LONG-TERM ANASAZI LAND USE AND FOREST REDUCTION: A CASE STUDY FROM SOUTHWEST COLORADO

Timothy A. Kohler and Meredith H. Matthews

Species of wood used for fuel changed significantly through time at a large Anasazi village in southwestern Colorado occupied from about A.D. 750 to 900. Changes also occurred in other records of plant use from this site, in the fauna utilized, and in the proportional representation of hafted tools. These and corroborating data from nearby sites suggest that the Anasazi occupation of the Dolores River valley and vicinity resulted in significant local deforestation. Anasazi settlement and mobility practices were affected by climate, human impact on the environment, and regional population densities.

We have two goals in this paper. The first is to test whether hypotheses of local forest reduction through prehistoric human activities proposed for other areas in the Southwest (see for example Dean 1969:147–148; Matheny 1971:159–160; McKenna 1986:27; Minnis 1979; Vivian and Matthews 1973:111) are supported or rejected by final data from the Dolores Archaeological Program (DAP) area of southwest Colorado. We use an empirical, pattern-seeking approach to the forest-depletion question, previously having experimented with theoretical models of wood-use rates and regeneration that suggested local deforestation as likely to have taken place (Kohler et al. 1984). Previous empirical examinations of this question using incomplete, preliminary data from the DAP (Kohler et al. 1984; Kohler and Matthews 1984) also tend to support the forest-reduction hypothesis in the vicinity of one major Pueblo I site.

Our second goal is to use the results of this test to broaden current explanatory models of Anasazi settlement and mobility on the Colorado plateaus. To the extent that such models (e.g., Dean et al. 1985) employ spatial and temporal environmental variability in explaining settlement behavior, they focus on variability due to climate. We will propose that human impact on these semiarid environments, even by simple agriculturalists, must be considered in understanding Anasazi settlement systems.

BACKGROUND

The problem of the Anasazi abandonment of the Four Corners Region of the American Southwest has received considerable attention for many years. There has been less interest in explaining the relatively short duration of occupation of most Anasazi habitation sites and the abandonments of local districts that are so common in Anasazi prehistory (Cordell 1984:303–325). In this paper we contend that the base cause of the relatively high residential mobility (at least in the context of sedentary agriculturalists) inferred from these site and local abandonments is a specific long-term land-use pattern. This pattern accommodates local overexploitation of wood resources by a local periodicity of occupation. Such behavior has not been obvious because it is obscured partially by higher-priority responses to climatic fluctuations, and perhaps by responses to social and demographic factors that are less well understood.

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RESIDUALS FROM CLIMATIC MODELS: THREE EXAMPLES

A central thesis of this paper is that models of Anasazi settlement primarily based on climatic change have been useful in explaining much, but not all, of the settlement behavior observed in the archaeological record. On Cedar Mesa in southeast Utah, for example, an occupation dating from about A.D. 200 to 400 was followed, after a hiatus, by a brief reoccupation in the late A.D. 600s and early 700s. After a second hiatus in occupation, this one over 300 years in length, a final colonization lasting some 200 years began about A.D. 1060 (Matson et al. 1988). Matson and his coauthors can link only the last two abandonments to climatic causes, and consider that the ability of spatially limited stands of dense pinyon–juniper woodland to support a shifting slash-and-burn agriculture may have affected the timing and duration of all the occupations.

From the northern portion of Black Mesa in northeastern Arizona comes another example of periodic occupation. Basketmaker II sites appeared by 600 B.C., but the occupation was small and probably intermittent. The northeastern portions of the mesa appeared to have been vacant during Basketmaker III times (Gumerman 1984:58–68). For the following periods, relative population levels graphed by Plog (1984:165) show two cycles of occupation. After resettlement toward A.D. 850, population size increased slowly until about 975, when it suddenly decreased. Shortly before A.D. 1025 another cycle began, and population climbed rapidly until about A.D. 1100, when it crashed. Plog suggests that this final abandonment cannot be explained (at least totally) by an arid period beginning about A.D. 1120, since the initial population decline took place before that time.

We draw a final example of periodicity in land use that cannot be explained completely by climate change from the portion of southwest Colorado studied by the Dolores Archaeological Program (Breternitz 1984). In the DAP study area there were two major episodes of population growth and decline between A.D. 600 and 1175, and perhaps a minor episode of decline that is not so well documented as the other two. A small colonizing population appeared shortly after A.D. 600 and grew slowly in size, augmented by probable episodes of immigration in the late 700s and mid-800s. A brief period of population decline or abandonment occurs in the northern portions of the DAP area from the early to the mid-800s (Lipe et al. 1985). The influx of population in the mid-800s raised the local population levels to their prehistoric maximum (at about A.D. 880), but shortly after A.D. 900 the DAP area was almost totally abandoned (Schlanger 1985, 1988). Beginning around A.D. 930 through about A.D. 1100 population again began to increase, though it never again approached levels of the late A.D. 800s. Another decline was followed by final abandonment about A.D. 1175. Nearby areas to the west typically had relatively high populations when DAP populations were low, and vice versa.

Much of the DAP population history is explainable through changing, climatically driven relative attractiveness for corn dry farming of the relatively moist, cool DAP area in relation to surrounding areas (Euler et al. 1979; Petersen 1986a; Schlanger 1988). However, the apparent abandonment of portions of the DAP area in the early 800s, the attrition of DAP population beginning in the A.D. 880s prior to a cold snap beginning a decade later, and much other movement within the project area, are not obviously explained by climatic phenomena, nor are the relatively low population levels in the A.D. 1100s. During both the early 800s and the 1100s, the DAP area was relatively attractive and should have been gaining in population. Perhaps the explanation for this departure from behavior expected on the basis of climatic change is due in part to the fact that the 800s (especially) fall at the end of a cycle of population increase at a point in a long-term land-use pattern where a locality normally would be abandoned due to near exhaustion of necessary but slowly renewable resources. From this perspective, in the early 800s a periodic abandonment was overridden by very favorable local climatic conditions prevailing through the mid-ninth century, postponing (but only temporarily) an inevitable abandonment of the area.

DEFORESTATION AS A CAUSE FOR SITE AND LOCAL ABANDONMENTS

It is not possible to explain the continual abandonment of small habitations across the Colorado plateaus as a result of climatic change when new residences so frequently were founded in the general
vicinity of the old. Nor, as the previous examples illustrate, is climatic change always the force behind abandonment of local districts. What then causes the relatively short life expectancy of most small habitation sites, and the longer, but still-limited occupational duration for the zones in which they are located? We propose a deforestation thesis. It contains elements of Stiger's (1979) interpretation of the Mesa Verde situation.

Stiger hypothesized that an increasing reliance on dry farming using slash-and-burn techniques on the mesa tops resulted in severe deforestation by the end of the Mesa Verde sequence. In support of his thesis, Stiger (1979:139–142) noted that: maize and beans increase in ubiquity through time in coprolites while the ubiquity of pinyon nuts decreases; pollen data from the period of occupation are dominated by disturbance species, with juniper and pinyon (the dominants in the pre-occupational landscape) increasing after abandonment (see also Wyckoff 1977); use of deer and jackrabbits increases at the expense of bighorn sheep and cottontail in later sites, as would be expected in an increasingly open, shrubby environment; and *tchamahias* (stone implements which may have been hafted as hoes) appear only late in the sequence, possibly indicating a short-grass fallow rather than a forest fallow.

We think Stiger is correct that deforestation occurred, although he may overstate the importance of a swidden cycle for maintaining soil fertility. In the DAP area about 30 km north of Mesa Verde, there is no evidence that loesses of similar origin to those on Mesa Verde would become infertile under nonintensive dry farming (Clay et al. 1985). Nor was crop reduction due to soil depletion noted in 16 years of continual dry farming of maize in an experimental garden in Mesa Verde National Park (Franke and Watson 1936). However, Matson et al. (1988) do cite evidence that soils beneath pinyon trees in western Colorado have nutrient levels two to 20 times greater than in adjacent shrub-covered areas and that aeolian sediments—that could act as a water-conserving mulch for a brief period after forest removal—accumulate beneath trees. Therefore, a preference for locating fields in recently cleared areas certainly cannot be ruled out. Nevertheless, since pinyon–juniper forest in the Mesa Verde region require over 100 years to return to their original condition after a heavy burn, such preferences could not have been the basis for a practical agricultural strategy in the absence of considerable mobility.

