Large game, agricultural land, and settlement pattern change in the eastern Mimbres area, southwest New Mexico

Karen Gust Schollmeyer *

School of Human Evolution and Social Change, Box 872402, Arizona State University, Tempe, AZ 85287, United States

Abstract

The 12th-century depopulation of large villages in the Mimbres region of the US Southwest has been attributed to a number of causes, including resource stress. This study combines archaeological evidence and models of environmental conditions in the eastern Mimbres area of southwest New Mexico to assess the magnitude and timing of food stress from a combination of a period of reduced precipitation and the effects of prolonged hunting and farming activities on the landscape. Results indicate that large game in the area was quite sensitive to hunting pressure, and was locally depleted long before settlement reorganization occurred. Access to arable land was somewhat reduced around the time of settlement reorganization, but productive land remained locally plentiful. Although the settlement reorganization did not improve access to large game or arable land, farmers’ perceptions of below-average conditions for agriculture relative to their expectations and past experience would have contributed to decisions to move.

Introduction

Resource stress is often assigned a causal role in changes in human behavior, including changes in settlement patterns. This study examines the role of food stress in the dramatic depopulation of large, long-occupied villages in the Mimbres region of the US Southwest at the end of the Classic Mimbres period (A.D. 1000–1130). I examine the availability of agricultural land and large mammals before and after this reorganization by combining information from GIS-based analyses of agricultural land availability, faunal analysis, stable isotope analysis of faunal remains, and mathematical modeling of the effects of human hunting on local large mammal populations. Results indicate that reductions in access to large game would have occurred long before the settlement reorganization took place, indicating game shortages were not a substantial factor in the settlement change. Instead of a response to a long-term imbalance between the human population and available large mammal and arable land resources, the shift was likely a reaction to a series of worse-than-normal years for agriculture in which arable land availability was still sufficient to meet basic needs, but lower than the average conditions for the preceding 80 years. In this area, farmers substantially changed their settlement strategy in part as a response to changes in agricultural productivity relative to their expectations based on previous decades, rather than to a quantifiable threshold of human demand for resources.

Settlement, population, and resource demands in the eastern Mimbres area

The Mimbres region includes southwestern New Mexico, extending slightly into southeastern Arizona and northern Mexico (Fig. 1). Much of the area lies within the Chihuahuan Desert in a region of arid to semi-arid basin and range topography. Vegetation consists largely of dry grassland and desert scrub, with pinyon-juniper woodland and ponderosa pine forests in upland areas (Brown, 1995). The Mimbres region is considered part of the larger Mogollon culture area, although by A.D. 1000 Mogollon material culture is fairly distinct from developments elsewhere in the Mogollon area. The region is well known for its Mimbres Black-on-white pottery, a type with distinctive naturalistic and geometric designs painted in black over a white slip.

During the Classic Mimbres period (A.D. 1000–1130), settlement consisted primarily of large aggregated villages located along streams, particularly in areas with wide floodplains to accommodate agricultural fields. Farmers grew maize, beans, and edible gourds in floodplains and other arable areas, and lived in villages composed of above-ground masonry rooms joined into loosely aggregated room blocks. Villages of up to 100 rooms or more were common in the Mimbres Valley (Fig. 1), with somewhat smaller villages of 50–100 rooms in the eastern Mimbres area (Anyon and Le-Blanc, 1984; Blake et al., 1986; Hegmon, 2002; LeBlanc, 1983). Many Classic Mimbres villages were constructed atop earlier Late Pithouse period (A.D. 550–1000) settlements, showing a long history of occupation of the same locations (Shafer, 1995). Scattered one-room structures were located in more diverse locations and...

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* Fax: +1 480 965 7671.
E-mail address: karen.schollmeyer@asu.edu

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are thought to have been used as field houses (Nelson, 1999:36–40). Classic Mimbres decorated ceramic assemblages consist mostly of Mimbres Black-on-white, with very little non-local pottery (Hegmon et al., 1999).

At the end of the Classic Mimbres period around A.D. 1130, the vast majority of villages throughout the Mimbres region were depopulated, and settlement patterns among the remaining population changed dramatically. In the Mimbres Valley, nearly all villages were depopulated. Small remnant populations persisted in a few villages in the southern reaches of the valley (Creel, 2000; Hegmon et al., 1999). In the eastern Mimbres area the population dispersed from villages into Reorganization phase (A.D. 1130-early 1200s) hamlets in more diverse settings along the same streams, including on the sites of former Classic period field houses (Hegmon et al., 1999, 1998; Nelson, 1999). Hamlets consisted of clusters of just three to twelve cobble masonry rooms, sometimes joined into small blocks. Ceramic assemblages from these hamlets include Classic Mimbres Black-on-white along with larger quantities of other pottery types (both imported and locally made) associated with neighboring regions that had been quite rare in Classic period sites (Hegmon et al., 1999, 2000, 1998). Explanations for this partial depopulation and accompanying change in settlement patterns

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**Fig. 1.** The Mimbres Valley and the eastern Mimbres area.
have focused on social pressures (Hegmon et al., 1998), a period of reduced precipitation and related declines in agricultural productivity (Minnis, 1978, 1985; Pool, 2002), and reductions in resource availability as a result of sustained heavy human use, including reductions in local large game populations (Cannon, 2000, 2001; Minnis, 1978, 1985; Nelson and Schollmeyer, 2003), overexploitation of plants used for food, fuel, and construction material (Minnis, 1978, 1985; Nelson and Diehl, 1999; Sanchez, 1996; Schollmeyer, 2005), and soil degradation (Sandor et al., 1990).

