8. Paleoecological Evidence for Systematic Indigenous Burning in the Upland Southwest

Christopher I. Roos, Alan P. Sullivan III, and Calla McNamee

Abstract: In the fire-prone coniferous ecosystems of the American Southwest where archaeological sites are abundant and the ecological legacies of ancient societies are incompletely understood, the “anthropogenic fire” hypothesis has been underappreciated. We use a multiproxy, stratigraphic approach to reconstruct variation in fire regimes over the periods of peak prehistoric population in two areas of the upland Southwest. Comparisons of these stratigraphic records to a tree-ring-based climate reconstruction indicate that the prehistoric residents of the Grand Canyon (A.D. 850–1150/1200) and late prehistoric (A.D. 1200–1400) and protohistoric (A.D. 1600–1870) residents of the Mogollon Rim region used fire in different ways as part of food production strategies. These analyses indicate that aboriginal landscape management practices, which included systematic low-intensity burning, generated upland ecosystems markedly different from those encountered today.

As the contributions to this volume illustrate, the investigation of human impacts on past environments has gathered momentum within archaeology. Increasing attention to human-modified environments has led some investigators to conclude that anthropogenic environments are ubiquitous, even in the precontact Americas (e.g., Denevan 1992; Mann 2005). However, the ubiquity of culturally modified ecosystems is not universally accepted. Particularly with respect to North America, scientists outside of anthropology and human
geography are less willing to accept arguments that precontact environments were affected by human land use in any significant way (e.g., Vale 2002). These scientists emphasize empirical studies of past environments often with the explicit purpose of using paleoenvironmental data to identify the local consequences of climate changes. Human-induced environmental changes, if present, are often considered by them to be “noise” because climate is assumed to be the primary driver of “natural” environmental change over the long term (cf. Burroughs 2005).

If archaeologists are genuinely interested in contributing to the dialog on human- and climate-related environmental changes (e.g., Redman et al. 2004), then we must engage “natural” scientists on their terms. This strategy means that the ubiquity of anthropogenic environments must not be dogmatically assumed. To persuade natural scientists that anthropogenic environments are a significant part of North American ecological histories, therefore, we must assemble relevant evidence that can be used to evaluate the null hypothesis that climate was the sole driver of environmental change. This challenge is daunting because identifying anthropogenic environmental signals may not be possible by employing traditional archaeological or paleoecological approaches (Dean 2004).

The foregoing argument is particularly salient for anthropologists interested in the cultural manipulation of environments through the use of fire (Stewart 2002). Ethnographers and ethnohistorians have documented nearly ubiquitous landscape burning by American Indians (e.g., Pyne 2000). Aboriginal uses of fire in ecosystem management are plentiful and include descriptions of its role in hunting, agriculture, wild-plant productivity, pest control, and warfare (Williams 2002). Many fire historians, however, particularly those who are familiar with fire-prone areas in the American Southwest (Allen 2002), do not readily accept the suggestion that American landscapes were widely shaped by Indian burning (contributions in Vale, ed. 2002).

Yet, from an anthropological perspective, hypotheses concerning the use of landscape burning to manage wild-plant predictability and productivity (Sullivan 1996) have implications for understanding variation in prehistoric livelihoods that became widespread after the introduction of maize approximately 3,500 years ago (Bonnicksen 2000:113–119). From a stewardship perspective, understanding the presence or absence of systematic indigenous burning, its ecological consequences, and resilience to climatic or land use changes have implications for deciding how ecosystem management and restoration should be structured today and in the future (Bonnicksen et al. 1999; Morgan et al. 2003). Nonetheless, the identification of human-influenced fire regimes will not be convincing unless other causal factors that affect variability in fire histories and their ecological consequences are considered (Periman et al. 1999). For these reasons, we investigate the relationships among climate, fire, and land use histories for two study areas in the upland Southwest (Figure 8-1) within a null model framework (Connor and Simberloff 1986). This approach allows us to evaluate the hypothesis that fire-regime variation was attributable exclusively to climatic change.
According to most scholars, prior to extensive grazing and active fire suppression, ponderosa pine (*Pinus ponderosa*) forests experienced low-intensity fires every 3–10 years that maintained an open-canopied, parklike forest (e.g., Fulé et al. 1997). The occurrence and extent of fires in a given year was dependent upon the properties and distribution of fuels. Although ponderosa pine forests “manage” their own fuel bed by rapidly dehiscing needles (DeBano et al. 1998:2–3), fires during the historic period (A.D. 1700–1900) were facilitated by the production of fine, herbaceous understory fuels during multiple wet years that were cured during subsequent dry years (Crimmins and Comrie 2004; Swetnam and Baisan 1996, 2003). Ponderosa pine trees have a number of fire-adapted traits, including thick bark, self-pruning branches, and high crown-scorch tolerance, that imply ponderosa pine forests evolved in the context of high-frequency surface fires (Covington 2003).

The historical role of fire in the development of woodlands dominated by pinyon (*Pinus edulis* or *Pinus cembroides*) and juniper (*Juniperus utahensis* or *Juniperus monosperma*) is a controversial topic (Baker and Shinneman 2004). It has been alternately suggested that pinyon pine, in particular, is very sensitive to fire or very...
difficult to kill with fire (cf. Floyd et al. 2003:264; Pieper and Wittie 1990; Wittie and McDaniel 1990:176). Reconstructions of historic-period fire regimes in pinyon-juniper forests have been difficult because the major species rarely record fire scars. Stand-age studies in the northern Southwest have suggested that fires in pinyon-juniper were probably high-severity crown fires but were exceedingly rare over the past few hundred years (Floyd et al. 2004; Floyd et al. 2003; Floyd et al. 2008). In the few studies that have reported fire-scar records for pinyon, surface fire return intervals have ranged from 5 to 74 years in the Texas borderlands (Poulos 2007:107) and 10 to 49 years in southern New Mexico (Brown et al. 2001:121). The emerging picture of pinyon-juniper fire ecology is one of variability, in part dependent upon the density, composition, and structure of understory and canopy species (Romme et al. 2008). Beyond the past 500 years, however, the fire ecology and fire history of pinyon-juniper woodlands, shrublands, and savannahs are not well known.

