USDA Forest Service.

Towner, R. H. 1997. The dendrochronology of the Navajo Pueblitos of Dinétah. Ph.D. diss., University of Arizona Press, Tucson.

Trierweiler, W. N. 1990. Prehistoric Tewa economy: Modeling subsistence production on the Pajarito Plateau. Pp. 1–296 in *The evolution of North American Indians*, ed. D. H. Thomas. New York: Garland.

U.S. Department of Energy. 1979. *Final environmental impact statement: Los Alamos scientific laboratory site, Los Alamos, New Mexico.* DOI/EIS-0018. Springfield, Va.: National Technical Information Service.

U.S. Department of the Interior/U.S. Department of Agriculture. 1995. *Federal wildland fire management—Policy and program review.* Boise, Idaho: National Interagency Fire Center.

Van Devender, T. R., and W. G. Spaulding. 1979. Development of vegetation and climate in the southwestern United States. *Science* 204:701–710.

Veblen, T. T., and D. C. Lorenz. 1991. *The Colorado front range: A century of ecological change.* Salt Lake City: University of Utah Press.

Weaver, H. 1951. Fire as an ecological factor in southwestern ponderosa pine forests. *Journal of Forestry* 49(2):93–98.

Weng, C., and S. T. Jackson. 1999. Late Glacial and Holocene vegetation history and paleoclimate of the Kaibab Plateau, Arizona. *Palaeogeography, Palaeoclimatology, Palaeoecology* 153:179–201.

Williams, G. W. 1997. American Indian use of fire in ecosystems: Thousands of years of managing landscapes. Unpublished paper presented at the annual meeting of the Ecological Society of America in Albuquerque, N. Mex., August 1997.

———. 2000. Introduction to aboriginal fire use in North America. *Fire Management Today* 60:8–12..

Wolf, J. J., and J. N. Mast. 1998. Fire history of mixed-conifer forests on the North Rim, Grand Canyon National Park, Arizona. *Physical Geography* 19:1–14.

Wooton, E. O. 1908. *The range problem in New Mexico.* Agriculture Experiment Station Bulletin No. 66. Las Cruces: New Mexico College of Agriculture and Mechanic Arts.

Wyckoff, D. G. 1977. Secondary forest succession following abandonment of Mesa Verde. *Kiva* 42(3-4):215–231.

FIRE, NATIVE PEOPLES, *and* THE NATURAL LANDSCAPE

Edited by

Thomas R. Vale

2002

ISLAND PRESS
Washington • Covelo • London