One puzzling aspect of the reorganization is that although several studies have succeeded in documenting environmental changes in the Mimbres area, unambiguous archaeological evidence of responses to resource stress has been more difficult to identify. Another enigmatic feature is the most dramatic depopulation occurred in the relatively wet and productive Mimbres Valley, while the drier eastern Mimbres area (in the rain shadow cast by the intervening Black Range) retained a much greater proportion of its population. It is possible that the population of the eastern Mimbres area more readily shifted strategies to accommodate the more challenging environment there. This greater flexibility may have been part of a land use strategy that emphasized mobility and diversity to reduce the risk of experiencing resource shortfalls (Nelson et al., 2006). I examine these issues by assessing human access to two important resources, productive agricultural land and large game animals, before and after the settlement reorganization and comparing resource availability to the demands of the human population during this time period. This allows me both to assess the likelihood of food stress around the time of the reorganization, and to determine whether the change in settlement patterns had an impact on resource availability for the local population, constituting either a reasonable response to resource stress or an effective tactic to reduce such stress.

Estimating population and resource demands

Assessing resource availability in relation to human needs requires estimates of site populations, population changes over time, and human nutritional demands. In this section I briefly discuss methods used to derive estimates of the population and resource demands of villages and hamlets along the Seco and Palomas drainages (Fig. 1), in order to provide context for the comparisons of resource demands and the availability of productive agricultural land and large game animals, before and after the settlement reorganization and comparing resource availability to the demands of the human population during this time period. This allows me both to assess the likelihood of food stress around the time of the reorganization, and to determine whether the change in settlement patterns had an impact on resource availability for the local population, constituting either a reasonable response to resource stress or an effective tactic to reduce such stress.


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growth (the lowest reasonable human demands and the highest reasonable deer productivity values).

Agricultural yields are difficult to calculate for the study area, but it is helpful to have some frame of reference for assessing whether the amount of productive agricultural land accessible to farmers under various precipitation conditions would have been adequate for growing crops to support the local population. I estimate that the prehistoric population required 1.2 ha of arable land per capita, a figure at the upper end of the range of published estimates for prehistoric and historic Southwestern groups using a variety of field settings similar to those likely used by Mimbres area farmers (Bradfield, 1971; Ford, 1968; Herhahn and Hill, 1998; Hill, 1998; Lange, 1959; Minnis, 1985:115–116; Rhode, 1995; Wetterstrom, 1986). The resulting arable land requirement for each temporal phase is shown in Table 2. These numbers probably overestimate the arable land requirements in the eastern Mimbres area. Ethnographic estimates this high are based on heavy reliance on runoff agriculture, and Minnis (1985:115) has argued that Mimbres farmers used primarily floodplain arroyo mouth fields; his conservative estimate for the somewhat wetter Mimbres Valley was only 0.6 ha per capita. The high value I chose is thus in keeping with my “worst case scenario” approach for agriculture.

Estimates of human nutritional requirements and associated demands on large game are based on an earlier study (Nelson and Schollmeyer, 2003). Studies in the prehistoric southwest have focused on the role of meat in supplying several important nutrients, particularly protein and fat (Speth and Scott, 1989; Speth and Spielmann, 1983; Spielmann and Angstadt-Leto, 1996). In the environment of the eastern Mimbres area, demands on large mammal populations to meet human minimum dietary fat requirements would have exceeded those for protein (Nelson and Schollmeyer, 2003). Dietary fat requirements vary with age, activity, and other factors (Cordain et al., 2000; Whitney and Rolfs, 1996); here, I focus on a low-demand scenario of 14 g per person/day, in order to avoid overestimating potential human impacts on deer populations. I assume a diet in which 80% of total kcal came from maize and 13% from game, a scenario in which game would have contributed about 18% of total dietary fat (Nelson and Schollmeyer, 2003). These estimates are in accordance with other estimates of maize and meat consumption in the prehistoric Southwest (Decker and Tieszen, 1989; Hegmon, 1989; Little and Little, 1997; Martin, 1999; Spielmann et al., 1990; Wetterstrom, 1986:84–85), and are similar to FAO/WHO estimates of the average modern diet in Latin America and the Far East, and to average worldwide values (FAO/WHO Expert Consultation on Fats and Oils in Human Nutrition, 1994).

In considering large game I focus on deer, by far the most common artiodactyl genus identified in the faunal materials from the study area. Individual and seasonal variability, along with a scarcity of appropriate studies, make the total fat content of deer and other wild game somewhat difficult to specify (Speth and Spielmann, 1983); in this study I use a value of 3.2 g of fat per 100 g portion of meat published for “roasted deer meat” from the USDA (National Agricultural Library, 2008), which compare favorably with estimates for hoofed mammals in the Southwest and elsewhere (Cordain et al., 2000; Speth and Spielmann, 1983). Processing bone for additional fat extraction (as discussed below) would have added additional fat to the diet, but is not considered in these estimates. Of the 18% of total dietary fat derived from game, I assume deer meat contributed 40% (or, a total of 7% of the total fat in human diets annually). When averaged over a year, deer consumption would have been about 222 g of meat per week, or about two hamburger-sized portions. Of course, prehistoric people could have used substantially less deer meat by relying on other foods, but this is not an unreasonable desired amount of meat to begin with for modeling purposes; this estimate is also similar to other estimates of prehistoric Southwestern deer demand (Johnson, 2006:212). If deer were available in sufficient numbers to fill this demand, I expect humans would have hunted to at least this level.

Table 2 estimates the annual deer harvest required to sustain the study area’s human population, based on an average sized (79 kg) Southwestern mule deer (Heffelfinger, 2006:59). About a third of this body weight is composed of internal organs often removed by contemporary hunters, but some of these could have been consumed prehistorically. In mammals the skeleton comprises about 7% of total body weight (Lynn, 1979). In this study, I use an extremely conservative 10% non-edible carcass weight to account for inedible bone and hide (Nelson and Schollmeyer, 2003), and assume items such as internal organs and bone marrow were potentially consumable. Although other studies use higher estimates of inedible weight (for example, Cordain et al. (2000) estimate 25% non-edible weight), this is in keeping with my overall “best case scenario” approach for estimating human demands on the local deer population.

