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THE SOCIAL CONSEQUENCES OF CLIMATE CHANGE IN THE CENTRAL MESA VERDE REGION

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Abstract

The consequences of climate change vary over space and time. Effective studies of human responses to climatically induced environmental change must therefore sample the environmental diversity experienced by specific societies. We reconstruct population histories from A.D. 600 to 1280 in six environmentally distinct portions of the central Mesa Verde region in southwestern Colorado, relating these to climate-driven changes in agricultural potential. In all but one subregion, increases in maize-niche size led to increases in population size. Maize-niche size is also positively correlated with regional estimates of birth rates. High birth rates continued to accompany high population levels even as productive conditions declined in the A.D. 1200s. We reconstruct prominent imbalances between the maize-niche size and population densities in two subregions from A.D. 1140 to 1180 and from A.D. 1225–1260. We propose that human responses in those subregions, beginning by the mid-A.D. 1200s, contributed to violence and social collapse across the entire society. Our findings are relevant to discussions of how climate change will affect contemporary societies.

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[3] Possibly including decreased infant mortality. Though similar suggestions can be traced back at least to Malthus (and see Dettling and Kearney 2011 for contemporary support) many archaeologists have viewed natality as regulated primarily by social norms and therefore not very elastic in the short term.

Abstract

Las consecuencias del cambio climático varían a través del tiempo y espacio. Por lo tanto, estudios efectivos de las respuestas humanas al cambio ambiental climáticamente inducido tienen que muestrear la diversidad ambiental experimentada por sociedades específicas. Nosotros reconstruimos historias poblacionales desde 600 hasta 1.200 d.C. en seis porciones ambientalmente distintas de la región central de Mesa Verde, en el suroeste de Colorado, relacionándolas con cambios climáticamente inducidos en el potencial agrícola. En todas menos una de las subregiones, aumentos en la extensión del nicho del maíz llevaron a incrementos en el tamaño poblacional. La extensión del nichodel maíz también está positivamente correlacionada con estimaciones regionales de tasas de natalidad. Las altas tasas de natalidad continuaron acompañando altos niveles poblacionales aún cuando las condiciones productivas declinaron en el 1.200 d.C. Nosotros reconstruimos desbalances destacados entre el tamaño del nicho del maíz y las densidades poblacionales en dos subregiones desde 1.140 a 1.180 años d.C. y desde 1.225 a 1.260 años d.C. Proponemos que, comenzando a mediados del 1.200 d.C., las respuestas humanas en estas subregiones contribuyeron a la violencia y al colapso social a través de toda la sociedad. Nuestros hallazgos son relevantes para las discusiones acerca de cómo el cambio climático afectará a las sociedades contemporáneas.

As contemporary societies grapple with the effects of climate change, there is increased interest in studies of the social impacts of climate change in the past. Such studies can improve understandings of the complex relationships between social and natural systems and inform decisions in the present (Diamond 2005; Foster 2012; Kintigh et al. 2014; Turner and Sabloff 2012; van der Leeuw and Redman 2002). Yet assessing the impacts of climate change on human societies remains difficult because critical social and natural variables—for example, population size and birth rates, subsistence potential, environmental diversity, and social organization—not only have differing degrees of sensitivity to climate change, but also vary across space and time.

Due to its long history of paleoclimatic research, environmental diversity, and well-preserved and researched archaeological record, the U.S. Southwest is well suited to studies disentangling the complexity of social and environmental relationships (Glowacki 2015; Hegmon et al. 2008; Kohler et al. 2010; Mills et al. 2013). Despite these benefits, most analyses have examined human-environment interactions as spatially uniform. The classic strategy is to use a tree-ring series as a proxy for regional temporal variability in maize production and to compare this to indices of demographic or social change. Yet, human societies typically encompass regions with considerable environmental diversity, and thus one would expect the effects of climate change on agricultural success to be locally variable (Adams and Petersen 1999; Glowacki 2015).

We know that for the greater Southwest—including most of Colorado, New Mexico, Utah, Nevada, California, and all of Arizona—soil moisture reconstructed from tree-rings was below average for nearly the entire thirteenth century A.D., reaching a nadir in the late 1200s matched by only three other episodes in the last millennium (Cook et al. 2015: Fig. 1). At roughly the same time prehispanic population size in the Southwest as a whole was likely reaching a maximum (e.g., Doelle 2000). Here we examine the collision between these broad-scale trends by focusing on population histories and the effects of climate variation for agriculture in six adjacent but ecologically distinct subareas of southwestern Colorado (Figure 1).

Prehispanic Pueblo peoples first settled this region in large numbers about A.D. 600, but their society collapsed rapidly between A.D. 1250 and 1280 (Glowacki 2015; Kohler et al. 2010; Ortman 2012), with the final depopulation corresponding to drought evident by the mid-A.D. 1200s (Douglass 1929:766–767) but most severe from 1276–1299; Douglass (1946:20) called this the great drought. Our reconstruction of the maize dry-farming niche—the portion of the landscape on which precipitation-fed maize agriculture was feasible (Bocinsky and Kohler 2014)—suggests that drought was not catastrophic throughout the region but made farming extremely difficult, if not untenable, in certain areas. Our reconstruction of population change suggests the great drought finalized a migration that was already underway, likely intensifying the significant violence associated with the final collapse of Mesa Verde society (Kohler et al. 2014; Kuckelman et al. 2002; Kuckelman 2010). Our results thus suggest that the effects of climate change are felt most directly at the margins of society, but the responses of those affected can destabilize entire societies. Here, and likely in many other cases, the success of an agricultural society during good times led to increasing vulnerabilities as a growing population spread into marginal land. Then, during climatic downturns, these marginal populations drive social instability through their attempts to access resources controlled by their less-vulnerable neighbors.

This work presents new results from the Village Ecodynamics Project (VEP; Kohler and Varien 2012). The project, begun in 2002, is now completing a second phase in which we have expanded the original 1800 km^2 study area in southwestern Colorado to a 4600 km^2 area in the heartland of the Mesa Verde region of the Pueblo cultural tradition (Figure 1; Lipe 1995:143; Varien 2000:6–7). This second phase, VEP II, also added a second study area in the northern Rio Grande region of New Mexico, the area to which most of the central Mesa Verde population moved during the thirteenth century (Ortman 2012). Our demographic reconstruction for this southern study area is presented by Ortman (2014).

We developed estimates of maize productivity and population size for the original VEP I study area, identifying two cycles of population growth and decline (Kohler 2012; Ortman et al. 2007, 2012; Varien et al. 2007). Here we extend this work to the larger VEP II northern study area, reconstructing demography and using a new technique to estimate the proportion of land within the maize niche for each of the following six subregions (Figure 2):

1. *Mesa Verde National Park* (MVNP) follows the federal boundaries to account for its unique history of research (Lister 2004). Most of this subregion has been surveyed, including recent re-survey of areas affected by wildfires (e.g., Kleidon et al. 2003, 2007); we treat the entire park as a single full-coverage block survey. The park contains the largest sites and site concentrations on the Mesa Verde cuesta, differing significantly from areas outside MVNP but on the cuesta, where significantly lower site densities have been documented (e.g., Chenault 1996).
2. *Mesa Verde Landform* contains the portion of the Mesa Verde landform not in MVNP. Its boundaries are defined by the north and west escarpments of the

Mesa Verde landform and the southern and eastern edges of the study area. The Ute Mountain Ute Tribe owns much of this land, including sites in the Ute Mountain Ute Tribal Park (Morris 1919; Nickens 1981; White 1992; Wilshusen and Blinman 1992). This subregion is generally lower in elevation than MVNP.

3. *Dolores* is centered on the Dolores River Valley, delimited on the south by the Mesa Verde escarpment and Weber Mountain, by the study-area boundary on the east and north, and by Highway 491 on the southwest. On the northeast it is bounded by the 2400-m contour, chosen because maize cultivation is difficult above this elevation and few prehispanic Pueblo habitations are found. Its best-known sites are the Early Pueblo villages investigated by the Dolores Archaeological Program (Breternitz et al. 1986).

4. *McElmo* is a large subregion on the western side of Montezuma Valley including McElmo Canyon, portions of Canyons of the Ancients National Monument (CANM), and many sites excavated by Crow Canyon Archaeological Center (Varien and Wilshusen 2002). Its boundaries extend from the Mesa Verde escarpment to Yucca House on the southeast, the 2400-m contour surrounding Sleeping Ute Mountain on the south, US Highway 491 on the northeast, the study area boundaries in the northwest, and the 1800-m contour to the southwest. The 1800-m boundary between this and the Hovenweep subregion is somewhat arbitrary, but distinguishes the generally higher and broader mesa tops in the McElmo subregion from the lower canyon country of the Hovenweep subregion.

5. *Hovenweep* is a triangular subregion bounded to the northeast by the 1800-m contour, by a west-trending ridge off the west edge of Sleeping Ute Mountain on the south, and by the study-area boundary on its west. It includes the Colorado units of Hovenweep National Monument—Holly, Horseshoe, Hackberry (Thompson 1993)—and Painted Hand Pueblo in CANM.

6. *Ute Piedmont* isolates the relatively low-elevation drainages flowing south and west from Sleeping Ute Mountain. It is defined on the east by the Mesa Verde escarpment, on the south and west by the study-area boundary and on the north by the southern edges of the Hovenweep and McElmo subregions. Most research is due to the Ute Mountain Ute Irrigated Lands Archaeological Project (Billman 2003; Billman et al. 2000).

Archaeological Data Sources and Methods

Data Sources

To characterize Pueblo population and settlement we compiled a database of all known archaeological sites, incorporating data useful for demographic reconstruction including tree-ring dates, pottery tallies, architectural attributes, feature counts and sizes, and surveyor assessments. There are over 18,000 sites in the database; 7600 of these are Pueblo habitations with one or more pit structures, aboveground rooms, and a trash midden (Table 1). Most habitations contain only one pit structure, but almost 2000 evidence multiple households, including 173 large sites we term “community centers.” These contain 9 or more pit structures, more than 50 rooms, or public architecture (Glowacki and Ortman 2012; Varien 1999).