Sullivan (1982) recently has proposed that a “burn plot” technique (differing from a swidden system by the absence of cutting prior to burning, thereby producing a lower-intensity fire) dominated prehistoric Mogollon farming strategies. At present we cannot determine whether a burn-plot or slash-and-burn technique better describes practices in the DAP area. A burn-plot strategy may have had less severe effects on the forest than a slash-and-burn system, though we suspect that whatever strategy was used would have had to open up the forest canopy somewhat to be effective.

*Fire as a Mechanism for Deforestation*

Obviously, fire would have been an effective and easy way initially to clear vegetation from a prospective field in areas of dense vegetation. Less obvious is that fire may be used for purposes other than field clearance or enrichment with long-term effects on the vegetation. For example, in some areas, fire has been used to aid in procurement of fuelwood (Lewis 1977:40–41). In many respects land use among the Tarahumar and Tepehuan, who inhabit areas in northwestern Chihuahua that resemble southwestern Colorado in climate and vegetation, may provide a useful analog for Anasazi land use. The Chihuahua groups removed brush and tree cover from prospective fields using slash-and-burn methods (Pennington 1963:50, 1969:21–22). In the process vegetation often was removed from large areas as fire escaped the fields (Pennington 1969:84 [note 61]). Grass fires intended to bring rain, and fire drives “aimed at the destruction of animals,” also were common practices among the Tarahumar until recent times (Pennington 1963:50). Certainly an inverse relation would have existed between the extent to which fire was used for these purposes and the availability of wood for fuel and construction. Therefore, attempts to intensify agricultural production or hunting activities in response to increasing population or deteriorating climate would have significantly affected availability of wood resources.
Fuel Use as a Mechanism for Deforestation

Fire is not the only way to explain deforestation. Samuels and Betancourt (1982) make a good case that the sparse local pinyon–juniper woodland that once surrounded Chaco Canyon was destroyed irretrievably by overuse for fuel. Indeed, the local vegetation (as reconstructed from packrat middens) before and after the main Anasazi occupation is quite different (Betancourt and Van Devender 1981). Using Drager’s (1976) estimates of population size for the Chaco Canyon area and probable fuel use rates from ethnographies, Samuels and Betancourt argue that the extermination of the forest can be accounted for simply by Anasazi demand for fuel. Their results, while suggestive, would be strengthened if it could be shown that fuel use did indeed change through time in a way that was coupled closely with the population history of the canyon. This would help establish the causal connection between the two phenomena, and would demonstrate that the vegetation changes actually had a significant effect on the way people used their environment.

Direct and Indirect Effects of Deforestation

Even if deforestation occurred, what is the justification for believing that it may have contributed to decisions to leave one place and move to another? What effects might deforestation have had that would result in such major accommodations?

Obviously deforestation would result in decreased returns to labor in fuel collection and construction. Such decreased returns might have been offset partially, but probably not totally, by changing the species mix used; changing harvesting strategies (for example, by ringing, drying, and harvesting trees for fuel rather than simply collecting deadwood from increasingly remote areas) or changing architectural forms to minimize heating requirements and the amounts of wood incorporated in original construction and later maintenance activities. Following Matson et al.’s (1988) argument for Cedar Mesa, it also is possible that forest depletion would result in decreased returns to labor in agriculture, although some labor involved in forest or sagebrush clearing also would have to be taken into account.

It also is plausible that deforestation would have had more subtle effects of varying significance. Drawing on a study by Borman and Likens (1979), Petersen and Matthews (1987) identify changes in the hydrological regime, status of biogeochemical soil nutrients, composition of local flora and fauna, and degree of erosion and sediment transport that might accompany deforestation. Anticipated faunal changes include loss of sage grouse with clearing of sagebrush, changes in fish species in the Dolores River as its waters muddy, attraction of migratory waterfowl to fields, increase in small game, and disruption of large-game migrations through the Dolores area. Even from a project-wide perspective, sample sizes of bone from migratory waterfowl, fish, and sage grouse precluded testing those expectations, and unambiguous evidence for a shift in the importance of big-game hunting versus garden hunting of small animals was not found (Petersen and Matthews 1987). It is difficult to specify archaeologically visible implications for changes in rates of erosion or, in the absence of actual field locations, changes in soil biochemistry. This leaves those records provided by human use of the local flora as the most promising lines of investigation.

In the remainder of this article we examine the hypothesis that in the course of their 300-year primary occupation of the Dolores Archaeological Program area the Anasazi severely depleted the local woodlands. We use one floral record—the changing species composition of charcoal from well-dated features with analyzed fuel remains—as the primary test for deforestation. This record is emphasized because fuel collection for domestic purposes primarily is casual (expedient) and therefore provides a more representative sample of the local environment than does wood selected for construction. Fuel gathering also reflects the floral composition of smaller catchments in comparison with most wind-borne pollen in sediment traps. Moreover, fuel-use records from Anasazi sites usually can be dated more accurately than either packrat-midden materials or nonarchaeological pollen. Finally, the period over which hearth contents accumulate probably is shorter than for packrat middens. This leads to some idiosyncracies in the contents of individual features which we hope to overcome by examining the contents of fairly large numbers of features.
ANASAZI FUEL USE IN THE DOLORES ARCHAEOLOGICAL PROJECT AREA

The area studied by the DAP centered on 15 linear km of the Dolores River valley just downstream from the small town of Dolores (Figure 1). It constitutes the core of an area approximately 230 km² in size that Kane (1983a:18) has called the “Escalante Sector.” Kane (1983a:18) defines a sector as a spatial division “within which the inhabitants of the internal communities and localities experience a sense of cultural identity.... Perhaps the best social analog for the sector is what Struwever (1969) terms the ‘maximum subsistence-settlement unit,’ a societal unit which ‘includes all people integrated at one or more intervals in the functioning of a subsistence settlement system.’”

Choice of a Study Site

If the Anasazi made a substantial impact on the extent and character of the woodlands in the DAP area, the best place to study any such impact is at a large, long-lived site that served to anchor the population within the sector. Perhaps it is only at such sites that the benefits received from ceremonial or other coordinated activities outweighed the costs associated with local degradation of the environment, and hence it is at such sites that any possible degradation might be visible most clearly. One such place is 5MT23, the Grass Mesa site (Lipe et al., compilers 1985). Because of the large amount of excavation at Grass Mesa, we will consider various records from this site in detail, and then briefly note corroborating trends from other sites within the DAP area.

History of Occupation at Grass Mesa

Along with McPhee Village 6 km south (upstream along the Dolores River), May Canyon Village 8 km to the southeast, Cline Crest Village 3 km to the southwest, and Windy Ruin 3 km to the west, Grass Mesa Village was one of the largest concentrations of population in the Dolores area during the ninth century A.D. (Figure 2). Beginning sometime between A.D. 720 and 750, the first occupation of the site consisted of generally small, deep pitstructures with wingwalls and large ventilator shafts associated with lightly built isolated surface rooms. One pitstructure, more than two-and-a-half times the size of the average pithouse, contained an anachronistic antechamber and possibly served as a “neighborhood”-wide focus of ritual activity.

After A.D. 760 pithouse size increased, perhaps because pitstructures began to serve as shared space among two or more closely cooperating households primarily based in adjacent surface structures that contained both storage and domestic space. Such supr ahousehold but still small social units are called “interhouseholds” by the DAP; possibly these represent extended families. At least one pitstructure was twice the average size, and a very large, roofed great kiva on the west end of the site, built around A.D. 800, was the only such structure in the project area at that time. A low point or hiatus in site occupation between about A.D. 830 and 850 may have resulted from population movement toward the southern end of the project area and the foundation of the House Creek and McPhee villages (Kane 1986:365).