Access to productive agricultural land and the Mimbres reorganization

Is there evidence for reduced access to productive agricultural land at the end of the Classic period? Did shifts in settlement patterns improve access to productive land in the study area? I address these issues using geographic information system (GIS) analysis to combine information on runoff capturing potential, soil characteristics, and floodplain characteristics in order to estimate the amount of arable land available under varying precipitation conditions from A.D. 1000 to 1200. An early period of relatively high precipitation was followed by a substantial decrease in the

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<td><strong>Annual resource requirements for the study area population, A.D. 1000–1200.</strong></td>
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period from A.D. 1120–1140. In contrast to the rest of the Classic Mimbres period, farmers after A.D. 1120 would have had to farm either less productive or more distant field areas (rather than very nearby optimal areas alone) in order to cultivate enough arable land to support local populations. Potentially productive land remained plentiful, but the timing of this change from reliance on the closest and most highly productive areas to the necessity for farming additional locations suggests this change in access played a role in the settlement reorganization around A.D. 1130.

This analysis estimates quantities of arable land at decadal intervals rather than making annual estimates of prehistoric productivity. Several well-known studies of agricultural productivity in other regions of the US Southwest do estimate annual yields (Minnis, 1985; Van West, 1994). Other studies have focused on the availability of potentially productive land, with or without also estimating annual yields (Herhahn and Hill, 1998; Hill, 1998; Kruse, 2007; Pool, 2002; Rhode, 1995). In the eastern Mimbres area, the available soil productivity and climate data are relatively imprecise; tree ring data are adequate for reconstructing relatively wet or dry periods but do not reliably indicate past annual precipitation in the study area, and local soil productivity is not well-studied there. Under these circumstances, examining changes in the amount of arable land under different precipitation conditions is more reliable without complex and misleadingly precise productivity reconstructions.

I use GIS software to create a map of the study area composed of 10 $\times$ 10 m cells. Each cell is assigned arability and productivity ratings in several categories based on its runoff capturing potential, soil characteristics, and potential for flooding. I then combine these productivity ratings to determine which cells would have been productive under varying precipitation conditions from A.D. 1000 to 1200. In order to be counted as “arable” in a given time period, cells must receive adequate moisture based on the cell’s runoff capturing potential and direct precipitation received during that time period. Cells must also be situated in an area not over susceptible to flooding given that time period’s precipitation level. “Arable” cells are then classified as “more productive” or “less productive” in a given time period based on soil characteristics determining their ability to capture and hold adequate moisture for crops, again based on precipitation levels during that time period. Finally, I compare the total potentially productive land available under different precipitation conditions with estimated requirements for the study area population. I describe the model and parameters fairly briefly here; additional details are available elsewhere (Schollmeyer, 2009:159–217).

Physical requirements of maize: precipitation, runoff, and soil characteristics

I use 30 cm as the minimum consumptive water requirement for maize; potential field areas must receive this amount of moisture to be considered arable. This is the minimum requirement for contemporary varieties to produce normal ears (Shaw, 1988). Although traditional varieties will continue to produce some harvestable maize with less water (Hack, 1942; Hogan, 1987; Muenchrath and Salvador, 1995), using 30 cm as a minimum allows me to examine a worst-case scenario for agricultural land, or the minimum amount of land that would have been arable. In the study area, the length of the frost free period would not have been a primary limiting factor for maize growth; over the 60-year period of record for the nearby Hillsboro weather station, there is a 90% probability of having at least 165 frost-free days (Western Regional Climate Center, 2005).

Each cell must receive enough moisture from a combination of direct precipitation and runoff to meet maize growth requirements in order to be considered arable. I use decade-level mean estimates of prehistoric precipitation to estimate whether adequate moisture reached potential field areas during the period from A.D. 1000 to the early 1200s. Historic precipitation patterns from three weather stations surrounding the eastern Mimbres area show a relatively high correlation with the historic portion of Grissino-Mayer’s (1997) tree-ring based precipitation reconstruction for southwest New Mexico; Hillsboro (records from 1940 to present, $r = 0.82$), Truth or Consequences (records from 1951 to present, $r = 0.75$), and Elephant Butte Dam (records from 1918 to present, $r = 0.743$) (Western Regional Climate Center, 2005). This correlation indicates the prehistoric portion of Grissino-Mayer’s reconstruction can provide a rough estimate of precipitation in the study area, and a good representation of relatively wet and dry periods there. Using this prehistoric reconstruction, I calculate mean precipitation for each 10-year period from A.D. 1000 to 1200. Based on this approximation of precipitation levels, I assign each decade to one of five precipitation categories based on precipitation relative to the mean of the entire period from A.D. 1000 to 1200 (Fig. 2). The “moderate” category encompasses precipitation values within a centimeter above or below the mean annual precipitation for the study area during this interval. Decades with precipitation values within this range represent the conditions most likely to have been expected by farmers growing maize in the study area. Drier and wetter categories are relative to this mean annual precipitation, and may have posed challenges for maize production. These are relative categories specific to this area and time period, and allow me to assess temporal changes in access to arable land that would have been meaningful to farmers accustomed to local conditions. From A.D. 1101–1120, the late Classic Mimbres period experienced unusually wet conditions. In contrast, in the last decade of this period precipitation levels dropped to their lowest in nearly a century. Precipitation remained quite low in the following two decades of the Reorganization phase. By the end of the Reorganization phase, mean precipitation per decade had risen back to middle Classic Mimbres period levels.