In the Madrean province of southern Arizona, southern New Mexico, and northern Mexico, pinyon-juniper woodland on the United States side of the international border is more dense with a discontinuous, shrubby understory in comparison to pinyon-juniper woodland on the Mexican side of the border, which has been subject to less intensive fire suppression (Kruse et al. 1996:102). This pattern suggests that prior to extensive grazing and fire suppression, some pinyon-juniper woodlands may have been more open with a diverse, herbaceous understory (Barney and Frischknecht 1974:91). From a fire-regime perspective, such an understory composition would have been significant because fires in grassy fuels are often faster moving and lower in intensity than shrub fires (DeBano et al. 1998:59–61). Consequently, fires in an open canopy and grassy understory may be less likely to induce high mortality rates in mature pinyon or juniper trees (Romme et al. 2008:7).

**Study Areas**

To evaluate the consequences of anthropogenic fire in Southwestern coniferous uplands, we chose two study locales whose rich archaeological heritages have been the subject of hypotheses concerning prehistoric burning—the Upper Basin of northern Arizona and the Forestdale Valley of east-central Arizona (Figure 8-1). These two study areas allow us to contrast fire regimes between pinyon-juniper woodlands (Upper Basin) and ponderosa pine forests (Forestdale Valley), as well as to evaluate the role of burning for wild-plant management (Upper Basin) and agricultural production (Forestdale Valley) during Ancestral Pueblo occupations.

**The Upper Basin**

The Upper Basin is a graben of the northeastern Coconino Plateau. Elevations in the Upper Basin range from 2,195 m at Desert View on the South Rim of the Grand Canyon to 1,829 m at the bottom of Lee Canyon. Surficial geology is almost exclusively Kaibab Formation limestone and sandstone (Hopkins and
Vegetation of the Upper Basin consists primarily of pinyon-juniper woodlands interspersed with pockets of sagebrush-grasslands (Brewer et al. 1991). Although the Upper Basin experiences at least 130 consecutive frost-free days and receives an average of 36–42 cm of precipitation annually (Hendricks 1985:127; Merkle 1952:376; Sullivan and Ruter 2006:185–187), a pronounced seasonal drought characterizes the late spring and early summer, as well as the early fall (Sullivan et al. 2002:53).

More than 20 km$^2$ of the Upper Basin, in the Kaibab National Forest, have been intensively surveyed (inter-surveyor distance = 10 m) by the Upper Basin Archaeological Research Project (UBARP). This survey has recorded the location and surface expression of 250 masonry ruins, 148 fire-cracked rock piles, and 790 artifact scatters, as well as other features (Sullivan et al. 2007). The vast majority of these remains date to the primary occupation of the Grand Canyon region, a.d. 850–1150/1200. On the basis of well-preserved paleobotanical assemblages recovered from catastrophically abandoned settlements (Sullivan 1987) and extra-mural plant-processing locations (Sullivan 1992), the prehistoric residents of the Upper Basin practiced a mixed gathering-gardening subsistence strategy that emphasized wild-plant resources (Sullivan 1986), which may have been propagated by controlled burning of understory vegetation (Sullivan 1996). By the early thirteenth century, Ancestral Pueblo people had ceased to occupy the Upper Basin on a perennial basis. Episodic use of the area thereafter by Hopi, Pai, and ultimately Navajo groups occurred sporadically during the protohistoric and historic periods (Cooper 1960:138; Morehead 1996; Schwartz 1990; Sullivan et al. 2001).

In 2000, UBARP placed backhoe trenches across Simkins Flat, which is an alluvial channel fan in Red Hawk Wash. Exposed sediments in the trenches were sampled for geoarchaeological and paleoecological analyses in 2000, 2001, and 2002 (McNamee 2003; Sullivan and Ruter 2006). Data from these original investigations, as well as the results of new geochemical analyses, are used in this study.

**The Forestdale Valley**

The Forestdale Valley is an upland alluvial valley excavated primarily into Cenozoic- and Permian-aged sedimentary rocks (Haury 1985 [1940]:142). Forestdale Creek drains south-southwest from headwaters along the Mogollon Rim, a fault scarp that defines the southern edge of the Colorado Plateau, to a Tertiary basalt flow that affects local base level and is inferred to be responsible for the unusually thick alluvial deposits in the valley (Haury 1985:13). Located just south of the modern town of Show Low, the Forestdale Valley is situated on the Fort Apache Indian Reservation near the center of the largest stand of ponderosa pine forest in the Southwest (Covington 2003). Elevations in the valley range from 1,791 m at the confluence with Corduroy Creek to 2,105 m along the Mogollon Rim. The valley experiences an average of 49 cm of annual precipitation split bimodally between summer rainfall and winter rain and snowfall. Because of cold air drainage, the valley experiences an average of 108 frost-free days (Kaldahl and Dean 1999:13).
The eastern Mogollon Rim region (defined here as the coniferous belt from Chevelon Creek on the west to the White Mountains on the east), which includes the Forestdale Valley, has been the subject of archaeological research for more than a century (Haury 1985; Hough 1903; Mills et al. 1999; Reid and Whittlesey 1999). Although humans may have occupied the region since the Terminal Pleistocene (ca. 13,000 cal b.p.), there is very little archaeological evidence for human use of the Forestdale area until the Pithouse Period (after A.D. 200). Pithouse Period archaeology (A.D. 200–1000) is characterized by dispersed, seasonally occupied small settlements (Gilman 1997; Haury 1985 [1940]; Haury and Sayles 1985 [1947]). Pithouse occupants practiced limited horticulture (Geib and Huckell 1994) but relied heavily on wild plant and animal resources, which probably resulted in an extensive rather than intensive environmental influence. Although there was a major population influx shortly after A.D. 1000 (Herr 2001; Newcomb 1999), occupations remained short-term (subdecadal to decadal) and land use continued to involve a mixed exploitation of wild and cultivated resources (Huckell 1999; Welch 1996).