The VEP II database augments VEP I site data (Ortman et al. 2007) with information from updated Sand Canyon locality site forms, surveys conducted since 2002 within the original VEP area, MVNP site databases and new data collected during the Mesa Verde Community Center Survey (Glowacki 2012), surveys in MVNP published by Rohn (1977) and Hayes (1964), the Ute Mountain Ute Irrigated Lands Archaeological Project reports (Billman 2003), excavation reports from Mancos Canyon (Reed 1958), and recently published data on Early Pueblo occupation in the region (Wilshusen et al. 2012). We also added new pottery data analyzed by Crow Canyon Archaeological Center from MVNP collections and by Abajo Archaeology from Hovenweep-area collections (Till 2012, 2014).

Population Estimation Methods

To reconstruct population history in each subregion we employed methods detailed in Ortman et al. (2007) and Varien et al. (2007), modified to suit the VEP II context. Here we briefly summarize our methods, including modifications made for VEP II.

Step 1: Calibration.—We use data from 87 well-dated archaeological contexts to calibrate change through time in pottery and architecture. The calibration dataset is identical to that used in VEP I (Ortman et al. 2007), except new data from Goodman Point Pueblo (Kuckelman et al. 2009) was added to refine the A.D. 1260–1280 calibration period. The resulting probability density distributions specify the relative probability that a site possessing a potsherd of a given type, or a specific architectural attribute, was inhabited during each of the 14 periods listed in Table 2.

Step 2: Probability Density Analysis.—A probability density analysis was performed for each site in the VEP II database by combining sample data for the site with the probability density distributions from step 1. For decorated pottery, we multiply the probability density distribution for each type by the number of sherds of that type in the assemblage, sum the results and divide by the assemblage size to produce a probability density that reflects relative intensity of sherd deposition over time. We refined the decorated pottery distribution using Bayes' Theorem by combining the initial distribution with a conditional distribution representing the relative probability of obtaining the observed pottery tally if in fact the site were inhabited during each period (Ortman et al. 2007:255–256). We also followed this procedure for utility pottery, architectural attributes, surveyor assessments, and tree-ring dates presented in Ortman et al. (2007:253–257). Finally, we averaged all available distributions—for decorated pottery, utility pottery, architectural attributes, surveyor assessments, and tree-ring dates—to produce a mean posterior distribution for each site (Ortman et al. 2007:253–261).

We made two additional modifications to the VEP I methods. First, we defined probability densities for surveyor assessments by 1) determining the number of periods corresponding to the date range given by the surveyor (n); 2) entering $1/n$ in the probability density distribution for each period in n; and 3) entering a zero for all remaining periods. Previously, periods outside the date range of the surveyor assessment were left blank. The revised method ensures that surveyors' assessments of non-occupation are as important as their assessments of occupation.

Second, we compute conditional probabilities only for those pottery types that actually occur in the sample. Originally, we did these calculations for types that were absent as well. However, excluding absent types has no effect on large excavated assemblages where nearly all types are present in at least trace amounts, and it improves the treatment of sites with small samples where type absences may be due to sampling error.

Step 3: Neighborhoods.—We estimate a probability density for the neighborhood around each site using pottery and a gravity model that integrates sample size and distance (Ortman et al. 2007:257–259, Equation 8). This is incorporated into the mean posterior distribution for sites with seven or fewer decorated sherds. In the previous study, we considered only decorated pottery and we applied a secondary weighting function to control for the fact that certain periods are intrinsically more likely in the calibration data. Here, we combine distributions for both decorated and utility pottery, which levels out the intrinsic probability across periods, so that there is less need for secondary weighting. Spatial neighborhoods condition the assessment of around 70 percent of habitation sites in the VEP II database—about 50 percent more than in the previous study due to the many small sites within MVNP that lack associated pottery tallies.

Step 4: Apportioning Households.—We estimate the total number of pit structures constructed over the course of each site's occupation using the number of pit structures observed in the field, the total site area and the total roomblock area. We assume that each pit structure was the primary residential space for a single household (e.g., Lekson 1988; Varien 1999). We then apportion these pit structures (households) to periods using methods that vary according to the number of pit structures present (see Ortman et al. 2007:262–264).

For the 2,604 sites with one pit structure and a pottery tally, we assign one household to the most probable period in the posterior distribution and we assign an additional household to periods corresponding to secondary modes in this distribution. For the 2,823 single-pit structure sites that lack a pottery tally, we enter the value of the posterior distribution for each period, thus apportioning a single household across all 14 periods corresponding to how likely those sites were inhabited in each period. This essentially spreads the population of poorly known small sites across multiple time periods. This is a significant change from the method used in VEP I, which would have allocated that household to a single time period largely based on our analysis of neighboring sites. But pottery tallies are rare in certain portions of our expanded study area, especially within MVNP, and an adequate sample of nearby sites with pottery tallies—something that was largely present in the block surveys of VEP I study area—was not available for the neighborhood analysis in our expanded VEP II study area.

For the 2,276 sites with two or more pit structures, we evaluate multiple regression equations predicting the proportion of total pit structures inhabited during the period of peak occupation, and the probability level indicating occupation in the mean posterior distribution. We generated these equations using the mean posterior distribution and total pit structures present at excavated sites for which actual occupational histories are known. We then combine these equations with the data for unexcavated multi-household sites to apportion pit structures across periods of occupation (Ortman et al. 2007:261–264).

Step 5: Estimating Regional Momentary Population.—To translate population histories for individual sites into population estimates for the study area, we first assume that all community center sites are known and that all habitation sites have been identified within surveyed areas. For non-community-center sites, we sum the apportioned households for all sites within surveyed areas in each subregion to calculate the total households within surveyed areas for each subregion and period. We then multiply these totals by the inverse of the surveyed fraction for each subregion (Table 3) and multiply that result by the ratio of the mean occupation span of houses to the period length (Varien et al. 2007:Table 3) to produce momentary household estimates for each subregion and period.

For community center sites, we sum the apportioned households across sites in each subregion and then "momentize" the total households using the average house occupation-spans appropriate for these sites (Varien et al. 2007:Table 3). We then add these to the estimates for small sites and multiply the result by an average household size of six persons per household (Lightfoot 1994). The results are point estimates for the average momentary population, in persons, in each subregion and period (Varien et al. 2007:283).

Step 6: Quantifying Uncertainty.—In VEP I we estimated regional momentary population using three different methods to provide a measure of uncertainty (Varien et al. 2007:280–281). Here we calculate *informal* 80 percent confidence intervals surrounding the point estimates for each subregion and period using the probability density distributions for each site, again treating small sites differently from community centers. We first calculated the standard deviation of the probability value for each period using all available lines of evidence except the neighborhood distribution. We then calculated a weighted average of these vectors across the small sites in each subregion, with the weighting provided by the peak population of each site. The result is an estimate of the variance of the small site population size for each subregion and period, expressed as a proportion. We then convert these variances into confidence intervals by dividing each variance by the survey fraction; taking the square root; multiplying by 1.285 (80th percentile in a normal distribution); and finally, multiplying by the momentary population estimate for the period.

Since in theory all community center sites are known, we follow the same procedure, but calculate a single set of confidence intervals for the entire study area. We add these to the results for small sites to produce an overall assessment of the likely imprecision of our momentary population estimates for the entire study area. These are not formal confidence intervals because they are not derived from probabilistic sampling theory (Baxter 2003:38–49). They indicate the uncertainty surrounding the *temporal* placement of households derived from a lack of congruity in our chronological proxies and also account for spatial inhomogeneity by incorporating subregional sampling fractions.

Modeling the Maize Niche

To evaluate agricultural reliability in each of the six subregions for each year between A.D. 600 and 1280 we reconstruct the areas (hereafter called the "maize niche") in which annual temperature and precipitation would have allowed maize to grow without management of surface water (Bellorado 2007; Benson 2011a). Bocinsky and Kohler (2014) generated annual, spatial reconstructions of temperature and precipitation for both the northern and southern VEP II study areas. Their maps define the locations meeting the minimum requirements for each factor. The resulting maps define the locations meeting the minimum requirements for both factors simultaneously as the total potential maize niche. Here we briefly summarize their methods.[1]

Using regional tree-ring chronologies, Bocinsky and Kohler (2014) generate annual reconstructions of net water-year precipitation (previous October through current September; Stahle et al. 2009) and growing-season growing degree days (GDDs in °F), a measure of accumulated heat calculated from average daily temperature from May through September. These reconstructions begin with spatiotemporal climate data derived from the 800-m-resolution monthly PRISM climatological dataset (Daly et al. 2008). GDDs are calculated using standard temperature thresholds for maize following Benson (2011a).

Climate landscapes are then reconstructed back to A.D. 1 via the "CAR" regression technique calibrated against the 1924–1983 period, an interval selected to maximize the available tree-ring chronologies (Bocinsky and Kohler 2014:7). These data are spatialized at each PRISM location across the study area. The CAR method determines the subset of all chronologies from the complete set of standardized tree-ring chronologies for the four-state Southwest from the International Tree-Ring Data Bank (Grissino-Mayer and Fritts 1997) that minimizes cross-validated prediction error for reconstructing precipitation or temperature. These chronologies are combined in a linear model to generate a reconstruction, which is scaled to match the mean and variance of the instrumental climate signal. The optimal combination of tree-ring chronologies is recomputed as the analysis moves back though time and fewer chronologies are available. For the present study the number of available chronologies is relatively stable (Bocinsky and Kohler 2014:Figure 6).