Given the low mean precipitation in the eastern Mimbres area (24.2 cm, well below the 30 cm minimum consumptive moisture requirement for maize) (Western Regional Climate Center, 2005)

![Fig. 2. Precipitation categories based on mean precipitation estimates over 10-year intervals in the eastern Mimbres area.](image-url)
and frequent periods of lower precipitation, fields would have to be situated to take advantage of runoff in order to be productive. The importance of runoff makes considerations of watershed and soil moisture absorption and retention properties critical for examining productive agricultural land in the study area. I identify areas receiving enough runoff for agriculture by calculating the runoff catchment area of each map cell to produce a flow accumulation grid. I then estimate the approximate amount of water (from runoff and direct precipitation) ending up in each cell in a hypothetical average year of each decade using the equation

\[
\text{water entering cell} = 0.15 \times (\text{flow accumulation grid})
\]

where 0.15 is the proportion of the runoff passing over an average cell that is absorbed by that cell (Hofes and Abrahams, 2003; Reid et al., 1999), 0.20 is the proportion of precipitation falling on an average cell that becomes runoff (Dunne, 1978; Rhode, 1995; Sandor, 1983), and pp is the precipitation value for the decade under consideration. These values, drawn from Southwestern studies, are only approximations for estimating the amount of moisture available; in addition to uncertainty about the actual annual precipitation, runoff is affected by the soil moisture content at the time of a precipitation event, soil texture, storm intensity and duration, vegetation type and density, and geomorphology (Wolock and McCabe, 1999).

Rather than relying on these estimates directly, I used the potential moisture values to assign each cell an arability category. Cells with potential moisture values of less than 30 cm (the minimum requirement for maize in my analysis) in a particular time interval were considered too dry to be arable during that interval. Cells with values of 30–605 cm in a time interval were considered arable. The 605 cm value corresponds to the potential moisture value of a cell with a watershed of 10 ha in an average year. Numerous studies in the US Southwest have shown that small watersheds of 8 ha or less are the preferred locations for agricultural fields (Hack, 1942; Homburg, 1997; Kruse, 2007; Sandor et al., 1986b, 1990). Cells with watersheds larger than 10 ha would have been highly vulnerable to washing out in high-magnitude runoff events, and were not considered arable in any time interval regardless of that interval’s precipitation. Surface surveys in the area confirm that this analysis correctly identifies the proportion of study area floodplains consisting of active or recently active water channels, although the exact locations of these channels would have been different prehistorically (Schollmeyer, 2009:189–192). Surface survey was also used to identify the proportion of floodplain areas retaining visible signs of past flooding activity, an area considered especially prone to flooding in wet years (Schollmeyer, 2009:189–192).

The exact locations of prehistoric fields could not be determined from surface survey information in this area (Schollmeyer, 2004a, b), but the areas identified as potentially productive with GIS include small side drainage areas, arroyo mouths, and a large proportion of the floodplains, the landforms on which one would expect to find fields based on studies of Southwestern farming (Doolittle, 2000; Mabry, 2005; Sandor et al., 1986a). This technique simultaneously identifies both areas suitable for flood farming, and upland areas where runoff fields could be situated. Irrigated fields, if they existed, would have been located in some of the areas identified as suitable for flood farming, but would have been more reliable and more productive than flood farmed fields. Because I focus on the availability of arable land rather than productivity estimates, however, the distinction between the two types of field is not important in this analysis.

In addition to receiving an appropriate amount of moisture, potentially arable soils must also be able to absorb that moisture and release it to plants. These qualities are described by soil permeability and available water capacity, characteristics described in published studies of soils in the study area (Neher, 1986). I combined the seven soil permeability categories used by the USDA into three broader classes, “most permeable” (USDA categories fast and very fast), “moderately permeable” (USDA categories moderate and moderately fast), and “least permeable” (USDA categories slow and moderately slow), and assigned each cell to the appropriate class. Cells in all permeability categories were considered productive in wet years. Cells in the “least permeable” category were considered only moderately productive in average years and unproductive in dry years; these cells’ soil characteristics would have prevented them from capturing adequate moisture for crop production from the limited precipitation in dry years. Similarly, cells in the “moderately permeable” category were considered productive in wet and average years, but only moderately productive in dry years, when they may have been unable to capture adequate moisture. Cell available water capacity showed no meaningful variability in this study and is not considered farther here (but see Schollmeyer, 2009:186–188).

The suitability of each map cell in the study area for agriculture in each decade is based that cell’s “arability” category (arable or not arable, based on the suitability of its watershed size for that decade’s precipitation category) and the cell’s “productivity” class (based on the suitability of its soil permeability for that decade’s precipitation category); the result is a grid of cells classified as potentially “most productive,” “moderately productive,” or “unproductive/not arable.” During moderate, dry, or very dry decades, the total area of arable land in the “most productive” category is the total area encompassed by cells valued “most productive” in the arable land grid, and the total area of “moderately productive” land is the total area encompassed by cells valued “moderately productive” in the arable land grid. During wet and very wet decades, the total area of arable land in the “most productive” category is the total area encompassed by cells valued “most productive” in the arable land grid, —25% of the area classified as prone to flooding (as discussed above); “moderately productive” arable land again consists of the total cells assigned a value of “moderately productive.” During all decades, cells assigned a value of 0 (uplands or slopes receiving too little runoff, gullies and streambeds receiving too much runoff, and rock outcrops as identified in soil survey data) are not considered arable.

Cultural practices and arable land

In order to examine those areas most likely to have been used by prehistoric farmers, I limit my evaluations of field areas to locations within a limited radius of any site in a site cluster. Many studies suggest the most intensively used field areas are within five kilometers or less of residences (Bradfield, 1971; Chisholm, 1968; Dennell, 1980; Herhahn and Hill, 1998; Higgs and Vita-Finzi, 1972; Hudspeth, 2000; Kohler et al., 1986; Varien, 1999:153–154), so I limit estimates of arable land to areas within this distance of residential sites. In order to account for topographic variation in the study area, I use a cost surface grid based on a 1:24,000 digital elevation model to identify a catchment area around each cluster equivalent to the energy expended walking a set distance (3 km, 4 km, or 5 km) on level ground, following the procedures outlined by Herhahn and Hill (1998). These catchments are not meant to suggest a bounded territory associated with the clusters or individual sites. Instead, they delimit the area most likely to have been used for fields by the cluster’s inhabitants.