By A.D. 1300, most of the area’s residents aggregated into a handful of large, perennially occupied villages (Kaldahl et al. 2004), resulting in a more intensive land use strategy that was heavily reliant upon agriculture (Ezzo 1992; Welch 1996). By the end of the fifteenth century, the Western Pueblo people ceased to occupy the area on a perennial basis and moved their permanent residences elsewhere (Mills 1998). The use of fire may have been important in Pueblo agricultural strategies, such as in “burn-plot” style agriculture (Sullivan 1982) or, less likely, in swidden-style field clearance (Kohler and Mathews 1988).

Early Apache occupation of the area is poorly understood, but Spanish documents indicate the presence of horticultural Apaches in the Upper Gila area by A.D. 1626 (Buskirk 1986:109). This report may be supported archaeologically by a terminus ante quem date of A.D. 1661 from Wickiup 2 at the Grasshopper Spring site (Whittlesey et al. 1997:198). According to oral tradition, Western Apaches used fire as an important part of hunting (Buskirk 1986:127, 131, 135–136), gathering (Buskirk 1986:165–166; Gifford 1940), and horticultural subsistence practices (Buskirk 1986:43, 61, 77).

In 2005, the Mogollon Rim Historical Ecology Project (MRHEP) initiated geoarchaeological and paleoecological fieldwork along the eastern Mogollon Rim. In collaboration with the White Mountain Apache Tribal Heritage Program, three Terrace 3 aged sedimentary deposits (ca. A.D. 1150–1910 according to Antevs in Haury 1985 [1940]:143–144) from the Forestdale Valley, upstream from most archaeological sites, were sampled by MRHEP (Roos 2008). Data from two localities, Forestdale Valley 6 and 10, are used here.

**Discussion**

For both the Upper Basin and the Forestdale Valley study areas, chronological control is provided by radiocarbon dates on detrital charcoal extracted from alluvial sediments and soils (Table 8-1) derived from Bayesian calibration (Buck et al. 1991) with the Intcal04 data set (Reimer et al. 2004) in the BCal online...
calibration software (Buck et al. 1999; http://bcal.sheffield.ac.uk). The calibrated age ranges are reported in calendar years a.d. at the 95-percent confidence interval. For reference, the traditional 2σ calibrated ages (using CALIB 5.0 and the Intcal04 data set) are reported in Table 8-1 as well.

Trench 1 on Simkins Flat disclosed evidence of sediment accumulation between cal a.d. 779–973 and the present, punctuated by episodes of erosion and braided channel formation between radiocarbon ages of cal a.d. 1045–1215 and cal a.d. 1416–1503. Archaeological and radiocarbon data indicate that sediments accumulated at Forestdale 6 and 10 between A.D. 1100 and A.D. 1910 (Haury 1985:145; Roos 2008:176–178). Although there is no evidence for erosion in either of these sequences, a brief episode of soil stability and channel entrenchment may have occurred in upper Forestdale Creek between A.D. 1400 and A.D. 1500 prior to resumed aggradation (Roos 2008:181).

**Long-Term Variation in Fire-Climate Conditions**

Many fire-history studies in the U.S. Southwest have evaluated fire-climate relations (e.g., Grissino-Mayer and Swetnam 2000; Kitzberger et al. 2001; Swetnam and Baisan 1996; Swetnam and Betancourt 1990, 1998). Most of these studies compare annually dated fire scars (Arno and Sneck 1977; Dieterich and Swetnam 1984) on living trees, snags, and stumps to interannual (Swetnam and Baisan 1996, 2003), decadal (Swetnam and Betancourt 1998), and centennial-scale (Grissino-Mayer and Swetnam 2000) climate-change data that are reconstructed from independent dendroclimatic models. Fire-scar–based fire histories in the U.S. Southwest are limited by an age-attenuation effect (Clark 1988:81; Whitlock and Bartlein 2004:479) to the past 300–400 years. Importantly, because fire-scar records are too short to rule out legacies of prehistoric human impacts to historic fire regimes, when these records have been used to evaluate human influences on fires and their frequencies, results often have been equivocal (e.g., Allen 2004:51–54; Grissino-Mayer et al. 2004).