We use these annual estimates of water-year precipitation and growing-season GDD to locate and determine the size of the maize-growing niche. Following previous studies we use 30 cm as the lower limit of precipitation for rain-fed maize agriculture (Benson and Berry 2009; Stahle et al. 2009), and 1,800 GDD as the minimum heat threshold for maturation of ancestral maize landraces (Bellorado 2007; Benson and Berry 2009:92). Places on the landscape that meet or exceed *both* thresholds in a given year are considered "in" the maize niche for that year. Summary statistics concerning the maize niche in each subregion are given in Table 3.

Consideration of factors such as the suitability of soils for ancient cultivation or the local feasibility of water management would alter the size and stability of the niches computed

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[1] These reconstructions use tree-ring proxies for temperature and precipitation, and tree-ring proxies for temperature in particular may underestimate low-frequency (long-term) variability.

here. Over time, Pueblo farmers undoubtedly transformed their environments through processes of niche construction and management (Laland and O'Brien 2010), while also potentially engaging in niche destruction through soil-nutrient depletion (Benson 2011a, 2011b; Kohler 2012). We acknowledge these limitations, but note that our method has the advantage of being applicable wherever suitable climate proxies are available. We hope that in the long run this will lead to productive inter-regional comparisons.

Results

Population Size and Movement

Table 2 presents population estimates for small sites and community centers for each subregion and period. These are graphed in Figure 3 as momentary population estimates for each subregion, showing study-area totals with 80 percent confidence intervals. Population levels in the Dolores subregion are negatively correlated with population levels in other subregions through time. In contrast, population trajectories are strongly positively correlated among the other subregions, with the highest correlations observed between McElmo and Hovenweep (r=.96), and McElmo and Ute Piedmont (r=.95). Table 4 and Figure 4 present the data from Figure 3 as population densities by subregion. The large McElmo subregion housed the most people in all but the A.D. 880 to 920 period (Figure 3); however, population *density* was highest in MVNP (though tied with McElmo in the A.D. 1225–1260 period). MVNP and McElmo densities diverged again during the final period, when density decreased in all subregions except MVNP and the Mesa Verde Landform.

Table 5 presents population growth rates by subregion and highlights those exceeding ±.7 percent change per year (intrinsic rate of ±.007)—a threshold suggestive of immigration or emigration according to Cowgill (1975). Numerous changes in momentary population size and density between period midpoints suggest that movement between subregions, or into and out of the study area overall, was commonplace at the temporal scales represented by these periods; of the 78 cells in Table 5, 47 (60 percent) are candidates for in/out migration. The Hovenweep, Dolores, and Ute Piedmont subregions were the least demographically stable, and MVNP, the most stable. These observations suggest that the Pueblo population, though certainly composed of "sedentary farmers," was in a continuous process of spatial adjustment and never approached a stable equilibrium.

Some of these population changes were likely driven by intrinsic demographic rates in addition to migration. Recent research has estimated crude birth rates (CBR; annual live births per 1000 people) from human skeletal remains for 10 regions in the U.S. Southwest, including the northern San Juan region (n=22 assemblages) encompassing our study area (Kohler and Reese 2014: CBR derived from juvenility indices plotted in their Figure 2, panel 10). CBRs for the northern San Juan region, evaluated at period midpoints, are given in Table 4. Although there is no significant relationship between these CBRs and population growth rates derived from the settlement data (compare the right-most columns of Tables 4 and 5), there is a highly significant relationship between the CBRs and the study-area population estimates themselves (Adj. R^2 = .90; p = <.001). Periods with larger populations strongly correspond to periods with higher crude birth rates, and vice versa. Although we cannot reconstruct population growth with CBRs alone—we would also need life expectancy which Kohler and Reese (2014) did not estimate for the northern San Juan—this strong positive correlation suggests changes in regional birth rates may account for more of the population variability we observe than previous studies have recognized.

The pattern of higher birth rates accompanying larger population sizes is a signature of exponential growth. But such a pattern cannot continue indefinitely, even under the most generous assumptions concerning creation of wealth and value (Trawick and Hornborg 2015). It is especially surprising that high growth continued into the twelfth and thirteenth centuries given osteological evidence for increasing "biological disruption" in Pueblo II and III times (Nelson et al. 1994) and extreme (literally unhealthy) reliance on maize by the mid-thirteenth century (Matson 2015). In the long run exponential growth must result in either a population crash, or a slowing of growth as population reaches some maximum loosely controlled by organization, technology, and production. In our case, as for Neolithic European societies at a similar socioeconomic scale (Downey et al. 2014; Shennan 2002; Shennan et al. 2013), the pattern seems to have been boom-and-bust rather than moderating growth as a threshold was neared. It is noteworthy that CBR continues to increase in the final, A.D. 1260–1280 period, even as population size was rapidly decreasing.[2] We return to this finding in the conclusions.

Overall, the VEP II population reconstructions re-affirm the existence of two main cycles of population growth and decline in this area (A.D. 600–980 and 980–1280) while adding significant subregional detail. In the early cycle, population density increased in all subregions except the Ute Piedmont, although the timing of these changes varied (Figure 4). During the second cycle, MVNP and McElmo densities increased markedly between A.D. 980 and 1100, whereas there was only a small increase on the Mesa Verde Landform. The MVNP population peaked from A.D. 1060 to 1100, declined from A.D. 1100 to 1225, and increased again from A.D. 1225 to 1280, even as the final depopulation set in elsewhere. Thus, MVNP appears to have held out the longest as central Mesa Verde society deteriorated in the 1200s (Glowacki 2015; Lipe 1995).

Since regional population was zero within a few years of A.D. 1280 but the average momentary population was around 21,000 in the A.D. 1260–1280 period, and 26,000 in the A.D. 1225–1260 period, the final depopulation must have set in prior to A.D. 1260, more than 15 years *before* the onset of the great drought. Late thirteenth-century climate deterioration, by itself, cannot explain the demise of Mesa Verde society (see also Glowacki 2015). As we demonstrate in the next section, the very poor conditions in the first half of the thirteenth century, encouraging migration into our area despite its already high populations, in fact set up the crisis.

Finally, our results suggest that more people lived in the central Mesa Region than previously estimated. Rohn (1989:166) suggested that in the A.D. 1200s "more than 30,000 people" lived in the entire northern San Juan region, an area significantly larger than our study area. The peak populations estimated here are roughly twice those estimated by Wilshusen (2002) for a similar area. We also place the Early Pueblo population peak some

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[2] This period is therefore a negative outlier in the regression of population size on CBR.

3,000 people higher than recently estimated for the same area by Wilshusen et al. (2012:19). These large populations depended heavily on maize.

Maize-niche history

Table 3 presents the 680-year history of the maize niche in all six subregions and the study area overall. Figure 5 graphs the continuous record of maize-niche extent in each subregion through time. Then in Figure 6, we summarize the dynamics of the maize niche in each subregion at each of the 14 period midpoints using four statistics: (1) the percentage of each subregion in the maize niche each year ("percent in niche"); (2) the running standard deviation of this percentage, averaged within each subregion ("variability"); (3) the running count of the number of consecutive years in which a given cell was *within* the maize-growing niche, averaged across the subregion ("good-year counts"); and (4) the running count of the number of consecutive years in which a given cell was *outside* the maize-growing niche, averaged across the subregion ("bad-year counts"). Each running measure is binned over the preceding 30-year period; for example, the percent in niche reported in A.D. 1100 is the average of the A.D. 1071–1100 period. Binning this way allows us to better relate landscape dynamics to human experience by portraying the *experienced* conditions to which humans were reacting.

The MVNP subregion consistently has the highest percent in the niche, followed by Dolores, Mesa Verde Landform, and McElmo (Table 3). MVNP also shows far less inter-annual and inter-period variation than the other subregions (Figures 5 and 6a). Every subregion exhibits some variability in the percentage in the niche (Figure 5) but Hovenweep and the Ute Piedmont exhibit the greatest variability, and on this basis we consider them to be marginal. All subregions exhibit an increase in the average percent in niche in the 800s and early 900s, a decrease later in the 900s and in early 1000s, and an increase during the late 1000s. As we have seen, all these correspond to changes in regional population size. After the late 1000s, all subregions exhibit considerable inter-period variability.

Panels b, c, and d in Figure 6 provide additional interpretation of variation in agricultural reliability and risk: What is the relationship between strings of good years and strings of bad years in each subregion? The Hovenweep subregion has consistently high variability values, and the Hovenweep and Ute Piedmont remain high around the 1200s when variability decreases in the other subregions. Additionally, the Ute Piedmont has low variability during the early-800s, mid-1000s, and mid-1200s, although these periods correspond with long strings of bad years (see below).

Figures 6c and 6d describe the average number of years in strings of consecutive good or bad years, respectively. Abrupt decreases in good-year counts or increases in bad-year counts would likely have been strongly felt by these farmers, influencing settlement locations, agricultural strategies, and storage and exchange practices. Good-year counts increase dramatically for most subregions during the late 800s, while bad-year counts generally decrease during the same period. The shift back to lower good-year count values during the early 900s corresponds with the decline in population size (Figure 3) and density (Figure 4) across all subregions. Bad-year count values were high in the Hovenweep and Ute Piedmont subregions relative to the other subregions. Hovenweep and the Ute Piedmont also do not exhibit the gains in good-year count values in the late 800s, early 1100s, and early 1200s seen in other subregions.

In sum, higher agricultural reliability is measured by relatively high and constant percentages in the maize niche, lower variability, and greater potential for successful harvests and storage (proxied here by counts of consecutive good versus bad years). The periods of demographic expansion noted above tend to correspond to periods of higher reliability. The exceptions to this pattern are found in the Hovenweep and Ute Piedmont subregions, where trends in variability are opposite those in other subregions. It is significant that population densities were also lowest in these two subregions during the first population cycle, when the regional population was smaller and better land was available in other subregions. The most important exception to the general positive relationship between agricultural reliability and population size is in the A.D. 1225–1260 period, when demographic expansion accompanied *decreasing* reliability. Based on our results, we rank the six subregions from most reliable to most marginal for dry farming as follows: (1) MVNP; (2) Dolores; (3) Mesa Verde Landform; (4) McElmo; (5) Hovenweep; and (6) the Ute Piedmont.