A final consideration in arable land estimates is the extent of fallingow. It is unclear under what circumstances soil nutrient depletion was a concern for prehistoric Southwestern farmers, or how they responded to it (Homburg, 1997; Sandor, 1995; Sandor...
et al., 1986b, 1990; Sullivan, 2000). Southwestern soils are often low in nutrients such as nitrogen, but traditional maize varieties in the area are adapted to these soils (Hogan, 1987; Muenchrath et al., 2002). Fields in the study area would not have been arable without substantial runoff (as discussed above), which would have added nutrients to the fields (Bradfield, 1971; Cushing, 1920; Hack, 1942; Kohler and Matthews, 1988; Muenchrath et al., 2002; Nabhan, 1984; Sandor, 1995). In this model, I assume fields lay fallow 50% of the time (Muenchrath et al., 2002). Although this is likely an overestimate, particularly for floodplain fields (Mabry, 2005:117–119; Minnis, 1985; Nabhan, 1979), this figure is in keeping with my overall approach of a “worst-case scenario” for agricultural land availability. Assuming 50% of potentially arable land was left fallow also takes into account the spacing needed between fields to re-accumulate runoff (Herhahn and Hill, 1998; Hill, 1995, 1998), a factor not addressed in this model’s runoff catchment area estimates.

Results of arable land estimates

The results of calculating arable land availability within a 5 km walking distance of sites for the period from A.D. 1000 to 1200 are shown in Fig. 3. Even in the modeled “worst case scenario” (high parameters for human demands and low productivity parameters), arable land in the “most productive” category would have been adequate to support local populations in most years if farmers in the study area were willing to use field areas within a 5 km field catchment area of their villages. Notably, the only exception to this occurs in the period from A.D. 1121–1130, the time of settlement reorganization and population movement from villages to hamlets. During the wet years of the middle and late Classic Mimbres period, farmers in most site cluster areas would have been able to focus on arable land within a smaller, 4 km field catchment area of their villages. Again, an exception to this was the period from A.D. 1121–1130, when larger field catchment areas would have been necessary. Even during this dry decade, however, the total arable land in the “most productive” category for all clusters was adequate to meet the needs of the study area’s total population; although some clusters lacked adequate land in this category within 5 km, other clusters still had more than enough. In other words, a balance between human population and highly productive land within 5 km of sites could have been achieved by simply moving some people from one settlement cluster to another, rather than the dramatic change in settlement we see archaeologically.

There is no significant difference between the Classic period and Reorganization phase in the proportion of land within 5 km of sites classified as arable in the driest years (the conditions at the time of settlement reorganization) (Fig. 4), or in the proportion of arable land classified in the “most productive” category in the driest years (the cells with soil permeability characteristics most conducive to capturing the small amount of precipitation available). Similar results apply to examinations of land within 4 km and 3 km of sites, and to comparisons for moderate and wet years (data not shown). Thus, the 12th-century dispersal from villages to hamlets does not appear to have increased the accessibility of productive land to farmers. The timing of the relative decline in arable land availability makes it likely that the reorganization was, in part, a response to this period of reduced precipitation and arable land availability. Conditions for agriculture at the time of settlement reorganization were at their worst in 80 years, making this the driest period in memory for late Classic period farmers. Further, human populations were far higher than populations in the preceding dry periods of the early Classic period and before, exacerbating the effects of reduced precipitation. However, these effects do not appear to have been dramatic enough to have necessitated a choice between leaving established villages or facing nutritional hardships. Even under the “worst case scenario” modeled here, cultivating both the “most productive” and “less productive” arable land within 5 km field catchment areas around villages would have provided more than enough arable land to support all village residents. These fields probably had lower crop yields or involved walking slightly farther than farmers in some villages were used to, but plenty of farming area was available within 5 km of sites in the study area as a whole—more than twice as much as needed, even in the driest years. Farmers’ response to this period of resource
stress appears to have been greater than predicted on the basis of likely nutritional stress alone, an idea I return to later in this discussion.

**Large mammal resources and the Mimbres reorganization**

Meat, especially from large game, comprised a relatively small portion of the prehistoric diet in the Southwest. However, artiodac-
tyls were probably highly desirable both as food (particularly as a source of protein and fat) and for social reasons (Driver, 2002; Grimstead and Bayham, 2010; Nelson and Schollmeyer, 2003; Spielmann and Angstadt-Leto, 1996). Puebloan ethnographies suggest that the “willingness” of large mammals to be captured depended on proper social behavior by hunters, and declines in large mammal availability were historically viewed as sympto-
matc of problems with the social and natural environment (Beagle-
hole, 1936; Parsons, 1925; Potter, 2004). Archaeological examples also indicate large mammals had important associations with rit-
ual and prestige in the prehistoric Southwest, often far beyond their dietary importance (Driver, 1997; Potter, 1997, 2000). In the Mimbres area, large mammals similarly appear to have been socially valued. In at least two sites with well-provenienced assemblages of figurative bowls, artiodactyl images are substan-
tially more common than those of lagomorphs. At Galaz Ruin, 34% of bowls with identifiable mammal designs depict artiodac-
tyls, and only 16% depict lagomorphs; the smaller bowl sample from NAN Ranch also contains substantially more artiodactyl images than lagomorphs (6 of 11 identifiable mammal images are of artiodactyls, two are of lagomorphs) (Kulow and Schollmeyer, 2005). However, lagomorphs dominate the faunal assemblages, comprising more than two thirds of mammal remains at both sites (Anyon and LeBlanc, 1984:216; Shafer, 2003, 1991); artiodactyls comprise less than 20% of the count of mammalian remains at either site. This pattern suggests large game was socially important in ways beyond its dietary contribution. Access to large game, including its abundance and the distance people had to travel in order to obtain it, would have been an important factor in farmers’ perceptions of their environment.

**Zoarchaeological and stable carbon isotope evidence**

The settlement reorganization around A.D.1130 was not accom-
panied by substantial changes in diet. Paleoethnobotanical analy-
ses of hearth samples from Classic Mimbres period villages and Reorganization phase hamlets show uniformly high ubiquity val-
ues for agricultural products, indicating similar levels of reliance on agriculture (Nelson and Diehl, 1999). The range of wild plants used also shows no change over time (Nelson and Diehl, 1999). Similarly, an examination of the animal species used in both peri-
ods indicates no changes in diet breadth, with similarly low species diversities in all assemblages (Schollmeyer and Coltrain, 2009).