The availability of annually resolved fire scars, the abundance of annually resolved local dendroclimate records from the Southwest Paleoclimate Project (Dean and Robinson 1977), and the statistical association of interannual moisture and fires (Crimmins and Comrie 2004; Swetnam and Baisan 1996, 2003), however, create an ideal situation for generating long-term reconstructions of fire-climate conditions that are independent of long-term fire-history reconstructions. For instance, Roos and Swetnam (2009) developed a multiple regression model of antecedent moisture conditions from dendroclimatic reconstructions based on 46 ponderosa pine fire-scar chronologies and two regional precipitation reconstructions (Grissino-Mayer 1996; Salzer and Kipfmüller 2005) across the southern margins of the Colorado Plateau. This model explains approximately 38 percent of the variation in landscape fire size ($r^2 = .381, p < .0001$) during the historic period (A.D. 1700–1899). In addition, it characterizes long-term variability in the frequency of regional fire-climate years by generating a 100-year moving average of a binary variable created from the presence or absence of peak fire-climate con-
<table>
<thead>
<tr>
<th>Sample #</th>
<th>Depth</th>
<th>Material</th>
<th>$^{14}$C</th>
<th>2σ Cala</th>
<th>95% CI Calb</th>
</tr>
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<tr>
<td>Simkins Flat</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RC-5</td>
<td>53</td>
<td>UID charcoal</td>
<td>610 ± 50</td>
<td>1286–1413 (1.00)</td>
<td>1465–1651</td>
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<tr>
<td>RC-1</td>
<td>83</td>
<td>Outer ring from burned <em>Pinus edulis</em> log</td>
<td>425 ± 40</td>
<td>1574–1626 (.15)</td>
<td>1465–1503</td>
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<tr>
<td>RC-4</td>
<td>100</td>
<td>UID charcoal</td>
<td>900 ± 38</td>
<td>1036–1213 (1.00)</td>
<td>1045–1215</td>
</tr>
<tr>
<td>RC-2</td>
<td>142</td>
<td>UID charcoal</td>
<td>1141 ± 36</td>
<td>804–984 (.96)</td>
<td>801–973</td>
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<td>Forestdale 6</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>6.2.24</td>
<td>47</td>
<td>UNWC</td>
<td>212 ± 54</td>
<td>1909–1953 (.15)</td>
<td>1632–1816</td>
</tr>
<tr>
<td>6.5</td>
<td>75</td>
<td>Twig</td>
<td>390 ± 33</td>
<td>1558–1631 (.31)</td>
<td>1555–1640</td>
</tr>
<tr>
<td>6.11</td>
<td>143</td>
<td>Conifer xylem</td>
<td>355 ± 38</td>
<td>1536–1635 (.54)</td>
<td>1453–1582</td>
</tr>
<tr>
<td>6.5.88</td>
<td>175</td>
<td><em>Pinus</em> needle</td>
<td>629 ± 95</td>
<td>1218–1447 (1.00)</td>
<td>1391–1504</td>
</tr>
<tr>
<td>6.6.119</td>
<td>237</td>
<td><em>Pinus</em> meristem</td>
<td>477 ± 69</td>
<td>1558–1631 (.12)</td>
<td>1378–1458</td>
</tr>
<tr>
<td>6.8.150</td>
<td>299</td>
<td><em>Pinus</em> meristem</td>
<td>777 ± 65</td>
<td>1361–1386 (.03)</td>
<td>1339–1395</td>
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</table>
Table 8-1.—Continued

<table>
<thead>
<tr>
<th>Sample #</th>
<th>Depth</th>
<th>Material</th>
<th>(^{14}C)</th>
<th>2σ Cala</th>
<th>95% CI Calb</th>
</tr>
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<tbody>
<tr>
<td>6.26</td>
<td>341</td>
<td>Conifer xylem</td>
<td>535 ± 57</td>
<td>1377–1449 (.57)</td>
<td>1286–1356</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1298–1372 (.43)</td>
<td></td>
</tr>
<tr>
<td>6.29</td>
<td>369</td>
<td>Conifer xylem</td>
<td>973 ± 59</td>
<td>972–1211 (1.00)</td>
<td>966–1176</td>
</tr>
<tr>
<td>Forestdale 10</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>10.1.17</td>
<td>33</td>
<td>Stem</td>
<td>371 ± 34</td>
<td>1544–1634 (.44)</td>
<td>1551–1641</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>1446–1529 (.56)</td>
<td>1488–1525</td>
</tr>
<tr>
<td>10.7</td>
<td>118</td>
<td>Pinus needle</td>
<td>615 ± 34</td>
<td>1292–1403 (1.00)</td>
<td>1361–1423</td>
</tr>
<tr>
<td>10.4.63</td>
<td>125</td>
<td>UNWC</td>
<td>518 ± 64</td>
<td>1292–1483 (1.00)</td>
<td>1326–1441</td>
</tr>
<tr>
<td>10.10</td>
<td>159</td>
<td>Twig</td>
<td>439 ± 34</td>
<td>1601–1615 (.03)</td>
<td>1418–1486</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1414–1500 (.96)</td>
<td></td>
</tr>
<tr>
<td>10.5.92</td>
<td>183</td>
<td>UNWC</td>
<td>619 ± 38</td>
<td>1289–1404 (1.00)</td>
<td>1292–1366</td>
</tr>
<tr>
<td>10.16</td>
<td>247</td>
<td>UNWC</td>
<td>672 ± 35</td>
<td>1347–1392 (.44)</td>
<td>1266–1311</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1271–1323 (.56)</td>
<td></td>
</tr>
<tr>
<td>10.7.138</td>
<td>275</td>
<td>Pinus needle</td>
<td>1120 ± 120</td>
<td>1064–1155 (.09)</td>
<td>1056–1257</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>668–1059 (.91)</td>
<td></td>
</tr>
<tr>
<td>10.8.152</td>
<td>303</td>
<td>Pinus needle</td>
<td>800 ± 97</td>
<td>1024–1316 (.95)</td>
<td>965–1144</td>
</tr>
</tbody>
</table>

Note: All dates were measured using AMS with the exception of RC-1 and RC-5, which were measured radiometrically. All calibrated ages are a.d. unless otherwise noted. UID charcoal = unidentified charcoal; UNWC = unidentified non-wood charcoal.

Source: Simkins Flat data adapted from McNamee 2003; Forestdale Valley 6 and 10 data adapted from Roos 2008.

\(^{a}\)Calibrated in CALIB 5.01 using Intcal 2004. Numbers in parentheses indicate the relative area under the curve (in %) for the respective calibrated age range.

\(^{b}\)Bayesian calibration function:


ditions (≥.5 standard deviations above the long-term mean). Figure 8-2 plots both annual model values and long-term frequencies of fire-conducive climate conditions in Z-scores (standard deviation units about the long-term mean). Predicted frequencies of fire-conducive moisture patterns were below average (less than 31 events per century) in the two periods a.d. 650–750 and a.d. 1300–1650, which, under exclusively “natural” fire regimes, would have resulted in less frequent fires, the accumulation of fuels, and the succession of understory plant communities to more shrub-dominated arrangements. In contrast, fire-climate frequencies were above average (more than 31 events per century) in the periods a.d. 750–850, a.d. 1100–1300, and after a.d. 1650. Although this model was generated from ponderosa pine fire-scar chronologies, the patterns of interannual moisture are probably relevant for surface fuels in all woodland environments, including pinyon-juniper (Crimmins and Comrie 2004).