Around 850 the site was repopulated, possibly by a wave of immigrants coming into the project area about that time. As recent arrivals in an already populated district, the new Grass Mesa population may have had to settle for a less-than-ideal location, since arable land sufficient to support a large population was relatively remote, and since the local vegetative environment remained significantly disrupted by the previous occupation.

Population for the next 50 years far exceeded earlier levels (Table 1). Until about A.D. 880, domestic architecture at Grass Mesa is similar to the ca. A.D. 800 plan, except that the existence of a larger unit of social incorporation is inferred from the tendency of the earlier interhousehold units to be incorporated into larger “roomblock units.” Kane (1986:369) hypothesizes that these new, larger corporate units (that reasonably could be thought of as clans) controlled land holdings, other economic affairs, and ritual functions. Pitstructure floor area during this time is bimodal with one peak at 20–25 m² (presumably representing the standard interhousehold structure) and another at 40–45 m² presumably representing structures shared by the larger corporate unit.
Figure 1. Vegetation zones near the Grass Mesa site (5MT23). Contemporaneous sites not shown. Vegetation reconstruction is for the relatively dry period from about A.D. 800–1000 (Petersen 1985d) and does not take into account possible effects of human disturbance.
became the vulnerability variable in nondomestic a season subphase; also cupation, (1987b) precipitation. Most area Kohler Architectural Architectural of Mesa, Natural (Schlanger 1985:139). The “DAP area” refers to the 65.5 km “Takeline” of the Dolores Project, and includes some uplands to the north, east, and west of the Dolores River in addition to the river valley. The Grass Mesa figures are per household; the DAP area figures are per capita and assume five people/household.

Architectural patterns, subsistence organization, and social organization appear to have undergone a radical shift around A.D. 880. The period from 880 until about 910 is called the Grass Mesa subphase; by its close the site again was abandoned, this time permanently. During the final occupation, pitstructures decreased in size, life expectancy, and energy investment, and contained fewer nondomestic features. Surface rooms appear to decrease in importance and became highly variable in their presence and characteristics. Evidence for suprahousehold cooperation is more limited and variable than in the preceding period. Efforts to explain these changes have proposed an increasingly seasonal (winter) occupation at the site, with fields located at increasing distance as arable land became scarce in the vicinity of Grass Mesa. Part of this scarcity may be due to the relatively high vulnerability to cold-air drainage of land near Grass Mesa, limiting the length of the local growing season, but a series of short summers beginning in the 890s that may have been important in forcing the final abandonment of the site probably occurs too late to explain the defining characteristics of the Grass Mesa subphase.

The Natural Environment of Grass Mesa

The environment of the DAP study area has been described thoroughly by Petersen et al. (1985). Most of the study area lies between 2,100 and 2,440 m in elevation, and receives an average annual precipitation of about 460 mm (Petersen 1986a). Well watered by southwestern standards, the area also supports a relatively dense vegetation, reconstructed for the A.D. 800–1000 period by Petersen (1987b) for the area around the Grass Mesa site in Figure 1.

![Population Chart](chart.png)

**Figure 2.** Momentary human-population estimates for the Grass Mesa site (Kohler 1985:3.31) and the DAP area (Schlanger 1985:139). The “DAP area” refers to the 65.5 km “Takeline” of the Dolores Project, and includes some uplands to the north, east, and west of the Dolores River in addition to the river valley. The Grass Mesa figures are per household; the DAP area figures are per capita and assume five people/household.

Table 1. Population Estimates for Grass Mesa Village.

<table>
<thead>
<tr>
<th>Date (A.D.)</th>
<th>Population Total Point Estimate, Pithouses</th>
<th>80% Confidence Interval</th>
<th>Best Estimate, N of Momentary Households</th>
</tr>
</thead>
<tbody>
<tr>
<td>725–800</td>
<td>80.0</td>
<td>35.8–124.2</td>
<td>22</td>
</tr>
<tr>
<td>800–840</td>
<td>20.3</td>
<td>14.0–42.0</td>
<td>17</td>
</tr>
<tr>
<td>840–880</td>
<td>94.1</td>
<td>51.3–136.9</td>
<td>92</td>
</tr>
<tr>
<td>880–910</td>
<td>184.2</td>
<td>121.4–247</td>
<td>124</td>
</tr>
</tbody>
</table>

*Note: Periods differentiable through characteristic ceramic assemblages (Blinman 1984).*  
*Represents number of known structures.*
Table 2. Growth Rate Estimates for Selected Species.

<table>
<thead>
<tr>
<th>Taxon</th>
<th>Location</th>
<th>Elevation in Meters</th>
<th>Interest Rate Annual Increase in Volume</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pinyon-juniper woodlands</td>
<td>New Mexico and Arizona</td>
<td>Various</td>
<td>.012</td>
<td>Howell 1941</td>
</tr>
<tr>
<td><em>J. osteosperma</em></td>
<td>Central Arizona</td>
<td>—</td>
<td>.006a</td>
<td>Herman 1953</td>
</tr>
<tr>
<td><em>J. monophylla</em></td>
<td>Central Nevada</td>
<td>2,073</td>
<td>.04a</td>
<td>Miller et al. 1981</td>
</tr>
<tr>
<td><em>Pinus ponderosa</em></td>
<td>Northern California</td>
<td>518–1,647</td>
<td>.13a</td>
<td>Oliver and Powers 1978</td>
</tr>
<tr>
<td><em>Pinus ponderosa</em></td>
<td>Northern California</td>
<td>1,220</td>
<td>.11a</td>
<td>Oliver 1979</td>
</tr>
<tr>
<td><em>Artemisia tridentata</em></td>
<td>Various</td>
<td>Various</td>
<td>.57a</td>
<td>McArthur and Welch 1982</td>
</tr>
</tbody>
</table>

* For a permanent 4-acre sample plot near Sedona, between 1938 and 1948, following a light harvest for fence posts.
* Estimated from data in Miller et al. (1981:Table 15) for average annual increase in total dry weight less foliage for four individuals.
* As predicted for unthinned plantations with a Site Index of 80 for trees between 10 and 50 years old; mean for various spacings.
* Calculated over 5-year period for growth on a productive site after thinning; mean for five stocking levels.
* For variety *tridentata*. Rough estimate based on annual growth estimates from McArthur and Welch (1982) for annual “yield” of foliage and woody growth, stated here as a proportion of total biomass as calculated from plant heights and crown diameters given by McArthur and Welch using regression estimates developed by Frandsen (1983).

The most common vegetation zone near Grass Mesa Village is pinyon–juniper, which is typical of the south- and west-facing, steep-walled slopes with thin rocky soils of the canyon walls. In addition to the dominants *Pinus edulis* and *Juniperus osteosperma* and/or *J. scopulorum* there is an important element of *Quercus gambelii* (Gambel oak). The mountain brush vegetation zone also occurs on steep slopes, especially those with a northern exposure. *Amelanchier utahensis* (serviceberry), *Fendlera rupicola* (fendler bush), *Cercocarpus montanus* (mountain mahogany), and *Q. gambelii* dominate this zone, with isolated occurrences of *Pinus ponderosa* (ponderosa pine) and *Pseudotsuga menziesii* (Douglas fir).

The big sagebrush vegetation zone is common on flat areas with deep, well-drained soils. In addition to *Artemisia tridentata*, important woody shrubs are *Chrysothamnus* (rabbitbrush) and *Purshia tridentata* (bitterbrush). Stands of oak woodland accompanied by various shrubby species occur on shallower soils surrounding pockets of big sagebrush, at somewhat higher elevations than pinyon–juniper. Finally, the riparian community consists primarily of *Populus angustifolia* (narrowleaf cottonwood) and species of *Salix* (willow).