Although no substantial changes in the diet of prehistoric farm-
ers occurred with the settlement reorganization, it is possible that the move to scattered hamlets increased the accessibility of large game. If the 12th-century settlement reorganization improved eastern Mimbres area farmers’ access to large mammals, I would expect the archaeological record to indicate that a greater percent-
age of the large mammals required for social and nutritional pur-
poses were available locally at Reorganization phase hamlets. Interestingly, analyses of fragmentation, large mammal abundance relative to lagomorphs, and skeletal element abundances show no changes indicative of improvement in access to large mammals with settlement reorganization (Schollmeyer, 2009; Schollmeyer and Coltrain, 2009). Large mammal bone fragmentation levels are similarly high in both periods, suggesting continued efforts to extract as much fat and other nutrients as possible from a limited resource (Schollmeyer and Coltrain, 2009). Large mammal abundance relative to lagomorphs is similarly low in both periods, showing no improvement in access with the settlement reorganiza-
tion (Schollmeyer and Coltrain, 2009). Finally, analyses of large mammal body part representation accounting for both meat and marrow utility do not indicate changes in the distance carcasses were transported from hunting areas to residential sites; there is no apparent difference in the amount of in-field carcass processing that took place before artiodactyls were transported to villages or hamlets (Schollmeyer and Coltrain, 2009).

It is potentially difficult for these measures to distinguish between scarcity so great that animals captured some distance away were transported nearly whole, versus the use of rare but locally acquired large game. Stable carbon isotope analysis of col-
lagen extracted from archaeological deer bone provides a way to distinguish between these possibilities (Schollmeyer and Coltrain, 2009). Deer comprise the majority of the artiodactyls identified in the eastern Mimbres fauna, making them most appropriate for this analysis. Deer diets in the study area are low in native C₄ and CAM plants (Boeker et al., 1972; Stephenson et al., 1985a,b), so animals captured near settlements with access to maize fields should show a higher level of maize consumption (shown in higher δ¹³C values in bone collagen from the consump-
tion of this C₄ plant) than those acquired from more distant areas with little human settlement (like the Black Range mountains 20 km to the west). Samples from eastern Mimbres area deer from the Classic period and Reorganization phase show no significant difference between periods in maize consumption (Schollmeyer and Coltrain, 2009). In both periods, some captured deer appear to have been consuming moderate amounts of maize (Schollmeyer and Coltrain, 2009). Although the archaeological evidence from both time periods indicates artiodactyls were a scare resource around sites (relative to lagomorphs) and tended to be very highly processed for nutrient extraction, some of the deer hunters did manage to acquire were obtained near fields where they had access to maize, rather than from more distant sources.

**A mathematical model of the deer population and the effects of human hunting**

Archaeological faunal remains show no statistically significant differences between time periods that would suggest changes in hunters’ access to large game. However, they cannot entirely rule out the possibility that more subtle changes in large game accessi-

I use an age-structured deer population model in annual time-steps to examine the likelihood of substantial changes in the study area’s deer population around A.D.1130, and to examine the effects of different levels of hunting on local deer populations. This model describes the growth of a population with just a few basic demographic parameters based on the population dynamics of deer in New Mexico, and represents the “best-case scenario” for hunters I can reasonably build under local conditions in the study area. A positive result (substantial negative human impacts on large game populations) is the most interesting result for this analysis, so I considered overestimating the potential for negative human impacts a more serious error than underestimating that potential. Thus, I chose the most favorable parameters for deer productivity from the range available based on modern deer population research in and near the study area.

Age classes in the model consist of fawns (born in each annual time step), yearlings and adults. Adults can live up to 10 years, and maintain constant survival and fecundity rates throughout the adult stage (Cooke, 1993:847; Heffelfinger, 2006:167; Logan, 2001). In each modeled year, the total deer population depends on the number of deer that were born and died in the previous year. Each year’s fawn population depends on the number of surviving deer in each age class from the previous year, multiplied by the age-class-appropriate fecundity rate. In other words,

\[ N_x(t+1) = S_xN_x(t) \]

where \( N_x(t+1) \) is the number of deer in age class \( x \) and \( S_x \) is the survival rate of that age class. The population in subsequent age classes (yearlings and adults) is based on the number of deer that survived the previous year:

\[ N_{x+1}(t+1) = S_xN_x(t) \]

where \( N_{x+1}(t+1) \) is the number of deer in age class \( x+1 \) and \( S_x \) is the survival rate of that age class. To calculate the total deer population at the end of each 1-year time step, the equation for each age class (fawns, yearlings, and adults) is solved, and their products added. I modeled this population using RAMAS Ecolab software (Açkakaya et al., 1999), which allowed me to include variability (both demographic stochasticity and annual variability in population parameters) and to easily translate harvest rates into numbers of deer harvested. A more abstract model based solely on survival, fecundity, and hunting rates gave results identical to those discussed here (Schollmeyer, 2009:143–146).