Settlement history and climate history

The analyses above assess the degree to which spatiotemporal patterns of agricultural reliability impacted people living in environmentally distinct portions of the central Mesa Verde region. Division of the VEP II study area into environmentally distinct subregions also allows us to explore whether population flux between subregions might have been an effective risk-buffering strategy. We investigate this possibility here by estimating the effective population density in each subregion, controlling for the size of the growing niche, and then assessing the relationship between population density and niche size through time.

Figure 7 shows a reconstruction of the “niche density,” or the average population in each subregion divided by the average niche size, for each period. Major niche contractions in the A.D. 1140–1180 and 1225–1260 periods generated substantial increases in niche density in the Hovenweep and McElmo subregions, exceeding those in all other subregions. During the 1225–1260 period niche densities in these subregions approach 20 persons/km^2. (As noted above, this niche reconstruction is driven only by climate; soil constraints would additionally reduce niche size, increasing effective population density). The peak Hovenweep and McElmo niche densities are at the upper end of the range reported by Van West (1994:Table 5.1) for societies pursuing a domestic mode of production, where household self-sufficiency is the economic goal (Sahlins 1972).

Figure 8 shows the responses of population density to changing niche size in each subregion across periods. We show the ordinary least squares fit for each subregion overlaid on a thick gray curve representing the local regression (LOESS) smoothing of all the data (14 periods x 6 subregions). With the exception of MVNP, all subregions show the expected positive relationship between niche size and population density across periods: as niche size increases, so too does population density. The strongest relationship (steepest slope) is for the McElmo subregion. The McElmo and Hovenweep subregions each have two prominent outliers, the A.D. 1140–1180 and 1225–1260 periods. During both periods, but especially from A.D. 1225–1260, population density was far higher than predicted by the overall relationship between demography and climate in these subregions. Populations in these areas and periods were therefore much more vulnerable to subsistence stress than populations in other locations and periods (see also Glowacki and Ortman 2012). We suspect these imbalances led to equally unprecedented social responses. Levels of conflict from A.D. 1140 to 1180 (Kohler et al. 2014) suggest existing storage, exchange, and conflict-buffering strategies were insufficient to prevent severe subsistence stress and social unrest. Recent simulation of sociopolitical evolution in a subset of this area (the VEP I study area) suggests that the surprising lack of violent trauma to human bone in the even-more-anomalous A.D. 1225–1260 period could have been due to the growth of political organizations able to suppress conflict across larger territories (Kohler et al. 2015). The A.D. 1225–1260 period is however characterized by aggregation into villages surrounding domestic water sources, a probable increase in agricultural intensification in the form of check dams and terracing in canyons (though these features are hard to date), the appearance and spread of defensive architecture and new forms of civic-ceremonial architecture, and probable migration from the region even as others packed into it (Glowacki 2015; Glowacki and Ortman 2012; Lipe and Ortman 2000; Varien 1999).

As in the other subregions, populations tended to grow in the Dolores subregion as the size of the maize niche increased; but as Figure 8 indicates, the Dolores subregion had an anomalously low population compared to the other subregions. Although differences in soils and domestic water sources likely contribute to this pattern (Glowacki and Ortman 2012; Kolm and Smith 2012: Plate 5.2; Varien 1999), evidence is accumulating that nomadic hunters were present in the Greater Southwest prior to the final depopulation of the Mesa Verde region (Gilmore and Larmore 2012; Ives 2014; Ives et al. 2014; Wilson and Blinman 1988). It may be that the Dolores subregion, which lies on the northeastern edge of Pueblo settlement, was becoming an increasingly dangerous place to live by the thirteenth century.

The relationship between niche size and population density in the MVNP subregion is unexpected and opposite to that in the other subregions; its population density *decreased* as the relative size of its maize niche increased. One possible explanation is that outside of a few favored areas such as Morefield Canyon (Benson 2011b) significant portions of MVNP were not particularly productive for maize, though they were consistently in the niche. This could induce some emigration as more land became locally available in nearby, possibly more productive, subregions. Since MVNP was consistently the most reliable place to dry-farm maize in the central Mesa Verde region, population packed into it during difficult periods and spread out from it during good periods, even as the baseline density remained high. This is reflected in the consistently high percentage of MVNP that is within the niche and the slight variation in this percentage across periods. The MVNP data also contribute to the overall positive relationship between niche percentage and population (the thick gray line in Figure 8), supporting our conclusion that it was the most reliable subregion for dry-farming maize in the study area.

Neither the Hovenweep nor the Ute Piedmont subregions supported significant populations during the first population cycle (Figures 3 and 4). This fact, combined with the niche modeling, suggests these two areas were agriculturally marginal relative to the other subregions. During the second population cycle, however, the Hovenweep subregion experienced several periods when its niche percentage and niche density approached levels seen in the neighboring McElmo subregion (Figures 6 and 7). Episodes of relative reliability were often followed by periods of high agricultural risk, and during such declines niche conditions more closely resembled those found in the Ute Piedmont subregion. It thus appears that the Hovenweep subregion in particular became an attractive destination for migrants during productive periods, but the people who moved there were especially vulnerable to subsequent climate downturns. Influx of population into marginal areas such as the Hovenweep subregion likely permitted climate fluctuations to fan social conflict based on production inequities among populations (perhaps including starvation in some populations). The core McElmo subregion was also experiencing unprecedented conditions from A.D. 1225–1260 (Figure 8). Evidently core areas (MVNP and McElmo) were unable to resist violence emanating from the periphery, contributing to the eventual collapse of Mesa Verde society.

Maize-Niche Size and Natality

We have shown that climatically driven changes in maize-niche size affected the size and distribution of population in the study area (Figures 7 and 8). We have also shown that estimates of crude birth rates (natality) exhibit a surprisingly strong positive relationship with momentary population size through time, presumably mostly due to the effect of CBR on population size rather than vice versa. To complete the triangle, we now point out that niche size also affects crude birth rates:

$$\begin{array}{l} CBR \;=\; -.014 \;+\; .102 \;*\; total\ maize-niche\ percentage \\ (.029) \;\; (.046) \end{array} \tag{1}$$

where standard errors are shown below the parameter estimates ($Adj.\ R^2 = .23$, and $p = .05$; CBRs are drawn from Table 4, and total niche percentages are from Table 3). Although the relationship is only marginally significant, and our data are insufficient for a formal causal analysis, these results suggest that Pueblo populations responded to changes in niche size through both migration and adjustments to CBRs. We are unaware of any previous demonstration from archaeological data (even one displaying only marginally significant effects) that climatic variability affected birth rates through effects on production.

Discussion and Conclusions

We have reconstructed prehispanic Pueblo demographic change across six environmentally distinct subregions within a 4800-km^2 study area and integrated these results with a reconstruction of annual change in the maize niche over 680 years. We noted two cycles of growth and decline, one from A.D. 600 to 980 and a second from A.D. 980 to 1280. We found that changes in population density and birth rates are related to climate-driven changes in the extent of the maize niche. The fact that (with the exception of MVNP) our subregions exhibit a positive relationship between population density and niche size suggests that these farmers responded to changing climate conditions at generational scales through adjustments in CBR, migration between subregions, and migration in and out of the entire study area.

If climate, via its influence on niche size, affected population size both directly through population movement and indirectly via natality, then the Neolithic history of the central Mesa Verde region contrasts with the findings of Shennan et al. (2013) who found little or no evidence that climate affected population boom-and-bust phenomena in Neolithic Europe.[4] Perhaps these differences are the result of the greater sensitivity of Southwestern maize farmers to climatic variability. It is also possible however that the high-resolution paleoclimatic data employed here allow us to identify climate effects that were also present in Europe but less visible in the available records. In both cases, though, it seems likely that rapid population growth in conjunction with a set of institutions and norms that evolved under very different conditions could have made these societies vulnerable to small perturbations of whatever source.

In our study area we identified large variability in niche size in marginal areas that we suggest became an important source of instability as the regional population expanded beyond the most reliable areas. This would have created a vulnerability that contributed to a variety of social stresses during climate downturns. During the A.D. 1225–1260 period, Hovenveep, McElmo, the Ute Piedmont, and the study area as a whole all reached their most unfavorable balance between population size and size of the area within which maize could be grown. This would have increased the likelihood of stress and competition—something supported by the dramatic changes in settlement patterns that characterize this interval—but also strongly suggests that the emigration streams that began, or gathered force, during this period were related to these imbalances. Deterioration in wood supply and deer availability, not discussed here, provided additional exacerbating factors (Johnson et al. 2005). Even during the worst periods, however, people in the most reliable areas would not have experienced long strings of no production. Thus, in a purely atomistic society, some people could have persisted in productive areas during droughts, even as people living in more marginal areas were forced to move.

The linkages reconstructed here characterize a population that was very sensitive to climate-driven variation in agricultural potential. One might expect a close coupling between population, demographic rates and climate to be characteristic of societies following a domestic mode of production, where families strive to be economically self-sufficient. There is abundant evidence that the economic system of Mesa Verde society was in fact organized along these lines (Bradley 1993; Hegmon et al. 1999; Kohler and Varien 2012; Kuckelman 2000; Lipe 1989; Rohn 1965; Varien 1999) and that community institutions generally supported household production (Adler 1994, 1996; Varien 1999). Yet, humans have invented a wide range of social institutions and technologies that embed households within larger and more interdependent economic networks. Such institutions and technologies can provide much stronger buffering mechanisms against agricultural risk than those evident in central Mesa Verde society. Several lines of evidence suggest the Pueblo societies formed in the aftermath of the Mesa Verde collapse developed a variety of such institutions and technologies (e.g., Lipe 1989; Kohler et al. 2014; Ortman 2012), thus weakening the overall

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[4] Although we questioned Cowgill's (1975) threshold for migration above, one of his main points was that archaeologists are quick to use changes in population as explanatory of other, social or political, change, but seldom offer explanations for why population itself changed. Here we work towards providing such an explanation.

coupling between demography and climate and improving the resilience of Pueblo societies to subsequent episodes of climatic variability.