Reconstructed Fire Regimes

As noted above, some coniferous environments in the uplands of the U.S. Southwest were characterized by high fire frequencies prior to modern fire suppression and grazing. Tracking changes in fire frequency alone, therefore, may not be a very useful measure of the extent of anthropogenic burning. The concept of the fire regime, which includes consideration of the frequency, intensity, seasonality, average size, type of fuels, and overall ecological impact of landscape burning, provides a better framework for investigating anthropogenic fire history. Therefore, we use multiple lines of evidence to reconstruct fire regimes, including sedimentary charcoal, grain size, soil phosphorus, stable-carbon isotope, and stratigraphic palynological data from alluvial channel fan sequences within the two study areas (cf. Adams 2004). These data will allow us to infer fire size and frequency (charcoal and soil phosphorus [P]), seasonality (grain size and carbon isotopes), fuel type (charcoal), and ecological impact (pollen and carbon isotopes) of past fires (Table 8-2).

Although sedimentary charcoal analysis is most often conducted on samples from more or less constantly aggrading and uneroded sedimentary sequences, such as lakes and wetlands (Whitlock and Anderson 2003), these types of depositional contexts are rare in the U.S. Southwest. In contrast, alluvial sedimentary contexts are abundant and often of direct relevance to locations of prehistoric and protohistoric occupation (Dean et al. 1985; Karlstrom 1988). Two properties of alluvial channel fans from small discontinuous ephemeral streams in small watersheds (<40 km²) make them well suited for investigating anthropogenic fire: (1) relatively rapid and steady aggradation punctuated by brief episodes of entrenchment (Bull 1997; Huckleberry and Billman 1998) and (2) local, slope-derived sources of sediment (Balling and Wells 1990; Hereford 2002). Moreover, experimental studies have documented the reliability of macroscopic sedimentary charcoal (>125 μm) for identifying local, watershed-scale fires (Blackford 2000; Clark et al. 1998; Clark and Royall 1995; Lynch et al. 2004; Whitlock and Millsbaugh 1996; Whitlock et al. 2004). Although variation in “background” charcoal
(unrelated to fire frequencies) has been interpreted in terms of changes in the type of biomass burned (Marlon et al. 2006), most studies interpret variation in charcoal in terms of the amount of biomass consumed (fire size). This may be an appropriate protocol for fire regimes characterized by woody understory vegetation or closed canopies and fire-return intervals measured in decades or centuries. However, in high-frequency surface fire regimes, such as those that characterize ponderosa pine forests and have been hypothesized for some pinyon-juniper woodlands (Romme et al. 2008; Sullivan 1996), changes in the type of biomass combusted may have an equally significant effect on sedimentary charcoal abundance (e.g., Marlon et al. 2006). Herbaceous plants produce fewer particulate by-products than woody plants, in part due to increased efficiency of combustion (DeBano et al. 1998:27). Consequently, a fire regime in which surface fires occur frequently enough to maintain herbaceous dominated understory plants (<5-10 years per plot) and burn predominantly within this vegetation would produce far less charcoal than a fire regime burning over similar-sized areas but within shrubby vegetation.

Wildland fire accelerates the mineralization of organically bound phosphorus (P) and often results in net increases in soil phosphorus after low- or moderate-
# Table 8-2. Geoarchaeological Proxies and Number of Samples Used to Reconstruct Fire Regimes

<table>
<thead>
<tr>
<th>Proxy</th>
<th>Sample N (Sinkins Flat/ FDV 6/FDV 10)</th>
<th>Expectations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sedimentary charcoal</td>
<td>66/179/161</td>
<td>Increased abundance = More frequent burning of woody fuels OR larger fire sizes in woody fuels</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Decreased abundance = Less frequent burning of woody fuels OR increase in patch-specific fire-return intervals (grassy fuels)</td>
</tr>
<tr>
<td>Soil P</td>
<td>8/25/15</td>
<td>Increasing concentrations = Increasing fire frequency</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Decreasing concentrations = Decreasing fire frequency</td>
</tr>
<tr>
<td>δ^{13}C</td>
<td>8/25/15</td>
<td>Less negative values = Increasing abundance of C\textsubscript{4} plants (frequent patch-specific burning)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>More negative values = Decreasing abundance of C\textsubscript{4} plants (less-frequent patch-specific burning)</td>
</tr>
<tr>
<td>Palynology</td>
<td>11/15/10</td>
<td>Higher representation of herbaceous taxa = More frequent patch-specific burning</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Higher representation of woody taxa = Less frequent patch-specific burning</td>
</tr>
</tbody>
</table>

*Note: FDV = Forestdale Valley.*

intensity fires (Covington and DeBano 1990; Covington and Sackett 1990; DeBano et al. 1998:120). Phosphorus that is mineralized from organic forms during combustion simultaneously becomes available to plants as well as erosion. If a portion of these phosphate minerals is deposited in alluvial contexts or if fuels on alluvial channel fans burn at the same time as surrounding hillslopes, stratigraphic soil phosphorus from alluvial deposits should provide an independent measure of biomass burning (and organic phosphorus conversions to mineral phosphorus).

Stable carbon isotope ratios have been used to track changes in the contributions of C\textsubscript{3} and C\textsubscript{4} plants to soil organic carbon pools (Biedenbender et al. 2004; Nordt 2001) and, therefore, can be used to assess the role of anthropogenic fire in maintaining disturbance taxa (e.g., Bowman et al. 2004). C\textsubscript{4} plants, with few exceptions, are “warm-season” herbaceous plants (grasses, weeds, forbs) that fractionate less against the $^{13}$C isotope and produce stable carbon isotope ratios ($\delta^{13}$C) in the range of about –12‰. Many important economic plants to ancient Southwestern-
ers, such as chenopodium, amaranth, and maize, are C₄ plants (Wills 1995:229). C₃ plants, which include some herbaceous plants but also virtually all woody shrubs and trees, fractionate more against \(^{13}C\) and produce \(\delta^{13}C\) values around \(-25\%\). Stable carbon isotope ratios of soil organic matter are representative of the plants that have grown and decayed there and, as a result, produce a mixed value that depends upon the proportion of C₃ and C₄ plants contributing to decayed organic matter. With high-frequency burning, which promotes the growth of herbaceous vegetation, \(\delta^{13}C\) values of upland soils should be expected to increase (become less negative). Less-negative \(\delta^{13}C\) values are indicative of increasing proportions of C₄ plants on the landscape (either on the fan, surrounding slopes, or both). Seasonality of burning may complicate the relationship between fire frequencies and carbon isotope ratios. For example, autumn burning promotes the growth of perennial cool-season grasses, which are C₃ plants.