**Expectations for Changing Fuel Species Through Time**

If there is a local reduction in the forest vegetation during the main Anasazi occupation of the DAP area, we expect that it is due to the joint effects of clearing fields for agriculture, probably with use of fire where vegetative cover would support it, and to a continual drain on the forest to supply wood for fuel and construction. Four primary expectations can be formulated for the direction of change in species selection for fuel use if the hypothesis of woodland reduction is true. In developing these expectations we assumed that fuel use is expedient, that people gather fuel without tools to the extent possible, and that charred woody taxa recovered from hearths and related features represent fuel resources. The first assumption finds some support in the statistical analysis presented below, where no evidence is found for selection of particular species for use in specific structure or feature types. The first two of the following expectations could be applied to most places within the
Anasazi culture area, while the last two are specific to the more densely-wooded areas where clearing fields by fire would be both necessary and feasible. The expectations are as follows:

1. *There should be a general decrease in the frequency of charcoal from arboreal species relative to that from shrubby species.* This would result from a clearing of vegetation zones dominated by trees, which then undergo seral stages lasting many decades during which various shrubby species dominate.

2. *Charcoal from rapidly growing species should increase in frequency relative to that from slow-growing species.* Increasing concentration on use of rapidly regenerating species in effect constitutes an “intensification” of fuel gathering. Unfortunately, growth rates have been measured in different ways using differing techniques, and it is hard to find reliable comparative data relevant to the DAP study area. Species for which roughly comparable growth data could be found are listed in Table 2. Most of the other shrubs in the local fuel record probably qualify as rapid growers along with sagebrush; on a qualitative level, the riparian species also frequently are described as fast growing.

3. *Charcoal from species that are fire tolerant or fire dependent should increase in frequency relative to charcoal from species that are intolerant of fire.* In their study of the environment of Mesa Verde, Erdman et al. (1969:17) attribute the importance of Gambel oak and serviceberry on the higher parts of the mesa to the effects of recurrent fires, and note that pinyon presently is increasing in this same zone, a fact which they attribute to recent fire protection. Other sources (reviewed in Harper et al. 1985:20) note that fire stimulates shoot production of both Gambel oak and those shrubs found with it. In a study of vegetation changes following burns in pinyon–juniper-dominated zones in west-central Utah that have an elevation and total precipitation similar to the Dolores area, Barney and Frischknecht (1974) show relatively rapid rebound of perennial grasses, sagebrush, and little rabbitbrush (*Chrysothamnus viscidiflorus*) following a burn, with juniper not accounting for even 20 percent of the ground cover until more than 80 years following a burn. Pinyon lagged well behind juniper in rate of recovery. In a study of the fire history of mixed conifer stands in east-central Arizona, Dieterich (1983:28) notes that fire should favor ponderosa pine (*Pinus ponderosa*) with its fire resistance and ability to regenerate in openings. He also cites evidence that quaking aspen (*Populus tremuloides*) is a major seral species following a fire. The edaphic factors favoring aspen are rare in the vicinity of the Grass Mesa site, however, and the species probably also was rare during the period of Anasazi occupation.

4. *Charcoal from species in habitats or with habits that make burning difficult or unlikely should increase in relative frequency through time.* Dieterich (1983:28) notes that a sizable component of aspen in a stand tends to have a “dampening effect” on severe fire; the same may be true for riparian woodlands. Charcoal from riparian species also might increase relative to that of other species since the riparian habitat is subject to severe cold-air drainage and therefore might escape clearance for fields.

Other expectations for woodlot reduction using other data bases are plausible and will be examined more briefly. Kohler and Matthews (1984) plotted the changing proportional representation of major vegetation types within successively larger radii up to 2 km from the Grass Mesa site. They inferred that the available stock of deadwood for fuel was exhausted within this distance by about A.D. 840 since it is then that the proportional representation of species in the fuel record stopped changing in the directions predicted if deadwood were being gathered from increasingly distant areas. This suggests that the relative frequency of hafted tools used to harvest or ring live trees and shrubs for drying for fuel should begin to increase after A.D. 840. We also expect increased representation of pioneer plants (favored by disturbance) and of animals favored by more open environments through time.

Several of the test implications for wood-resource depletion also are test expectations for agricultural intensification. Given that the farming systems in the DAP area apparently did not include terracing or water-control features, the main mechanisms for agricultural intensification would be shortening the fallow cycle and farming at greater distances from the residence. Since both types of intensification also disrupt the vegetation, the fact that some of the data which follow could be read as indicating agricultural intensification is of little concern.
Methods of Sampling and Quantification

Disregarding samples taken for $^{14}$C or tree-ring dating, two main types of botanical samples were retrieved from DAP sites. Vegetal samples were taken at the discretion of the excavator to collect readily visible materials such as samples of rooffall or concentrations of maize. One-liter flotation samples were taken systematically according to guidelines contained in the Dolores Archaeological Program Excavation Manual (Kane and Robinson 1984; see Matthews [1985a] for a general discussion of the botanical data base).

Crew chiefs had considerable latitude in sampling a particular structure (taking into account variables such as the inferred mode of abandonment and the intensity of excavation) but hearths and other fire-altered features were also a high priority for flotation sampling. Features containing cultural rather than postoccupational fills, and features with good contextual information and good preservation, were sampled preferentially. Materials from surface structures are poorly represented in the Grass Mesa data, mostly due to severe recent disturbance by pothunters. However, the statistical analysis that follows shows no significant difference in the woody charcoal assemblages from pitstructures and surface structures.

In sum, we know of no important biases resulting from field selection of features for sampling, nor in the later subsampling of that population for analysis, and for the statistical analysis below the analyzed fuel materials are considered to be a simple random sample of the fuels used on Grass Mesa during each period. Table 3 shows the numbers and types of fire-related features containing charred woody plant parts from the Grass Mesa site that were both sampled and analyzed. Seven other features with analyzed fuel materials are excluded from this table and from the following analysis because they cannot be dated adequately.

All quantification of species in features is on a presence/absence scale. Such a ubiquity measure (Gasser 1982; Hubbard 1980; Minnis 1985) is conservative, and considerable change in the relative importance of fuel species can, in theory, be missed by a presence/absence measure. However, a ubiquity measure may help to compensate for the many vagaries of preservation, including the fact that some woods leave less charcoal when burned than others (Zalucha 1983).

Ubiquity data usually are presented as the percentage of features containing a specific taxon. We quantify ubiquity here as the number of times a specific taxon occurs in discrete features in the sample of interest. For example, Grass Mesa has a total of 879 identified “occurrences” of distinct taxa in 107 distinct features, indicating that on the average, eight taxa were identified in each sample analyzed. Presenting the data in this form, rather than as percentages, facilitates statistical analysis. For consistency, then, when percentages are used later in this paper (for example in the last column of Table 4 and in all figures) the denominator is the total number of occurrences rather than the total number of features.