The inherent plausibility of the relationships identified in this study strengthen our confidence in our reconstructions of population, demographic rates and agricultural potential, even though all three quantities have been difficult to estimate for societies known only through archaeology. To build a more robust and general understanding of relationships between human societies and the environment, similar methods need to be developed and applied across a wider range of societies and environments, at spatial and temporal scales that meet or exceed those investigated here. Only in this way will the relative contributions of climate, history, demography and sociopolitical institutions to long-term social dynamics become clear.

In this case, we find that growing inequities in access to reliable agricultural land and the food it produced created vulnerabilities that were primarily social and political. The fact that regional populations did not persist, and that Mesa Verde society collapsed by A.D. 1285, indicates that sociopolitical processes unleashed by the effects of climate change on maize production during the thirteenth century had a larger impact on this society than could be predicted from the changes in niche size alone. Thus, it is not merely climate change, but the way in which climate change interacted with a historically constituted social landscape and a pattern of great reliance on maize agriculture, that best accounts for the collapse of Mesa Verde society (see also Glowacki 2015).

This is an important and cautionary note for those attempting to forecast the effects of climate change and population growth in our world today. A few years ago Warner and colleagues predicted that:

> climate change will have a progressively increasing impact on environmental degradation and environmentally dependent socio-economic systems with potential to cause substantial population displacement. The key concerns in Less Developed Countries (LDCs) will include serious threats to food security and health, considerable economic decline, inundation of coastal areas, and degradation of land and fresh water resources [2010:689].

They lamented however that little is known about the “interplay between environmental change and stresses on ecological systems, resulting socio-economic vulnerability and potential outcomes in terms of population displacement or induced migration” (2010:689–690).

We hope the example developed here of just such an interplay provides a lesson at a small scale (but over the long term) from which the world today may learn. Even in the few years since the Warner et al. article was published evidence has accumulated that climate change, either in the direction of warmer temperatures or more extreme rainfall, leads to significant increases in conflict, violence, or political instability which itself may accelerate large population displacements (Hsiang et al. 2013). Kelley et al. (2015) argue that the recent Syrian drought, and the mass migration to urban areas that it induced, is connected with its current instability, and that droughts of the length and severity experienced recently in the

Fertile Crescent are now more than twice as likely given human interference in the climate system. Closer to home, mean global circulation model predictions for the American Southwest and Central Plains in the next century under a “business as usual” scenario predict soil moisture balances by A.D. 2100 that are even more unfavorable than any analyzed here (Cook et al. 2015). Given that human activity has contributed to this climate change, our hope is that human intervention, guided by knowledge of past experience gained through archaeological studies like this, can also ameliorate conditions that lead to human suffering, conflict, and mass migration.

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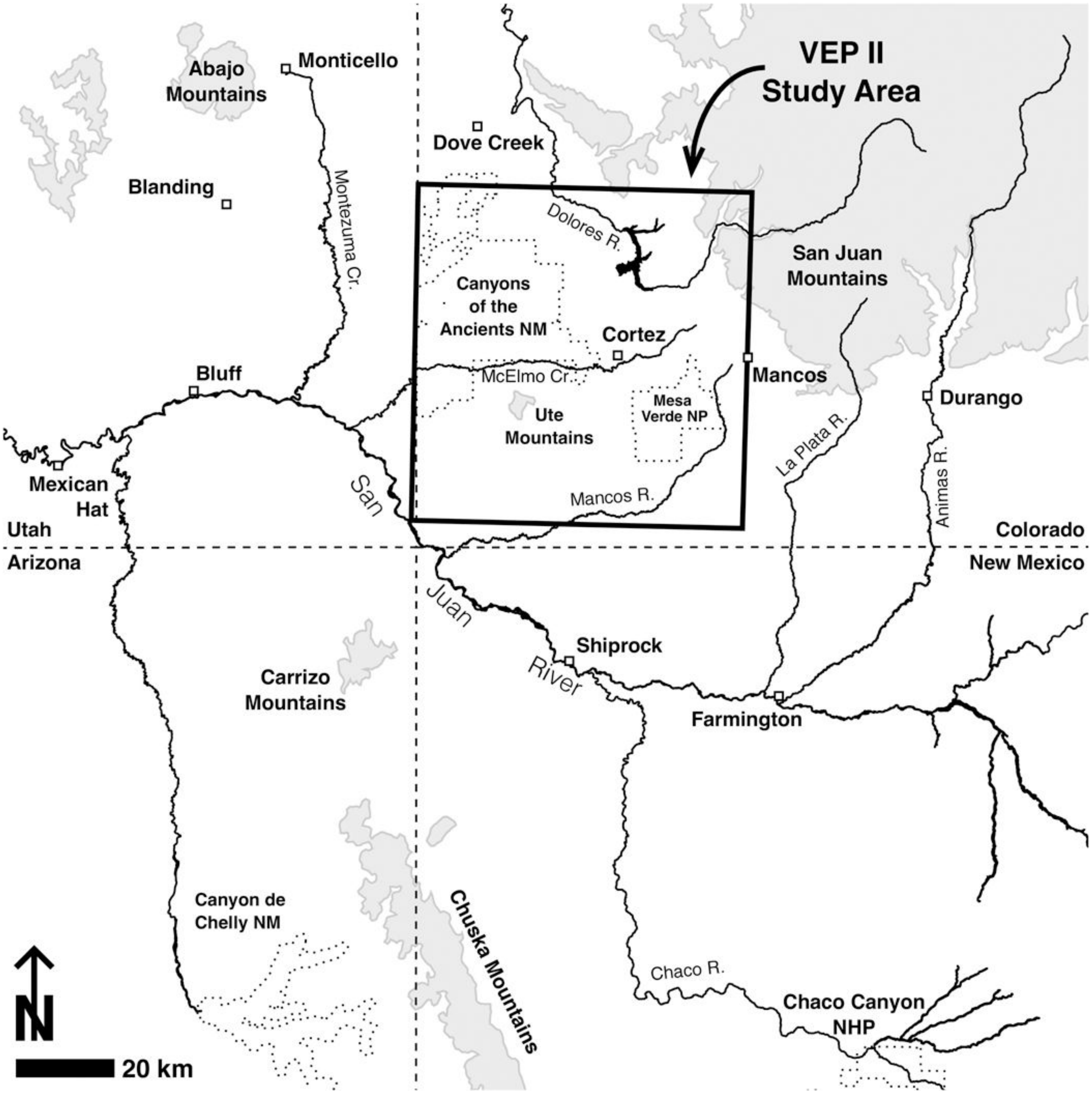

Figure 1.

Location of the central Mesa Verde Region and the VEP study area.

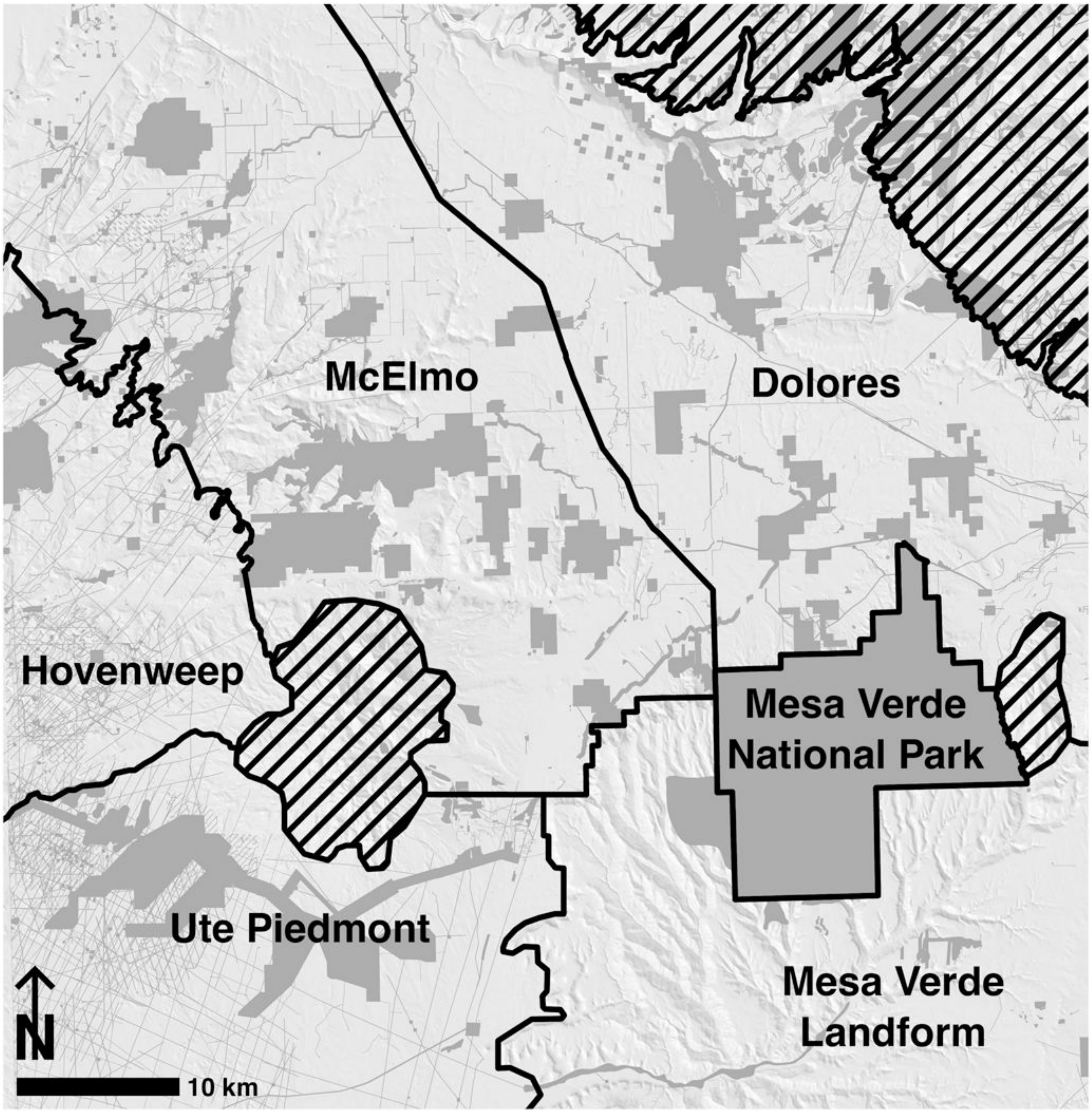

Figure 2.