In contrast to carbon isotopes of soil organic carbon, which can lag vegetation changes, pollen assemblages respond immediately to changes in plant composition and are sensitive to more than two taxa (e.g., C₃ vs. C₄). Variation in sequences of pollen taxa assemblages provides a more direct measurement of vegetation change related to climate, disturbance, or land use (e.g., Wyckoff 1977). Pollen taxa were aggregated into three categories for discussion here: trees, shrubs, and herbs. Although varying proportions of these taxa do not directly relate to their abundance on the surrounding landscape, the relative abundance of these three pollen taxa is relevant to the investigation of fire history. Herbaceous plants, including grasses, weeds, and forbs, dominate the understory of forests and woodlands that burn with a high frequency. Additionally, these plants include many wild plants of economic importance to prehistoric and protohistoric residents of the Mogollon Rim and Grand Canyon areas (Buskirk 1986; Sullivan 1987, 1992; Sullivan and Ruter 2006).

### Upland Fire-Regime Variability

The data from Simkins Flat (Figure 8-3) produce an integrated picture of local fire-regime variation for the Red Hawk Wash watershed. Prior to A.D. 1100, high soil phosphorus concentrations, low charcoal concentrations, and elevated representation of herbaceous pollen taxa indicate very high-frequency fires that burned almost exclusively within herbaceous vegetation (low charcoal concentrations), and which may have actively promoted herbaceous plant production on the channel fan itself. Despite the low representation of arboreal taxa in pollen assemblages, pinyon and juniper trees must have been relatively abundant away from the fan. In fact, contemporaneous archaeological sites above the fan yield abundant arboreal pollen (see Table 8-3), which suggests that the reduced arboreal pollen representation in the Simkins Flat sequence is due to localized abundance of herbaceous plants. The large charcoal peak (burning in woody fuels) that immediately precedes an erosion event may coincide with archaeological evidence for catastrophic burning of at least one settlement after A.D. 1064 (Sullivan 1987) and exceptional fire-climate conditions in A.D. 1067 (see
Figure 8-3. Stratigraphic data for Trench 1 on Simkins Flat in the Upper Basin. Approximate occupation periods are marked on the right (see also McNamie 2003; Sullivan and Ruter 2006:200). Vertical dashed lines indicate overall mean values for grain size, charcoal, soil P, and $\delta^{13}$C.

Table 8-3. Arboreal Pollen Percentages for Archaeological Sites and Alluvial Sediments from the Upper Basin

<table>
<thead>
<tr>
<th>Site</th>
<th>Type of Features</th>
<th>Dates A.D.</th>
<th>Range of Arboreal Pollen Relative Abundances (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MU 125</td>
<td>Multiroom masonry structure</td>
<td>1070–1080</td>
<td>30–75</td>
</tr>
<tr>
<td>MU 235</td>
<td>Fire-cracked-rock pile</td>
<td>417–559</td>
<td>55–80</td>
</tr>
<tr>
<td>MU 125A</td>
<td>Stone alignments and terraces</td>
<td>ca. 1050–1150</td>
<td>25–80</td>
</tr>
<tr>
<td>ASM 17</td>
<td>Multiroom masonry and wood structures</td>
<td>1049/1054–1064</td>
<td>46–75</td>
</tr>
<tr>
<td>Simkins Flat</td>
<td>Alluvial sediments</td>
<td>ca. 800–1200</td>
<td>15–36</td>
</tr>
<tr>
<td>Simkins Flat</td>
<td>Alluvial sediments</td>
<td>ca. 1200–1900</td>
<td>50–75</td>
</tr>
</tbody>
</table>

Note: Arboreal pollen abundances between 50 and 80 percent are common for “natural” conifer woodland settings whereas abundances below 50 percent occur in the context of local herbaceous plant production but do not imply canopy reduction. Contemporaneous samples from less than 2 km away from Simkins Flat indicate “natural” woodland conditions, even in proximity to archaeological sites.
Figure 8-2). This evidence suggests the possibility that uncontrolled landscape fires burned through portions of the pinyon-juniper canopy, catastrophically destroyed at least one settlement, and destabilized the Red Hawk Wash watershed, which resulted in entrenchment of the channel.

This interpretation is not unequivocal, however. For example, the expansion of wild-seed production areas into shrubby patches may have contributed more charcoal as higher population levels required increased food production after A.D. 1000. Yet another land use–based alternative is that “slash” (e.g., branches, bark) that accumulated from the processing of trees for architectural construction may have added to the mix of fuels combusted in landscape fires, thereby producing an increase in woody-fuel burning and charcoal deposition. Neither of these alternatives is incompatible with the crown-fire explanation and this highlights the potential vulnerability of these anthropogenic environments to devastating fires when climate and fuel conditions became optimal (Baker and Shinneman 2004; Floyd et al. 2004).

Once alluvial deposition resumed on Simkins Flat prior to A.D. 1400, charcoal abundance increased, which indicates that fires may have remained somewhat frequent but became spatially discontinuous, creating a mosaic of trees, shrubs, and herbs attributable to longer fire-return intervals for the individual patches. In other words, the watershed’s fire regime was responding more to “natural” rather than anthropogenic factors. Increasing frequencies of fire-conducive climate conditions may have driven short-lived increases in herbaceous pollen and soil phosphorus, thereby contributing to several prominent charcoal peaks prior to the second episode of erosion that occurred after A.D. 1650. The near-surface samples (above 20 cm depth) indicate a radically different environment of reduced C$_4$ plant inputs to soil organic matter (SOM), decreased herbaceous pollen and charcoal, and an increase in soil phosphorus. The elevated soil phosphorus is unlikely to be ash derived in light of the other proxy data. Rather, it may be attributable to artificial phosphorus enrichment from cattle grazing on the fan (Macphail et al. 2004).