Because of sample-size problems associated with the use of categorical variables, it is impossible to test for change through time in fuel species without first aggregating some categories in the four dimensions of interest (species, feature type, structure type, and period). The great kiva materials were combined with materials from other pitstructures; materials from hearths and fireplaces, ash pits and ash piles, and warming pits and burned pits were placed into three grouped-feature categories; and the time periods were aggregated into three categories (A.D. 720–840, 820–880, and 880–910). The overlap between the first two time periods is necessary unless seven features dated only to

| Table 3. Distribution of Feature and Structure Types in the Grass Mesa Fuel Sample (All Periods). |
|---------------------------------------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Surface structures                                            | Fire Places     | Ash Pits        | Warming Pits    | Burned Pits     | Ash Piles       |
| 26                                                             | 2               | 1               | 0               | 2               | 0               |
| Pitstructures                                                 | 58              | 12              | 1               | 1               | 1               |
| Great kiva                                                    | 0               | 0               | 0               | 2               | 0               |

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<table>
<thead>
<tr>
<th>Subdivision</th>
<th>Class</th>
<th>Family</th>
<th>Genus</th>
<th>Species</th>
<th>Frequency of Occurrence</th>
<th>Relative Frequency (%)</th>
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<td>Gymnospermae</td>
<td>Cupressaceae</td>
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<td><em>menziesii</em></td>
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<td>Angiospermae</td>
<td>Monocotyledoneae</td>
<td>Gramineae</td>
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<td>.57</td>
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<td><em>Zea</em></td>
<td><em>mays</em></td>
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<td>Dicotyledoneae</td>
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<td><em>Salix</em></td>
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<td>Fagaceae</td>
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<td><em>Quercus</em></td>
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<td></td>
<td><em>Sarcobatus</em></td>
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<td></td>
<td>Saxifragaceae</td>
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<td><em>Fendlera</em></td>
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<td><em>Rosa</em></td>
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<td></td>
<td>Anacardiaceae</td>
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<td><em>Rhus</em></td>
<td><em>aromatica</em></td>
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<td>Aceraceae</td>
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<td><em>Acer</em></td>
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<td>Cactaceae</td>
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<td><em>Opuntia</em></td>
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<td>.11</td>
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<td></td>
<td>Eleagnaceae</td>
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<td><em>Shepherdia</em></td>
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<td>7</td>
<td>.80</td>
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<tr>
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<td>Cornaceae</td>
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<td><em>Cornus</em></td>
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<td>.23</td>
</tr>
<tr>
<td></td>
<td>Compositae</td>
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<td><em>Artemisia</em></td>
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<td>22</td>
<td>2.50</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td><em>Chrysothamnus</em></td>
<td></td>
<td>5</td>
<td>.57</td>
</tr>
</tbody>
</table>

*Note: Taxonomic organization follows Lawrence (1951).*

between 820 and 860 (and placed in the middle time period) are to be discarded. In fact all of these features probably postdate A.D. 840, so the apparent overlap is of little concern.

Thirty taxa of woody plants are represented in the features of interest. These categories, and the total number of occurrences for each category (i.e., the count of features in which each taxon was represented), are listed in Table 4. Materials were assigned to the most specific taxonomic category possible during analysis. Some aggregation already has taken place in this table: *Shepherdia* and *S. argentia*, *Fendlera* and *F. rupicola*, *Prunus* and *P. virginiana*, and *Prushia* and *P. tridentata* are...
combined at the genus level here, though not in the original analysis. Charcoal that could not be identified to subdivision or better was excluded from the table.

The test expectations give some guidance in aggregating these categories. All the dicots except the cactus (discarded as too rare) and the Salicaceae can be aggregated into a fast-growing shrub group; most of these are also favored by fire. Indeterminant dicots are included in the shrub group, since if the proportional representation of the broadly identified materials is the same as in the more specifically identified charcoal, 68 percent belongs to the shrubby group. The proportional representation of this group should increase through time if our hypothesis is true.

The Salicaceae (nearly all of which probably is cottonwood) are aggregated into a fast-growing arboreal group from a relatively fire-resistant and agriculturally unattractive habitat. We also expect this category to increase through time.

Among the grasses, Zea mays is maintained in a separate category with the expectation that use of cobs for fuel might increase through time if other, presumably more desirable fuel materials are becoming scarce. Phragmites is discarded as a very rare category for which there are no clear expectations.

Among the gymnosperms, pinyon and juniper clearly belong together in a slow-growing category that is sensitive to fire. Indeterminant gymnosperms have a 70 percent chance of belonging to the pinyon–juniper group, and are classed with them. This category should decrease through time. Ponderosa pine and Douglas fir constitute a category for which there are no clear expectations. As trees, they might be expected to decrease in ubiquity, yet both are relatively resistant to fire during most of their life cycles, and both grow relatively rapidly. Unidentified Pinus has an almost even chance of belonging to this group. Because of conflicting expectations, ponderosa, Douglas fir, and Pinus are excluded from the statistical analysis although they are presented in a graph. We are then left with four categories of species—pinyon–juniper, corn, cottonwood, and shrubs—for which there should be clear evidence of change through time if our hypothesis is true.

Results of Analysis

The analysis that follows has two purposes: to determine whether significant change occurs as predicted and to determine whether or not it is necessary to control for the fact that the types and location of proveniences containing fuels also change through time. These two goals were addressed simultaneously with a 4-way log-linear analysis using BMDP program P4F (Dixon 1983:143–206). Log-linear analysis can be thought of as an extension to standard contingency-table analysis that allows the effects of more than two categorical variables to be examined simultaneously. Certain combinations of attributes that occur rarely or not at all (such as hearths in surface structures in the earliest and latest portions of the sequence) were declared as structural zeroes so that they do not contribute to assessing the fit of the statistical model (see Dixon 1983:197–200; Feinberg 1981:140–163).

The most promising of the many possible statistical models was one in which three two-way interactions were fit: between structure type (S) and period (P); feature type (F) and period; and species (C) and period. This model (SP, FP, CP) is shown in Figure 3 along with several other models which stand in a nested relation. The observed frequencies in the complete four-way table, and the expected frequencies calculated under the favored model, are shown in Table 5. This model is the most parsimonious of those that fit relatively well, and indicates that feature type, structure type, and species used all change through time, but that change in fuel species specifically is linked to change through time, and is therefore not the result of changing relative frequencies in the feature types or structure types from which the fuels were recovered. (That is, no CS or CF interaction is needed to reproduce adequately the observed frequencies in Table 5.)

Three tests of significance for the CP (species/period) interaction are also shown in Figure 3. The only difference between models 1 and 3 is the deletion of the CP interaction; since 3 is nested in 1 the difference in their likelihood-ratio chi-squares (in conjunction with the difference in their degrees of freedom) can be calculated to show that the probability that the CP interaction is zero is .0502 (Feinberg 1981:56–57). Model 4 is the best in the second row, and contains the CP term; in model
Figure 3. Selected hierarchical statistical models with tests of fit for the interactions among feature type (F), period (P), structure type (S), and species category (C). Models with a high $p$ value fit the fuel data on the Grass Mesa site better than models with a low $p$ value. The “family” of models with interactions among only two variables at a time shown in this figure fit as well as, and were more parsimonious than, any three-variable interaction models. The significance of particular two-variable terms can be assessed by calculating the difference in chi-square values between nested models that differ only in the presence of that term. For example, by comparing models 1 and 5 it can be seen that the FP interaction is highly significant (low $p$ value), suggesting that any model fitting these data must take into account the fact that feature types having sampled fuel materials change significantly through time.
8, which is nested in 4, this term is deleted, and in this context, the probability that its value is zero is .0553. Finally, the only difference between model 7, the best in the third row, and model 11, which is nested in it, is the absence of the CP interaction; in this context, the probability that this interaction is zero is .0718.

Having established that change through time in the fuel-species categories probably is not due to chance effects in our sampling procedure, and that change in the frequencies of the various structure or feature types from which the sample was drawn are not confounding variables, we can graph the changes through time in the observed fuel-species categories from Table 5. This is done in Figure 4 after adding back in the major species categories excluded from the statistical analysis because of unclear expectations for change through time. As hypothesized, the relative ubiquity of the pinyon-juniper category decreases, and that of shrubby species increases. Cottonwood does increase slightly, but ubiquity of maize cobs and cob fragments declines in the final period, contrary to our expectations. A decline in maize ubiquity prior to abandonment also was noted by Matthews (1985b) in a slightly different sample of macrobotanical materials from the Grass Mesa site, and in part may result from field locations and seasonal habitations at a greater remove from the village as closer locations for maize production deteriorate due to the joint effects of environmental exhaustion and climatic change.

**Corroborating Data from Grass Mesa**

Working with a different set of materials from much the same sample of features, Matthews (1985b:16.42) has shown that 16 taxa of pioneer plants tend to increase in ubiquity through time on Grass Mesa. The most important of these are species of *Amaranthus, Chenopodium, Physalis, Portulaca*, and members of the Cruciferae and Gramineae. To some extent, the increased presence of these plants may be due to their incorporation into the agricultural system as part of a multiplecropping strategy and so they may not bear simple witness to an increased local environmental disruption.