Subregions and survey coverage in the VEP II study area. Surveys are shown in dark gray. Hatched regions are not included in this study due to lack of known habitation sites.

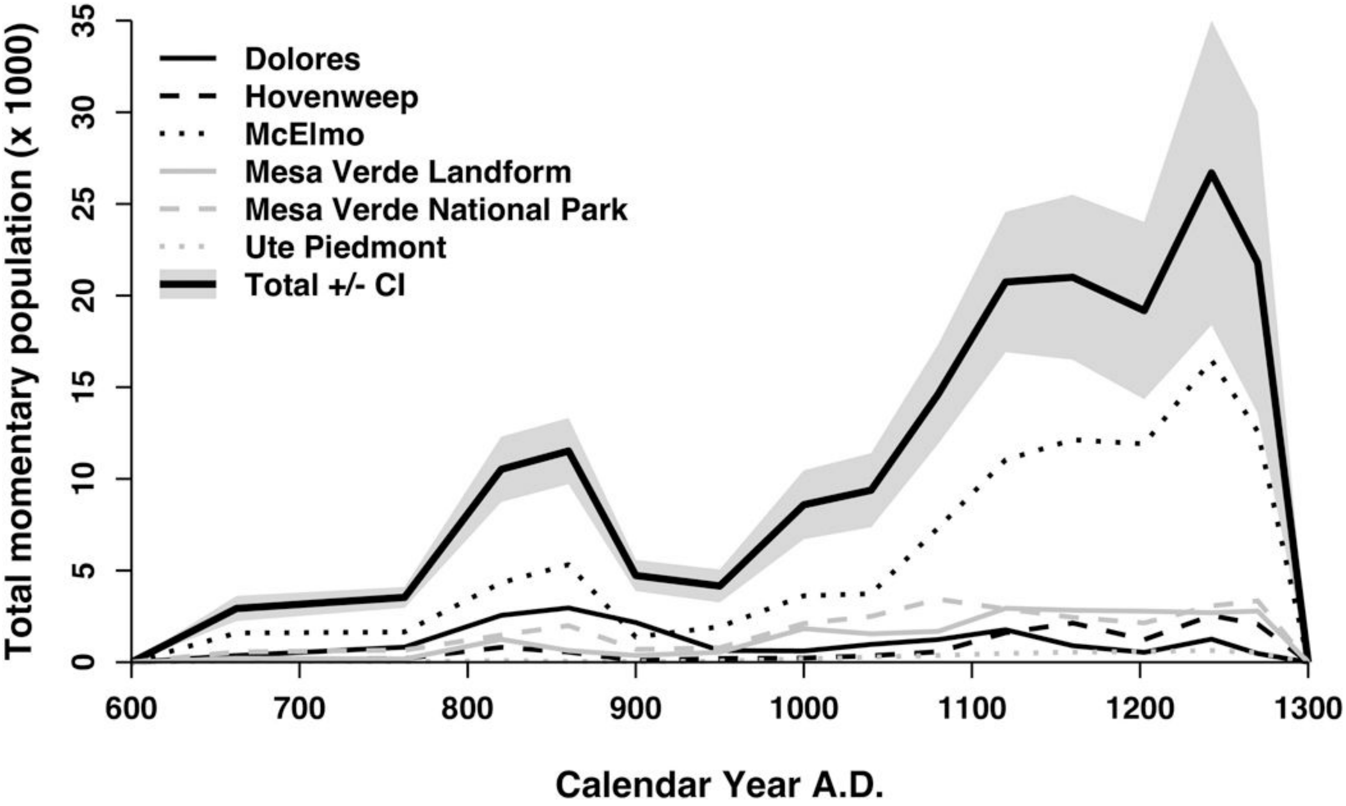

Figure 3.

Population size by sampling subregion through time. The population size for the entire study area is shown as a thick black line bounded with 80% informal confidence intervals in gray.

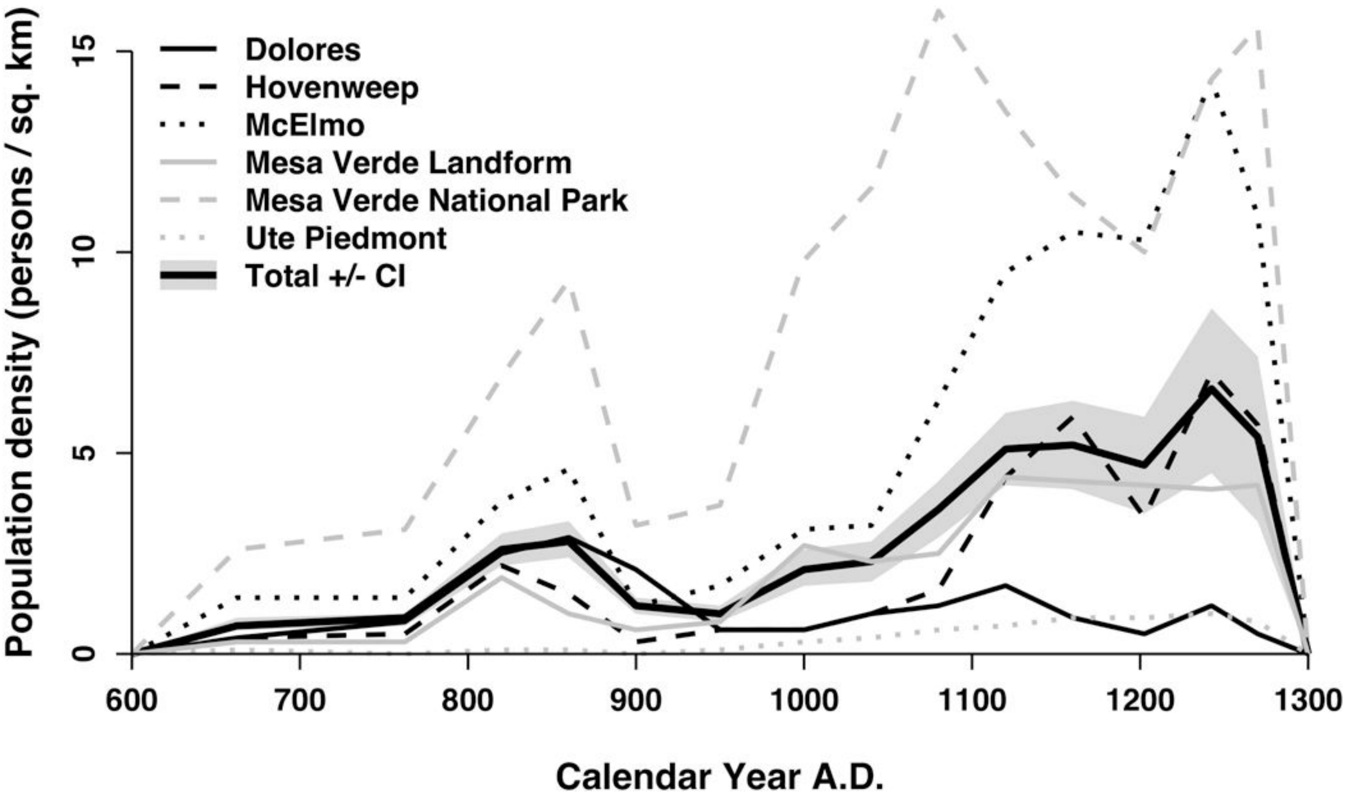

Figure 4.

Population density by sampling subregion through time. The average population density for the entire study area is shown as a thick black line bounded with 80% informal confidence intervals in gray.