For the Forestdale Valley (Figures 8-4 and 8-5), the data indicate at least three different fire regimes between A.D. 1100 and A.D. 1910. Prior to A.D. 1400, large amounts of woody biomass were frequently burned (abundant charcoal, moderate to high soil phosphorus), probably during the spring or early summer, which increased sediment yields and produced fining-upward depositional units. Between A.D. 1400 and A.D. 1600, fire frequency (decrease in soil phosphorus) and fire size (decrease in charcoal peak size) appear to have diminished in comparison to the period prior to A.D. 1400. Neither fire regime seems to have resulted in the expansion of herbaceous plants (pollen assemblages). After A.D. 1600, charcoal abundance and variability declined in the context of uniformly sandy sediment, increasing herbaceous pollen influx, higher soil phosphorus concentrations, and slightly greater input of C$_4$ plants to SOM. These trends indicate a significant shift to very high–frequency fires for a given patch, with the possibility of a change in seasonality as well. One mechanism that could explain the change in sedimentation to uniformly sandy alluvium would be an increase in rainfall intercept by groundcover (vegetation) during the monsoon, which would have reduced over-
Figure 8-4. Stratigraphic data for locality 6 in the Forestdale Valley. Approximate occupation periods are marked on the right (adapted from Roos 2008). Vertical dashed lines indicate overall mean values for grain size, charcoal, soil P, and $\delta^{13}$C.

Figure 8-5. Stratigraphic data for locality 10 in the Forestdale Valley. Approximate occupation periods are marked on the right (adapted from Roos 2008). Vertical dashed lines indicate overall mean values for grain size, charcoal, soil P, and $\delta^{13}$C.
all sediment load. An increase in dormant-season burning of understory plants, a pattern consistent with fire-scar studies of Apache burning (e.g., Seklecki et al. 1996), would have increased herbaceous groundcover the following spring, thereby resulting in increased intercept of rainfall by vegetation. The minor increase in C₄ plant contribution (stable carbon isotopes) relative to the increases in herbaceous pollen may indicate fall burning as well (Roos 2008).

Discussion

We may now evaluate the hypothesis presented above: was fire-regime variability attributable to climate exclusively? For pinyon-juniper woodlands near the Grand Canyon, the answer is an emphatic “no.” The period of greatest predicted fire frequency in the climate reconstruction is after A.D. 1650 (see Figure 8-2). In contrast, the period of greatest fire frequency in the Simkins Flat stratigraphic record was between A.D. 800 and A.D. 1100/1200, although the climate reconstruction predicts average fire frequencies during this period. Pollen-based climate interpretations for this period (A.D. 900–1300) would predict elevated Pinus pollen inputs because of hypothesized increase in the regularity of monsoon moisture (Davis and Shafer 1992; Peterson 1994). The Simkins Flat record documents an inverse pattern that we think is attributable to intensive human promotion of wild, herbaceous vegetation. The charcoal, phosphorus, and carbon isotope data all corroborate the pollen data and suggest that this enriched understory vegetation was encouraged by the systematic application of fire to understory fuels. Furthermore, regular inputs of sedimentary charcoal after A.D. 1100 seem to indicate that the woodlands around Simkins Flat experienced a return to “natural” fire regimes, which may have included patchy surface fires (cf. Baker and Shinneman 2004; Floyd et al. 2003). The pollen assemblage data imply that fires were not frequent or widespread enough to have a homogenizing effect on understory plants (e.g., conversion to grassy or herbaceous vegetation), but the charcoal evidence suggests that fires did occur regularly even after prehistoric occupation terminated.

For the ponderosa pine forests surrounding the Forestdale Valley, the climate hypothesis may be rejected as well. The three fire regimes inferred from the stratigraphic record are inconsistent with the predictions of the fire-climate reconstruction. However, anthropogenic burning likely complemented natural fire regimes. Pre-planting burning of understory vegetation during the late prehistoric occupation (prior to A.D. 1400) would have mimicked the timing and fuels of natural, pre-monsoon fires (Sullivan 1982). Increased agricultural burning would have accelerated charcoal deposition (an increase in biomass combusted and possibly an increase in fire frequency) without necessarily promoting a herbaceous understory because domesticated plants would have occupied the newly burned patch. We should also note that there is no evidence for canopy reduction, as is predicted by the swidden agricultural burning model (Kohler 2004; Kohler and Mathews 1988).

The dramatic shift in seasonality and ecological impact of fires before A.D. 1600 is not explicable in climatic terms either. However, the timing of this shift
coincides with conventional interpretations of Western Apache colonization of the area (Whittlesey et al. 1997:198). As mentioned above, the Western Apache are known to have used fire in agriculture, hunting, and wild-plant management (Buskirk 1986; Gifford 1940). The shift to high-frequency autumn burning before A.D. 1600 is particularly consistent with postharvest burning of wild seed patches (Buskirk 1986:165–166), which may also have served to improve the predictability of hunting locations the following spring (Stewart 2002:221). An increase in burning during the dormant season (autumn, winter, or early spring) has been observed in fire-scar records of Apache burning elsewhere in the Southwest (Kaye and Swetnam 1999; Seklecki et al. 1996).