---

*Table 5. Distribution of Fuel Categories Through Time (N of Occurrences = 710).*

<table>
<thead>
<tr>
<th>Period (Years A.D.)</th>
<th>Structure Type</th>
<th>Feature Type</th>
<th>Pinyon-Juniper</th>
<th>Corn</th>
<th>Cottonwood</th>
<th>Shubs</th>
</tr>
</thead>
<tbody>
<tr>
<td>780–840</td>
<td>Surface</td>
<td>HF</td>
<td>0 (3.7)</td>
<td>0 (1.3)</td>
<td>1 (1.7)</td>
<td>0 (4.0)</td>
</tr>
<tr>
<td></td>
<td>Ash</td>
<td>1 (1.0)</td>
<td>0 (0.4)</td>
<td>1 (0.5)</td>
<td>1 (0.5)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>0 (0.3)</td>
<td>0 (0.1)</td>
<td>0 (0.1)</td>
<td>0 (0.3)</td>
<td></td>
</tr>
<tr>
<td>Pit</td>
<td>HF</td>
<td>22 (22.3)</td>
<td>9 (7.9)</td>
<td>10 (10.1)</td>
<td>23 (23.7)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ash</td>
<td>5 (6.0)</td>
<td>2 (2.1)</td>
<td>2 (2.7)</td>
<td>8 (6.4)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Other</td>
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<td>0 (0.1)</td>
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<tr>
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<tr>
<td>Pit</td>
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</tr>
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<td>2 (4.1)</td>
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</tr>
</tbody>
</table>

* Cells contain the observed and the expected ( ) frequencies under the model SP, FP, CP.
* Declared as structural zeroes in model.

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Neusius and Gould (1985), in their discussion of the Grass Mesa faunal assemblage, document several temporal trends expected if fauna increasingly were taken from the more open environments typical of active and abandoned fields. They explain these trends as due to increased use of a pattern of hunting embedded in agricultural fieldwork (Linares 1976). Since garden hunting itself is made possible by changes in animal biomass and species composition resulting from land clearing, cultivation of crops, and falling of fields (Neusius 1984), it is difficult to provide contrastive expectations for a shift in strategy toward garden hunting versus a shift in the character of the total environment from which the animals were being sampled. Thus, several of their expectations for increased garden hunting also are expectations for increased deforestation. In this light, the increasing proportions of 32 taxa (mostly small animals, including birds) likely to have frequented fields or other disturbed areas, the increasing relative frequencies of rodents and lagomorphs, and the increasing ratio of jackrabbits to cottontails in the faunal assemblage generally follow the trends expected from less-forested environments.

Species of wood used for construction at Grass Mesa change through time in some of the same ways as wood used for fuel. Identification is unreliable for *Populus* and other nondatable woods, since they were sampled less systematically than woods that had potential for dating. The clearest trend is for an increase through time in the use of ponderosa pine, along with some indications of a decrease in juniper. These trends probably do not reflect changing selection of species as surface structures become more important through time since the vast majority of the Grass Mesa specimens from all periods are from pitstructures. The ponderosa specimens are mostly young and undatable. Given the intolerance of ponderosa for shade and its relatively high tolerance of fire, this increase is consistent with a more open habitat, and more frequent burning, although climatic explanations for the increase also have been proposed (Petersen 1986a:314–315). Since construction is relatively rare in comparison with fuel use, and since human selectivity for appropriate characteristics of length and diameter in construction wood may result in long-distance harvesting (Betancourt et al. 1986), we suggest that this record is less useful than the fuel-use record for reconstructing local vegetation.

Finally, as explained above, an increase was expected in the relative frequency of axes through time under conditions of wood depletion. In the DAP area both flaked stone and nonflaked (ground) stone axes are found; the relative frequency of each is shown in Figure 5 for Grass Mesa. Disregarding
the earliest occupation, the expected pattern of increase is present in both types. Site-formation processes remaining equal, the frequency of axes in an assemblage probably reflects per-capita construction activities, forest-clearance activities, and possibly other activities as well as the increased need to harvest fuel with tools rather than by hand, which is what we hope to monitor. It may be that the high frequencies of axes in the earliest assemblages are typical for colonizing agriculturalists in wooded areas, and may result from forest-clearance activities.

Evaluating a Plausible Alternative Cause for Change in Fuel Use

One important alternative remains as a possible cause for changes in fuelwood use documented at the Grass Mesa site. Based largely on high-elevation pollen studies in the neighboring La Plata Mountains, Petersen (1986a) and Petersen and Mehringer (1976) have reconstructed the climate in the project area during the Anasazi occupation as similar to that of today, though somewhat drier during some segments of the occupation. Specifically, the period from about A.D. 600 to 740 was similar to present conditions except for a brief drier interval in the mid-A.D. 600s. The period from A.D. 800 to 1000, however, is reconstructed as drier than the present, with the driest conditions occurring around A.D. 900. Decreased annual precipitation was offset during this time to some extent by increased summer precipitation, reconstructed from high frequencies of pinyon pollen in Petersen’s La Plata mountain sites. During the occupation of Grass Mesa, from the mid-A.D. 700s to 900, then, there was a slow but constant trend toward decreased annual/winter precipitation that Petersen also finds reflected in pollen samples from upland (noncanyon) sites in the DAP area by an increase in sagebrush pollen relative to arboreal pollen (Petersen 1986b). This regional trend toward relatively more sagebrush than at present is simultaneous with and parallels, to a certain extent, our findings for changing wood use for fuel. Could these changes in fuel use be due to a change in the vegetational mosaic due to desiccation, rather than to the effects of human disturbance?

Few expectations potentially visible in the fuel-use record can differentiate between these rival explanations for changing fuel use. Both the desiccation and human-impact models anticipate a decrease in juniper and perhaps ponderosa and Douglas fir, and an increase in rabbitbrush and xeric shrubs (including sagebrush). However, if desiccation were responsible for these changes the ubiquity of riparian species (largely cottonwood) and of mesic shrubs should decrease, while the ubiquity of
xeric shrubs, sagebrush, and pinyon (favored by increased summer precipitation) should increase more dramatically than anticipated by the human-impact model.

The changing ubiquity through time of taxa that can help distinguish between the desiccation and the human impact hypotheses is shown in Figure 6. The “mesic-shrub” group includes the same species as the shrub group used earlier except that Chenopodiaceous shrubs, sagebrush, rabbitbrush, and oak have been excluded. The chenopods are graphed as “xeric shrubs” and the cottonwood category includes all the Salicaceae. Species such as rabbitbrush that could not provide contrastive evidence for one of these two models were excluded.

Results of the comparative evaluation of the human-impact and desiccation models provided by Figure 6 are somewhat mixed, but in general the notion that the fuel record is providing a sensitive proxy for climatic change is poorly supported. As predicted by the desiccation model, oak does decrease at first, but then increases during the time of maximum desiccation. Xeric shrubs that today do not grow in the project area do appear in the fuel record for the first time in the final period, but remain an insignificant portion of the assemblage. Contrary to the desiccation model, but as anticipated by the human-impact model, mesic shrubs generally increase through time. Interpreted in conjunction with Figure 4, this probably is due to the increasing extent of seral vegetation in areas formerly dominated by unidentified pines and pinyon–juniper. Weakly supporting the human-impact model is the slight decrease in pinyon, since it takes place in the context of what appear to be large increases in pinyon regionally. Unanticipated by either model, but perhaps more damaging to the hypothesis that the changes in fuel species are due to desiccation rather than to human impact, is the absence of any general increase through time in the relative ubiquity of sagebrush.

Taken as a whole, these data provide some support for Petersen’s reconstruction of a trend towards increased desiccation during the occupation of the Grass Mesa site. However, the fuel-use record appears to be influenced less heavily by regional climatic change than by human impact on the local environment.