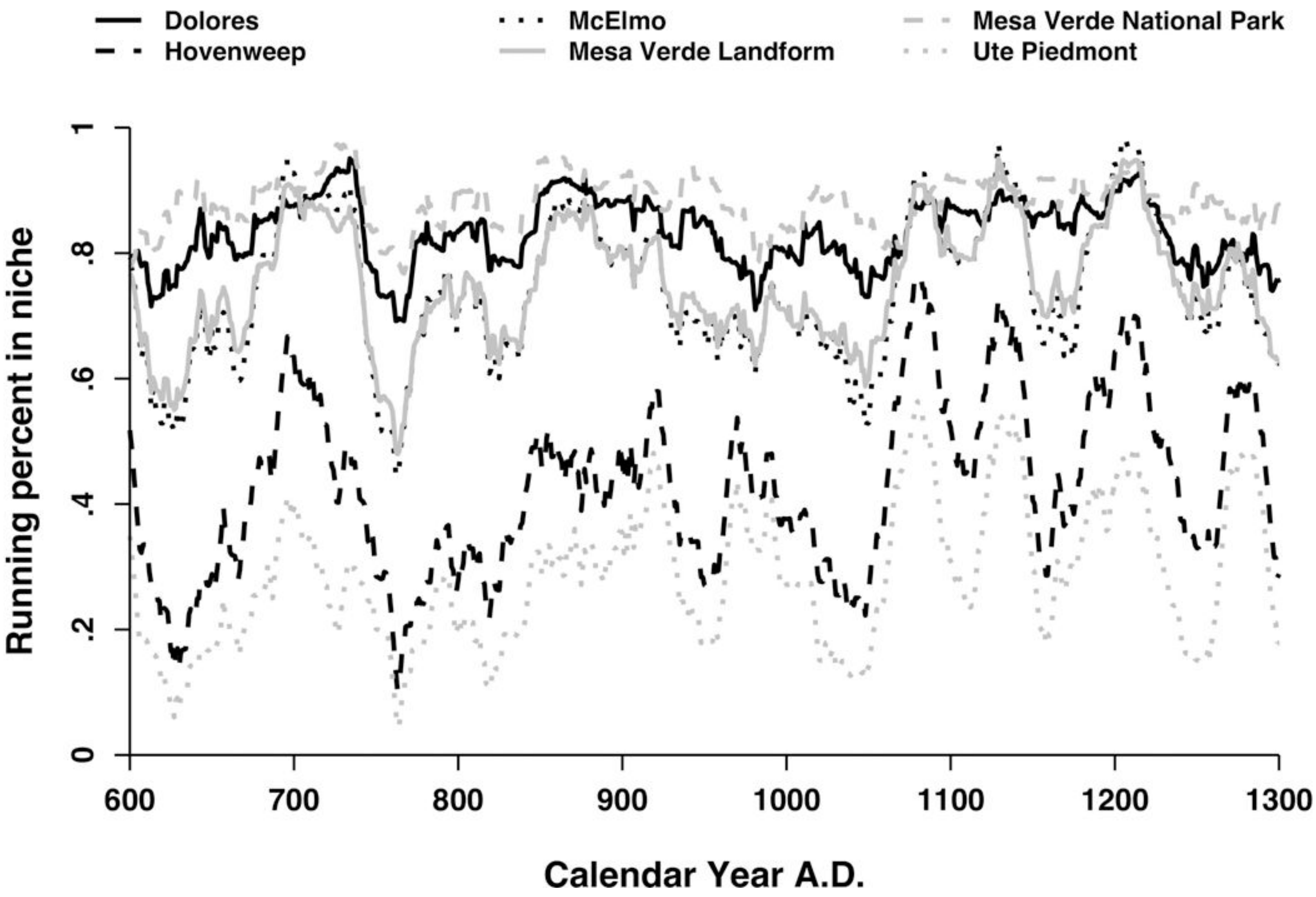

Figure 5.

Running means of the percent of each subregion in the niche, through time. Means are calculated using a 30-year bin-width.

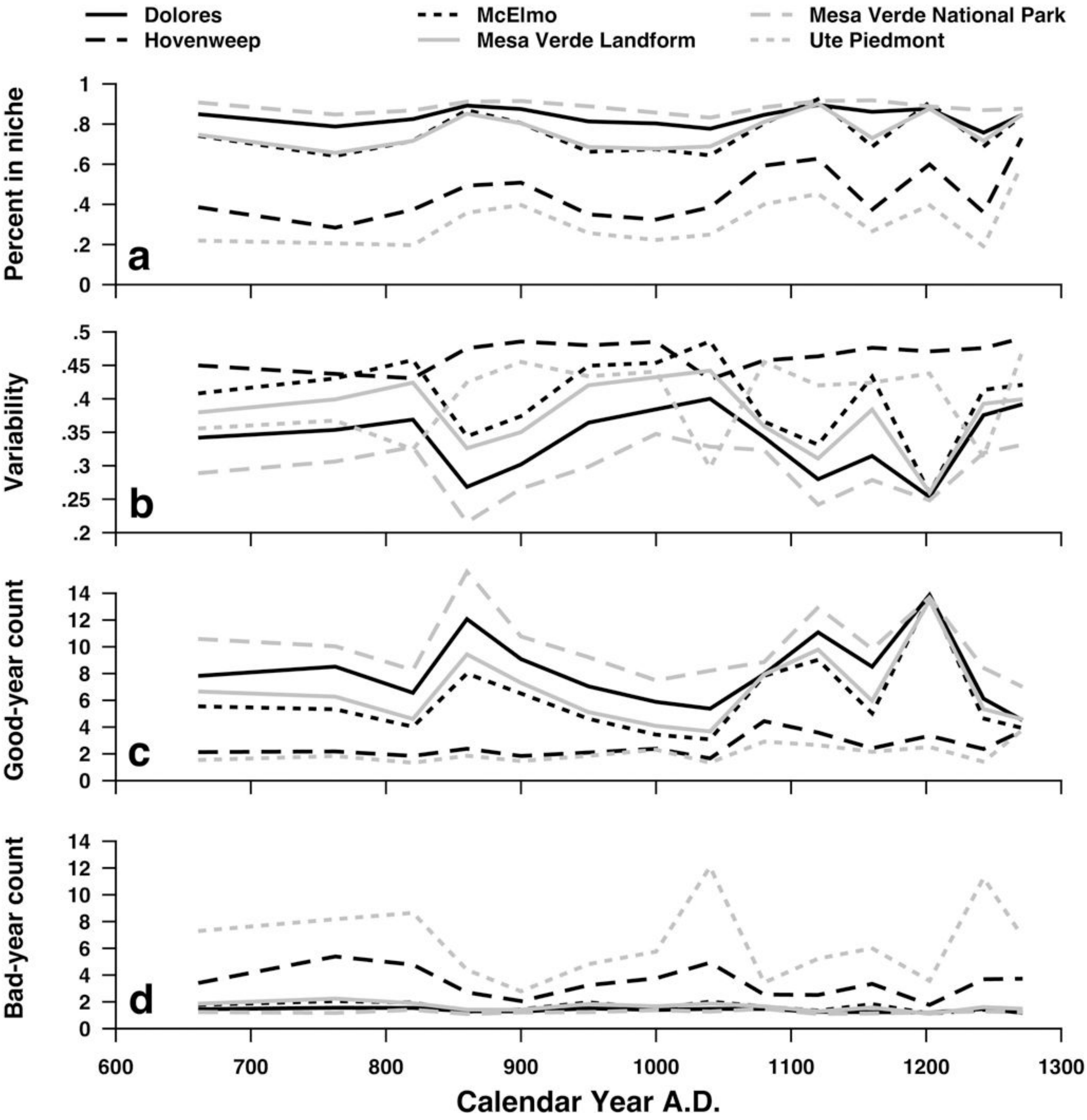

Figure 6.

Niche metrics by subregion and period, shown at period midpoints. a, the percent of landscape in the maize niche; b, the mean standard deviation (“variability”); c, the mean number of consecutive years inside of the niche (“good-year count”); d, the mean number of consecutive years outside of the niche (“bad-year count”).

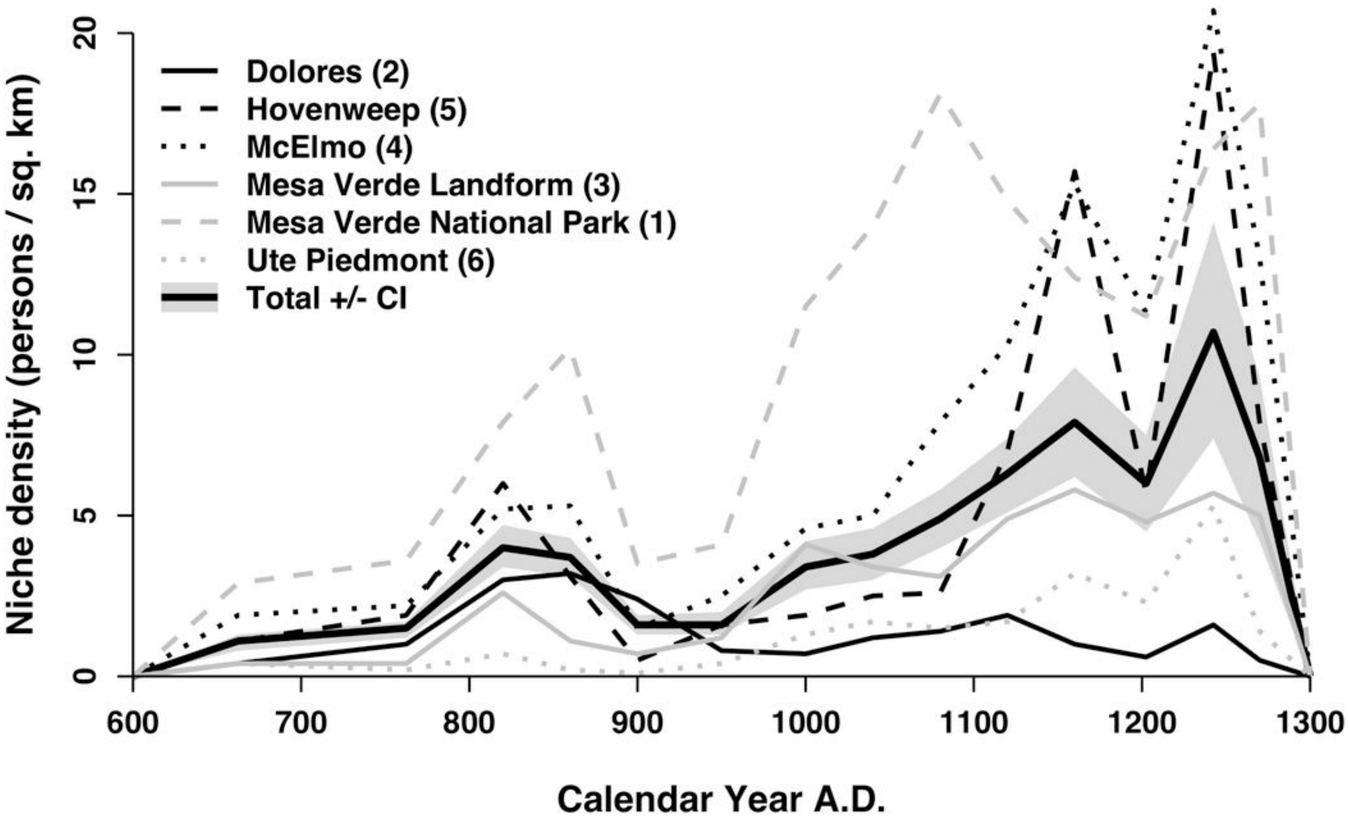

Figure 7.