These results are valuable for renewing interest in studies of subsistence in the prehistoric and protohistoric U.S. Southwest, which have tended to overemphasize the importance of maize agriculture and its antiquity (e.g., Damp et al. 2002). Many of these studies give the impression that maize cultivation was the primary driver of subsistence-related activities of Southwestern peoples (Matson 1991; Matson and Chisholm 1991). In the Grand Canyon, archaeobotanical and pollen evidence from well-preserved “Pompeii-like” assemblages and geoarchaeological evidence from Simkins Flat, which postdate the introduction of maize by millennia, do not support this assertion (Sullivan 1987; Sullivan and Ruter 2006). Additional studies of the diversity of Southwestern subsistence strategies will help us understand prehistoric decision making with respect to resource ranking (Barlow 2002), investigate opportunities and constraints in the “niche construction” of prehistoric farmers and gatherer-gardeners (Rocek 1995), and advance the study of human impacts on past environments.

These considerations are particularly important in the archaeological investigation of resilience and sustainability (Redman 2005; van der Leeuw and Redman 2002). In applied historical ecology studies today, recent (A.D. 1700–1900) fire-regime reconstructions have been used to argue for the reintroduction of fire, or the discontinuance of fire suppression, to Southwestern forests (e.g., Fulé et al. 1997). This chapter demonstrates that “natural,” lightning-driven ignitions and climate-driven fuel loads may not be sufficient to produce “healthy,” parklike forests in all climate conditions. In the Forestdale Valley, Apache burning during a period of frequent fire-conducive climate conditions (see Figure 8-2) propagated herbaceous ponderosa parkland and produced distinctive paleoecological signatures compared to contemporaneous unoccupied areas (Roos 2008), despite frequent natural and anthropogenic fires throughout the records.

In contrast, the prehistoric high-frequency anthropogenic burning of herbaceous vegetation in pinyon-juniper woodlands may have created an environment that was vulnerable to climatic change. Long-term drought that coincided with a multiyear warm period between A.D. 1066 and A.D. 1075 (Figure 8-6) combined with exceptional regional, antecedent moisture patterns to create a situation in which coarse fuels may have carried a catastrophic fire through the landscape, which destroyed settlements and destabilized the watershed. After abandonment, the ecosystem entered a new adaptive cycle (sensu Holling and Gunderson 2002), in which a mosaic of herbs, shrubs, and trees was maintained by an entirely different fire regime.
Conclusion

Previous attempts to consider the feasibility of widespread anthropogenic burning in the upland coniferous ecosystems of the pre-Hispanic Southwest produced unconvincing results because they did not incorporate the full range of factors that influence changes in fire regimes and their effects on fuels, geochemistry, and plant communities. By incorporating archaeological and geoarchaeological evidence, in contrast, we rejected the hypothesis of exclusively climate-driven, “natural” fire histories and sustained the idea that prehistoric gatherer-gardeners of the Grand Canyon region used fire to increase the productivity of herbaceous wild-plant communities in pinyon-juniper woodlands (Sullivan 1996). Similarly, evidence from the Forestdale Valley tends to support the burn-plot hypothesis for Mogollon agriculture (Sullivan 1982) and the burning of surface fuels by Western Apache people to increase the productivity of herbaceous wild-plant communities in ponderosa pine forests.

The long-term ecological consequences of these anthropogenic environments were somewhat variable. In each case, anthropogenic burning maintained consistent productive environments for generations. However, after more than two centuries of anthropogenic burning, extraordinary interannual moisture conditions, which coincided with a multiyear drought and multiyear warm period from A.D. 1066 to A.D. 1075, produced coarse-fuel loads that may have carried a settlement-destroying, watershed-altering canopy fire in the Upper Basin. Occupation of the Upper Basin continued for at least 100 years after this event, but the ecological consequences were apparently long lasting. Patch structure and vegetation composition never returned to previous conditions.
Along the Mogollon Rim, approximately 200 years of agricultural burning produced modest landscape impacts until abandonment, destabilization, and erosion of upland gardens and fields occurred in the late fourteenth century A.D. Western Apache burning beginning in the sixteenth century A.D., in contrast, transformed the upland environments but did not increase their sensitivity to long-term droughts or unusual fire-climate conditions. Unlike the ecological consequences of low-intensity burning in the Upper Basin’s pinyon-juniper woodland, therefore, the long record of anthropogenic burning in the Forestdale Valley may have made the ponderosa pine forest there less vulnerable to fires caused by long-term climate change (Roos 2008).

These examples illustrate that an understanding of the processes by which anthropogenic environments are initiated and maintained, and an appreciation for the ecological consequences of these environments, such as variation in their stability, sustainability, and resilience, should be established and evaluated with a wide range of paleoenvironmental records. Anthropogenic landscape changes are neither uniformly detrimental nor beneficial. Even when the processes are similar, as in the cases of prehistoric Grand Canyon and protohistoric Forestdale Valley burning to promote wild-plant foods, the long-term ecological consequences may be dissimilar. By adopting a multidisciplinary paleoecological framework, archaeologists can contribute to the evolving discourse regarding human behavior and climate change and provide resource managers with the appropriate historical ecological contexts to evaluate alternative land use strategies in the present and for the future.

Notes

1. Because of the overwhelming abundance of charcoal in our sediments, we restricted ourselves further to counting macroscopic charcoal greater than 250 μm in size.

2. The following taxa divisions were used for partitioning pollen types to trees, herbs, and shrubs. For Simkins Flat, Juniperus, Pinus, Pseudotsuga, and Quercus were grouped as trees; Artemisia, Ephedra, and Rosaceae were grouped as shrubs; Compositae, Chenopodiaceae-Amaranthaceae, Eriogonum, Poaceae, and Euphorbia were grouped as herbs. For Forestdale Valley, Abies, Cupressaceae, Picea, Podocarpus, Pinus, Quercus, and Juglans were grouped as trees; Ceanothus, Cercocarpus, Cowania, Prunus, Ephedra, Justicia, Purshia, Artemisia, Rosaceae, Sarcobatus, and Salix were grouped as shrubs; Ambrosia, Liguliflorae, Compositae, Chenopodiaceae-Amaranthaceae, Eriogonum, Graminaceae, Boorhavia, Cleome, Euphorbia, Umbelliferae, Plantago lanceolata, Erodium cicutarium, Liliaceae, Cruciferae, and Tidestromia were grouped as herbs.

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