**Summary: Grass Mesa**

Significant change through time in the species of wood found as charcoal in contexts suggesting use as fuel has been documented for a large village site in the valley of the Dolores River in southwest Colorado. Many of these changes are consistent with what might be expected if the Anasazi engaged
in large-scale clearing and burning of the dense pinyon–juniper forest that dominates the vicinity of this site. Some of these changes probably are reinforced or accelerated by decreasing precipitation during the time of occupation. Concurrent changes in the composition of the fauna used at the site, in the increasing ubiquity of pioneer plants, and in the relative frequency of axes also could be explained in part by local deforestation.

From these data alone it is impossible to reconstruct the spatial extent of this impact. However, in a simulation of the size and shape of agricultural catchments for all sites in the DAP area through its entire Anasazi occupation (Kohler et al. 1986) it was suggested that during the A.D. 880–910 period the average distance from habitation site to field was at its greatest. For just the Grass Mesa site, some fields conservatively are estimated to have been located 3 km away during this time. We thus anticipate that the zone of significant human impact around Grass Mesa extended at least 3 km by the time the site was abandoned. The simulations of field placement (no actual fields could be discerned) suggest that little or no original forest would have remained in the direction of adjacent contemporaneous settlements to the south, southeast, and southwest by this time.

**Corroborating Data from Elsewhere in the DAP Area**

Fuel data only from several other sites in the DAP area very briefly will be presented to show that some trends observed on Grass Mesa are general to the project area. Four kilometers upstream from Grass Mesa along the east side of the Dolores River is a relatively small Pueblo I village site called Rio Vista (5MT2182; Wilshusen 1986a). The sample of analyzed fuel materials from this site, when pooled with materials from a nearby large hamlet called the Periman site (5MT4671; Wilshusen 1986b; Yarnell 1983) is large enough to warrant examination. The demographic histories of the two sites have been pooled in Figure 7, where they are displayed with population estimates for the McPhee Village, which will be discussed next.

In its location slightly above and east of the river, and in the vegetation mosaic surrounding it, Rio Vista Village is quite similar to Grass Mesa. The changing relative frequencies of fuel taxa at Rio Vista–Periman (Figure 8) also show many similarities to those displayed for Grass Mesa in Figure 4. In both records pinyon–juniper tends to decrease while shrubs and cottonwood increase. The large increase in use of shrubs corresponds with the first portion of the period of high population in this location.

Continuing up the Dolores River about 2.5 km on its west side is McPhee Village (Kane 1985), a concentration of several large room blocks, each of which bears a separate site number. The
population history for McPhee Village is also shown in Figure 7, and the reconstructed vegetational mosaic around this village is shown in Figure 9. Compared with the vicinity of Grass Mesa, pinyon-juniper, mountain brush, and oak are much less common, and big sagebrush is much more common.

The fuel-use record pooled for all sites in the village is displayed in Figure 10. Pinyon–juniper was never used commonly for fuel here, although a sharp decrease is evident between the first occupation and the main occupation. Use of shrubs for fuel also tends to increase from the first through the main occupation of the area, declining sharply after a hiatus in occupation that apparently permitted some regeneration of unidentified pines, pinyon–juniper, and cottonwood. Use of the fast-growing cottonwood tends to increase during the period of main occupation. In all, many of the expectations for local wood depletion are exhibited in this record, although the changes are not so clear as in the two previous cases, probably because the vicinity contains so much sagebrush at the onset of occupation that it is relatively insensitive to disruption that lowers the successional stage of the vegetation in the categories of taxa we have defined.

A final examination of fuel use comes from a group of nine closely spaced sites about 3 km west of McPhee Village. These sites were chosen because the occupation here began as early as or earlier than anywhere in the project area, and because as a group these sites represent a more or less continuous use of a single area by a small population. Six of these sites (5MT2192, 2193, 2194, 2198, 4545, and 4614) are single-household habitations. The other three (5MT2191, 2203, and 4512) are interpreted as seasonally used field houses. Kane (1983b:61–78) provides a general introduction to this portion of the project area, which is characterized by low relief in comparison with the incised valley environments of Grass Mesa and Rio Vista villages, and by greater local availability of pinyon–juniper than at McPhee Village. However, mountain brush and riparian vegetation were relatively remote compared to McPhee Village (see Figure 9).

Figure 11 shows the changing fuel use through time at these sites. Apparently even this rather small-scale though prolonged occupation was sufficient to cause vegetation changes similar to those seen previously at much larger sites. A general decrease in pinyon–juniper and unidentified pine and a general increase in corn and shrubs is apparent despite rather small sample sizes in all portions of the occupation. These changes begin before the desiccation reconstructed by Petersen (1986a) begins, strengthening our contention that the main cause of the changes seen in the other fuel-use records is not climate change.

The decline in use of cottonwood is contrary to expectations but coincides with the rise in population in McPhee Village. The closest major source of this riparian vegetation would have been
Figure 9. Vegetation zones near McPhee Village and a cluster of nine West Sagehen sites (Petersen 1987a). Except for Rio Vista (2182) and Periman (4671), other contemporaneous sites are not shown.
in the vicinity of McPhee Village, and its decline in West Sagehen suggests that either the resource specifically was depleted, or that the Sagehen occupants were being denied access to it, which is hard to understand except in the context of general scarcity.

In summary, all for the DAP area for which we have adequate fuel samples experienced some reduction in pinyon—juniper and increase in shrubby species in accord with the change expected if there were significant human alteration of the landscape through burning, clearing, and woodlot harvest for construction and fuel materials. Evidence that burning was an important mechanism in this change, at least in the earliest portion of the occupation, comes from another record in the western portion of the DAP area. Analysis of charcoal frequencies from sediments in the Sagehen Flats marsh (Petersen 1985) shows that large-scale burning accompanied the first colonization of the DAP area in the early A.D. 600s. Unfortunately, the marsh record is truncated after that time, so there is no evidence for the frequency or severity of burns during the main occupation.

**TOWARD BROADENING CLIMATIC MODELS OF ANASAZI SETTLEMENT**

In the first part of this paper we briefly reviewed evidence pointing to a pattern of local periodicity in early northern Anasazi land use. Much relatively local settlement relocation, and some abandonment and reoccupation at the spatial scale of the sector, cannot be explained by climatic arguments alone, although much larger-scale population movement within the Colorado Plateaus probably is affected by climatically-driven shifts in location of productive agricultural land (cf. Euler et al. 1979).

We then presented evidence that the DAP Anasazi effected major changes in their vegetative environment. In at least one case, that of the Grass Mesa site, and probably in others as well, these changes also had predictable consequences for the make-up of the local fauna and the artifactual assemblage. Land use resulting in this degree of impact could be practiced so long as sufficient rejuvenated areas were available for relocation, but must have become counterproductive at some stage in Anasazi prehistory. The appearance of water-control features in the archaeological record of the northern Anasazi after A.D. 1000 probably signals a change in land use toward more intensive cultivation (Wilcox 1978), a change that probably was adaptive to circumstances in which mobility was limited, and forest resources had to be husbanded more carefully. This apparent intensification of land use may have been unable to wholly compensate for increasingly limited possibilities for mobility, however, since it is about this same time that changed patterns of physiological stress and

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**Figure 10.** Change through time in relative frequency of taxa used for fuel in the McPhee Village area. Sample size: 513 occurrences in 69 features.

Dean et al. (1985) recently have proposed a general model of Anasazi culture change encompassing sets of environmental, demographic, and behavioral variables. They distinguish between environmental variation that is low (greater than 25 years) and high (less than 25 years) in frequency, between differing amplitudes of change, and recognize that environmental variation has different effects on behavior depending on the relationship of the current population to the carrying capacity of the environment. Under appropriate circumstances, several possible behavioral responses to environmental variability are predictable, including mobility, local shifts in settlement location (especially between uplands and valley floors), changes in subsistence mix (which should be enlarged to include the mix of all resources utilized), exchange practices, ceremonials, intensity of agriculture, and maintenance of territorial boundaries.