Model parameter values were drawn from studies of modern Southwestern deer, preferably mule deer from as close to the study area as possible. Detailed discussion of each value is available elsewhere (Schollmeyer, 2009:137–142). Population dynamics are controlled largely by fertility and mortality. In this model, fertility is controlled by the fecundity rate for each age class: adult deer (1.07), yearlings (0.60), and fawns (0.03), based on doe fetal rates in Southwestern studies (Heffelfinger, 2006:Table 15; Logan, 2001:486–487; Mackie et al., 1982; McCullough, 1987). Mortality is controlled by the survival rate for each age class: adult deer (0.85, meaning 15% mortality), yearlings (also 0.85), and fawns (0.39), with each rate again based on Southwestern studies (Heffelfinger, 2006:168; Logan, 2001:353; Mackie et al., 1982). Annual variability for each of these parameters was based on published standard deviations (Logan, 2001). Variability in each parameter and demographic stochasticity were incorporated at each time step according to the standard procedures of RAMAS Ecolab (Açkakaya et al., 1999), with the simulation run 500 times in order to estimate mean trends of population abundance. A starting deer population density of 0.83 deer per km² is based on a local wildlife biologist’s estimate for an unhunted 627 km² property that comprises much of the western portion of the 968 km² study area (N. Lawson personal communication, 2000; Nelson and Schollmeyer, 2003). I added human harvest to this basic population model to assess how hunting rates affected the deer population over 50-year intervals. Hunting rates assumed fawns were not hunted and that hunting rates for all other age classes were equal. In reality fawns were probably hunted at some level, but an appropriate rate is difficult to determine, and assuming no fawn hunting is in keeping with my approach of modeling a “best-case scenario” for deer population growth.

According to this model, the maximum sustainable harvest rate for eastern Mimbres deer (the maximum harvest rate for which the simulated population size does not decrease over time) is 18.1%. This value is slightly lower than those used by modern game managers in many parts of the US, which are often around 20% (Day, 1986:94–95; Hesselton and Hesselton, 1982:895). However, deer recruitment rates in Southwestern deer populations are quite low compared with other parts of the country (Heffelfinger, 2006:239), and the eastern Mimbres area is relatively low in deer productivity even within the Southwest. Studies in Arizona and New Mexico have found that in some areas, harvesting as few as 10% of does is enough to cause long-term population declines (Short, 1979), so a population harvest rate of 18.1% is not unheard of. Assuming the starting deer population density discussed above, this translates to a harvest of about 94 deer per year in the study area.

How does this sustainable harvest rate compare to the demands of the prehistoric human population? Fig. 5 shows this harvest rate relative to the level of demand in each time period. The center horizontal line in the figure represents the mean population over all 500 model runs, and the vertical lines at each time step show one standard deviation around this mean. The diamonds shown at each time step show the minimum and maximum population reached in any of the 500 runs. Maximum abundances show a greater difference from the mean than do minimum abundances, because the sources of variability in this model are additive; a succession of more than usually productive years can occasionally produce a very high maximum abundance. Although it is theoretically possible for the deer population to occasionally reach very high levels under this model, this very seldom happens (as shown by the fairly narrow range within the standard deviations). In a real population, intraspecies competition for resources would combine with predation to keep the deer population at or below the carrying capacity for the area.

In the best-case scenario modeled here (assuming no previous human hunting, the highest plausible survival and fecundity rates, and reasonably low demands for deer), an 18.1% annual harvest rate provides enough deer to fill the demands of the local population during the early part of the Classic period, before about A.D.1050. However, by the middle portion of the Classic period (A.D.1050–1100), filling the human population’s demands as modeled here would require a 26% harvest rate. Within 15 years, maintaining this level of demand would reduce the local deer population so dramatically that even maintaining this high 26% harvest rate would bring in less than half of the desired number of deer (Fig. 6). Farther increasing the harvest rate (to bring in more animals) would make the deer population decline even faster.

Deer population under this scenario would have begun to decline rapidly and dramatically in the middle Classic period. At some point, harvest rates would have decreased as hunters’ deer encounters became increasingly rare. By that time, however,
hunters would already have reduced the local deer population so much that even at reduced hunting rates, human demands on deer could easily prevent the deer population from recovering. Fig. 7 provides one example of this phenomenon, showing mean population over 500 model runs. In this scenario, humans hunted at the 26% harvest rate required to fill the modeled middle Classic phase demand for just 5 years, then decreased their deer demands (and their harvest rate) to half of the former level. After just 5 years, the deer population is already so low that in order to meet even this much-reduced demand, hunters in this scenario must harvest the reduced deer population at a rate of 18.6%, slightly higher than the maximum sustainable rate of 18.1%. Despite dramatic reductions in hunting, the local deer population does not recover; instead it shows a very brief initial increase followed by a protracted decline under continued overharvesting.

This model indicates that after as little as 5 years of hunting at a reasonable level of demand by the middle Classic period population, eastern Mimbres deer numbers may already have declined so much that even reducing human demands by half would have failed to halt their continued decline. Prehistoric agriculturalists could (and clearly did) survive on less deer meat by relying more heavily on other plant and animal foods. The study area landscape does not support large numbers of nut-bearing trees or prairie dogs (both important fat resources in other areas), but the archaeological record from these sites shows that prehistoric people did use a wide range of resources to meet their dietary needs. Although other foods were available, the demand modeled here is not an unreasonable desired quantity of deer for the local population, considering their status as both a high-ranked food resource and a socially prestigious one. Harvesting deer at sufficient levels to obtain this desired quantity of animals annually would very quickly have reduced the deer population to levels at which farmers could expect to obtain deer meat only a few times per year. This would have been a dramatic change for local people, particularly after the relative plenty of the early Classic period.

The results of this deer population modeling are robust; although some argument is possible about the values and assumptions used here, only a dramatic increase in deer productivity could change the fact that the modeled human demand at the height of human occupation in the study area was far greater than the local deer population could have supported. Similarly, it would take more than a 30% reduction in the estimates of human demand used here to lower the middle Classic period deer demand to a level supportable in the study area. The results of this deer population modeling also agree with the results of the faunal analyses. Deer appear to have been a scarce resource throughout much of the Classic Mimbres period, with no improvement during the Reorganization phase.

An even earlier depletion scenario characterizes the Mimbres Valley. Cannon (2000, 2001) documents a decline in large mammal availability by the latter centuries of the Late Pithouse period (A.D. 550–1000), including both decreased artiodactyl abundance relative to lagomorphs and changes in artiodactyl body part representation suggestive of long-distance transport. The Mimbres Valley’s Late Pithouse period human population was probably higher than that of the eastern Mimbres area, but the Mimbres Valley is also more mesic and productive for many plants and animals. Pithouse period occupations in the eastern Mimbres area are poorly understood. However, given the high level of fragmentation in large mammal bone in all the eastern Mimbres assemblages, it is certainly possible that declines in deer and other large mammal populations in the study area occurred even earlier than the middle Classic phase decline indicated here.