A simple broadening of this model to encompass environmental variability caused by the dynamic effects of local human impact on the environment, as well as the environmental variability caused by climate change on which these authors focus, much improves its fit with DAP data. While population levels in the Dolores area were relatively low (prior to about A.D. 840), mobility within the project area from locations such as Grass Mesa toward unoccupied areas to the south, as well as among the numerous small habitations that typically were occupied only one or two generations, appears more likely to have been a response to local deforestation and its ramifications for food production, availability of fuel, and composition of fauna than a response to climate change. Local residential mobility is inexpensive in the sense that it can be timed to coincide with the periodic need to rebuild or remodel structures and need not entail abandoning site “furniture” or disrupting social ties.

Migration into the Dolores area around A.D. 850, encouraged by increased desiccation elsewhere and permitted by the still relatively small local populations, radically changed this situation. Local residential mobility became increasingly difficult. Intensification of food production and hunting and enlargement of catchment areas to support the much larger population in an increasingly altered environment probably resulted in increased deforestation via positive feedback mechanisms discussed for the Tarahumara above. A new level of (probably kin-based) social organization arose at this time, possibly as corporate units serving to allocate increasingly scarce and valuable agricultural land (Kane 1986:369).

By the late A.D. 800s, converging low-frequency trends of population growth and environmental
degradation put the local population at risk from high-frequency environmental processes. A series of short growing seasons beginning about A.D. 895 and continuing intermittently through A.D. 910 is reconstructed from high-altitude central Colorado tree rings (the best available proxy, though not as direct as one would wish). Possibilities for local residential mobility were limited and would have been insufficient in any case, given the spatial extent of the short growing seasons and the depleted nature of the local landscape. Long-distance emigration was the eventual response of the vast majority of the population. In evaluating the role of climate change alone in this emigration, it is well to note that although high-frequency dry conditions began in the A.D. 870s, the short growing seasons to which DAP dry farmers would have been especially sensitive did not begin until the mid-890s after some emigration had begun.

Spatial and Temporal Scales of Pueblo I Mobility

Three scales of Anasazi residential mobility that are unrelated to (but may be overridden by responses to) climatic change may be identified from the Dolores data in conjunction with the other northern Anasazi examples. Analogous scales also have been identified by Binford (1983) for historic Nunamiut hunters and gatherers. At the smallest scales, there was movement within a given year through a zone that Binford refers to as the “annual range.” In the case of the logistically organized Nunamiut, a variety of different “site types” was occupied within an area of some 4,000 km² (Binford 1983:380–382).

On a longer time scale, the positioning or hub of this annual range drifted slightly, resulting in a series of contiguous, overlapping annual ranges. Binford found that these somewhat larger zones, averaging more than 5,000 km² according to his informants, might be used by a Nunamiut band for 6 to 10 years as some nonmigratory prey animals and fuelwood became increasingly scarce in the vicinity of good camping locations, and as excrement, flies, and other vermin accumulated in these same areas.

At the largest temporal and spatial scales, the long-term land-use pattern that these inland caribou hunters would have maintained in the absence of significant Western intrusions was reconstructed by Binford through interviews with old Eskimo men. The hub of activities eventually would shift to create a new zone that overlapped little or not at all with the previous one. Perhaps four or five such zones, together encompassing an area larger than 20,000 km² over a period of 40 years, would be exploited before the first was occupied again. Binford refers to the total area thus periodically used by a single band as its territory. As he points out, this pattern of use should create periodicities of occupation both in individual archaeological sites and in the areas in which they are located.

The Anasazi (and particularly the northern Anasazi prior to about A.D. 1000) practiced regular residential mobility on temporal and spatial scales analogous with, though far from identical to, those described by the Nunamiut for Binford. Presumably this behavior is economically motivated. To the extent that mobility is possible, it probably is desirable from an energetic point of view to harvest (or otherwise use up) slowly renewing resources at unsustainable rates, and then move to an adjacent area, not occupied for some time, where the cycle can be repeated. A particular locality within a region or territory then can return to a more mature condition before another cycle of occupation begins. The chief alternative to this extensive land-use practice is an intensification of resource use (possibly including changes in the mix of resources used) which, in the absence of technological change, is less labor efficient, though more efficient in terms of land and resource use.

There are important differences between the Anasazi and the Nunamiut cases. Populations practicing agriculture typically have greater constraints on their mobility than do hunter–gatherers, and consist of much larger groups that cooperatively exploit and together move to a new area. In part as a result of these factors, Anasazi land use within an area remained anchored at one or several large sites that were occupied more or less continuously for most of the time a local area was in use, even while the smaller residential sites were moved across the landscape. (The group of small West Sagehen sites discussed above seems to be an exception to this model, perhaps because their locations were tied to exceptionally productive lands and to nearby, though probably intermittent, marsh resources.) The larger population size of the cooperating Anasazi group was made possible
by, and required, more centralized coordination than in the hunter-gatherer case, a coordination probably achieved in most cases through ceremonial activities that incidentally entailed sharing of information and economic resources, and promoted group solidarity. Such “ceremonial” activities were concentrated at these long-duration, large residential sites such as Grass Mesa with its great kiva.

The imperfect analogy between the early Anasazi and the Nunamiut simply is this: Just as the annual ranges of a single Nunamiut band drifted over the course of a few years to encompass a somewhat larger area, so also were small Anasazi residential sites moved across the local landscape on a time scale of one or two generations, while maintaining some affiliation with a local community. On a larger spatial scale and longer time scale, just as the Nunamiut abandoned distinct zones within a decade, Anasazi communities as a whole would also relocate within a sector every few generations, as was hypothesized for the community centered on Grass Mesa in the early A.D. 800s. On still larger scales, cooperating groups of Anasazi communities occupied and abandoned sectors over a period of two or three centuries unless there were other constraints. In both the Anasazi and Nunamiut cases these periodic abandonments and reoccupations were tied in part to the slow regeneration rates of key biotic resources.

CONCLUSIONS

The demonstration that fuel use changes through time in a long and well-dated series of features at sites in the Mesa Verde region lends empirical support to hypotheses recently put forward by Stiger, Samuels and Betancourt, and others before them, that Anasazi farming and harvest of wood for fuel resulted in substantial reduction in the local woodlands. We also have argued that, so long as regional population densities permitted, this depletion in turn contributed to considerable local residential mobility on short time scales, and on longer time scales, contributed to movement within or between sectors.

Acknowledgments.—Most of the data and some of the analyses reported on here were developed during the Dolores Archaeological Program (Contract No. 8-07-40-S0562), funded between 1978 and 1985 by the Bureau of Reclamation, U.S. Department of the Interior. The program was directed by David A. Breternitz, Allen E. Kane, William D. Lipe, Timothy A. Kohler, and Christine K. Robinson. We appreciate comments on earlier versions of this manuscript by Breternitz, Kane, and Lipe, and by R. V. N. Ahlstrom, E. Blinman, J. Haas, T. W. Killion, K. L. Petersen, S. S. Plog, J. J. Reid, J. D. Rogers, A. H. Schroeder, and C. M. Sinopoli. Figure 1 was drafted by June Lipe, Figure 3 by Eileen Draper, and Figure 9 by Jafus Trammell. Kohler thanks the School of American Research, Santa Fe, where he held a Weatherhead Scholarship while most of this manuscript was being written. This investigation was supported in part by funds provided by the Washington State University Graduate School.

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NOTE

1 All DAP collections, notes, forms, and computerized data are available through the Anasazi Heritage Center 
of the Bureau of Land Management, Dolores, Colorado. Data for the log-linear analysis of Grass Mesa fuels 
were compiled from DP Job 4390 dated 7 July 1985. All other fuel and construction wood analyses were run 
on a copy of the final DAP data base (dated 31 December 1985) maintained at Washington State University, 
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