What did these patterns mean for Reorganization phase hunters? By the end of the Classic Mimbres period, local deer would
have been so depleted that even the lower demands of the somewhat reduced Reorganization phase human population would have far outstripped deer availability. Dispersing this human population out of villages and into hamlets scattered in a variety of settings may have increased access to other wild resources, but not to deer. In a landscape as deer-poorest of the study area appears to have been in the middle and late Classic period, hunters would have been ranging quite far to obtain animals, and the field houses that were remodeled into hamlets after A.D. 1130 are very unlikely to have been deer refugia attractive to human hunters. The eastern Mimbres reorganization took place in a landscape that had been locally deer-depleted for at least 50 years, and probably longer. Although stable carbon isotope analysis indicates some deer were still available in the area, the chances of success for any given hunt must have been quite small. Human attitudes towards or feelings about this level of deer depletion may have contributed to dissatisfaction that contributed to the A.D. 1130 reorganization, but that reorganization could not have improved access to deer.

Resource stress and the Mimbres settlement reorganization

Below-average conditions for resource access at the end of the Classic Mimbres period likely contributed to the settlement reorganization, but they do not explain its magnitude. Access to the most productive agricultural land was reduced in the decade preceding the reorganization, but plenty of arable land remained available. Access to large mammals was low, but this had been the case for at least 50 years before the reorganization took place. The residential abandonment of long-established villages in favor of scattered hamlets after A.D. 1130 did nothing to improve resource access that could not have been accomplished by shifting residence between existing Classic Mimbres villages.

What, then, did changes in resource access mean for the 12th-century reorganization? This study suggests that eastern Mimbres area farmers made substantial changes in settlement strategies in response to below-average conditions, not to long term population-resource imbalances. In the decade before the settlement reorganization, access to the most productive land immediately around villages was at its lowest in 80 years; this would have been a hardship to farmers used to better conditions, despite the continued availability of highly productive land somewhat farther away. The decision to leave the Classic Mimbres villages for scattered hamlets is a somewhat stronger response than one might expect under these conditions, but other factors played an important role. Access to large mammals remained chronically low, a situation that may have colored hunters’ perceptions of the welfare of the social and natural world. Other lines of evidence also point to potential unrest in Mimbres society. The Classic period was characterized by relatively homogeneous material culture as expressed in architecture and ceramics, a pattern that may have been linked to high levels of social control in parts of the Mimbres region (Hegmon et al., 1998). Despite this possible tension, there is little evidence for physical violence during the Classic Mimbres period (Hegmon, 2002; Hegmon et al., 2008), although this topic has seen relatively little focused research. Among other things, Classic Mimbres social control may have included use-rights to the most productive land immediately surrounding villages (Shafer, 1999). After the reorganization, hamlets show a remarkable expansion in architectural and ceramic diversity, including greatly expanded social connections outside the Mimbres area, and mix previously discrete traits in novel ways (Hegmon et al., 1998). Perhaps the declining availability of highly productive fields near villages after A.D. 1120 contributed to building tensions already present in the Mimbres social system, including strife over use-rights to the remaining high-productivity fields.

Conclusions

Each of the diverse methods used to explore large mammal availability in this study points to the same conclusion: large game animals, particularly deer, were depleted in the areas around Classic Mimbres villages. Other studies in the US Southwest document similar depletion of large game in the immediate environs of large, long-occupied villages (Badenhorst and Driver, 2009; Cannon, 2001; Driver, 2002; James, 2004; Spielmann and Angstadt-Leto, 1996; Szuter and Bayham, 1989; Szuter and Gillespie, 1994). One sobering aspect of this analysis is the apparent ease with which humans could push a sensitive resource into a state of decline from which recovery was quite difficult as long as any sizeable human population remained in the area. Fortunately for southwestern large mammal populations, refuges in areas less densely populated by humans were common enough that these species were not locally extirpated, and animals did eventually recover in affected areas once local human use declined; deer, pronghorn, and elk are very common in much of the US Southwest today.

The relationship between 12th-century Mimbres settlement pattern changes and the availability of agricultural land supports the idea that farmers’ decisions to relocate their primary residences were linked to perceptions of relative changes in the natural and social environment rather than to archaeologically visible thresholds of resource stress or long-term population-resource imbalances. A number of other studies in the US Southwest document a similar lack of direct correspondence between apparent levels of resource stress and the strength of human responses at times of dramatic settlement pattern change (Judge, 1989; Van West, 1994:188; Varien et al., 2007). Perceptions of risk and vulnerability have a profound influence on human reactions to events, including the strength of reactions relative to different levels of risk (Bollig and Schulte, 1999; Mbow et al., 2000; Ortiz, 1979). In particular, farmers’ estimates of risk, variance, and return rates tend to be based on their personal knowledge of the past and of present conditions, not on probabilistic estimates (Ortiz, 1979; van der Leeuw, 2000). Estimates of success or failure are often related to human control over the outcomes, with hazards perceived as greater when humans lack the ability to control them (Bollig and Schulte, 1999; Mbow et al., 2000). A prolonged decline in productivity, particularly one related to forces of drought beyond human control, would have been seen as profoundly negative by 12th-century farmers even if the decline was not severe enough to cause lasting nutritional deprivation. Such a decline in productivity may have been perceived as part of a larger pattern of failure for a particular social system or way of doing things, particularly when combined with social stress in aggregated communities, and other perceived symptoms of discord between humans and aspects of the social and natural environment (like a long-standing reduction in large mammal hunting success rates). Although this study focused primarily on variables in the natural environment and on resource stress, its results highlight the profound importance of social variables in structuring when and how humans modify established land-use practices in response to changing conditions.

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