Niche density (persons per square km of arable land) by subregion through time. The niche density for the entire study area is shown as a thick black line bounded with 80% informal confidence intervals in gray. Subregion ranks appear in parentheses.

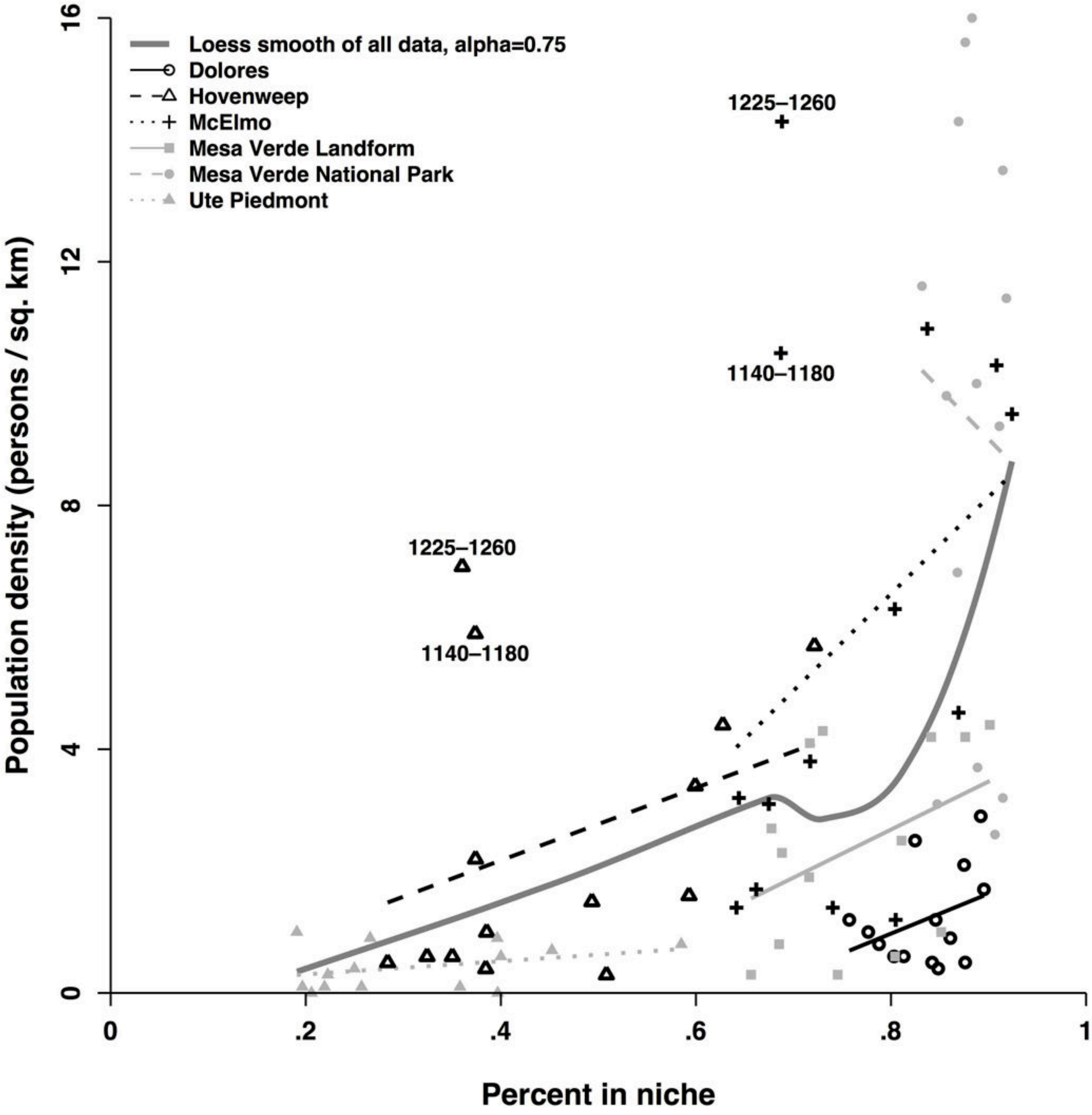

Figure 8.

Regressions of niche size on population density across periods by subregion (observed periods and linear models) and for the study area as a whole (loess fit, α=.75). Named periods are outliers, but were included in the fits shown here.

Table 1.

Temporal and functional classification of components in the Village Ecodynamics Project database.

Function	Paleoindian	Archaic through Basketmaker II	Ancestral Pueblo (600–1280 CE)	Numic / Navajo	Historic	Unknown	Not Recorded	Total
Not recorded	22	310	2476	223	479	748	1653	5911
Indeterminate	1	13	908		11	104	110	1147
Isolated Find	1	2	19	1	1	18	12	54
Artifact Scatter	2	64	695	4	2	17	66	850
Ceremonial Site		1	34	4	5	3	1	48
Plaza		2	see Centers[a]					2
Clay quarry			2				1	3
Field house	1		664				20	685
Kiln			435				6	441
Limited activity	1	17	700	8	31	80	205	1042
Reservoir			25		7	2	3	37
Rock art		2	50		2	11	13	78
Stone quarry		1	15		1	11	36	64
Storage		4	340	1	1	26	2	374
Water control			348		5	18	13	384
Single habitation		17	4124		16		82	4239
Multiple habitation		5	1953	2	9		16	1985
Indeterminate habitation		12	1568	2			82	1664
Community Center			172					172
Total	28	450	14528	245	570	1038	2321	19180

[a] Plazas are likely underrepresented in the database for ancestral Pueblo components as a component functional classification. They would likely occur as architectural attributes of larger Community Centers.

Table 2.

Momentized population estimates in community centers and small sites.

		Dolores		Hovenweep		McElmo		Mesa Verde Landform		Mesa Verde NP		Ute Piedmont		Study Area Total		
begin (AD)	**end (AD)**	**centers**	**small sites**	**centers**	**small sites**	**centers**	**small sites**	**centers**	**small sites**	**centers**	**small sites**	**centers**	**small sites**	**centers**	**small sites**	**80% “C. I.”**
600	725	1	361	3	146	34	1558	1	207	223	338	0	60	262	2669	684
725	800	101	722	2	196	134	1515	7	168	190	472	0	31	434	3103	564
800	840	294	2264	4	809	256	4082	71	1175	475	1006	0	88	1100	9423	1777
840	880	445	2515	4	552	202	5120	80	555	487	1507	0	51	1218	10300	1798
880	920	508	1657	4	88	155	1222	25	346	269	427	0	29	962	3769	847
920	980	59	576	3	198	163	1770	3	540	238	548	0	61	465	3693	895
980	1020	42	570	4	223	67	3556	50	1780	361	1750	8	177	533	8056	1876
1020	1060	84	887	0	354	96	3637	60	1488	522	1977	60	217	822	8560	2018
1060	1100	102	1134	0	570	768	6569	24	1659	948	2487	0	372	1842	12792	2705
1100	1140	108	1663	12	1597	1416	9622	72	2867	456	2451	0	479	2064	18677	3824
1140	1180	60	838	12	2125	1752	10383	108	2725	378	2068	0	548	2310	18688	4498
1180	1225	72	464	12	1221	3198	8709	144	2642	432	1710	0	574	3858	15320	4830
1225	1260	54	1206	456	2090	6186	10291	48	2651	744	2327	150	493	7638	19057	8303
1260	1280	24	446	360	1711	5448	7143	18	2773	690	2658	54	467	6594	15198	8209

Table 3.

Summary characteristics of six subregions within the study area, A.D. 600–1280, averaged over each period.

Subregion	Area (km^2)	Survey Coverage (%)	Mean Elevation (m)	Percent of Subregion in Maize Niche	Mean Variability	Mean Good-year count	Mean Bad-year count	No. of Years Completely Outside/Inside of Niche
Dolores	1022	18	2136	83	.34	8.28	1.41	12/66
Hovenweep	364	18	1654	43	.46	2.48	3.49	98/150
McElmo	1156	20	1941	74	.40	6.04	1.68	63/330
Mesa Verde Landform	666	5	1990	75	.38	6.77	1.70	20/58
Mesa Verde National Park	215	100	2250	89	.29	10.23	1.24	13/166
Ute Piedmont	640	23	1622	29	.39	1.94	6.53	116/61
Total or Mean	4064	22	1939	68	.38	5.99	2.51	10/0

Table 4.

Population Density (persons per square kilometer) in the study area (subregions listed in decreasing order of long-term population density), and regional crude birth rates.

begin (AD)	end (AD)	Dolores	Hovenweep	McElmo	Mesa Verde Landform	Mesa Verde National Park	Ute Piedmont	Crude Birth Rate, northern San Juan[a]
600	725	.4	.4	1.4	.3	2.6	.1	.035
725	800	.8	.5	1.4	.3	3.1	.0	.039
800	840	2.5	2.2	3.8	1.9	6.9	.1	.041
840	880	2.9	1.5	4.6	1.0	9.3	.1	.04
880	920	2.1	.3	1.2	.6	3.2	.0	.04
920	980	.6	.6	1.7	.8	3.7	.1	.039
980	1020	.6	.6	3.1	2.7	9.8	.3	.041
1020	1060	1.0	1.0	3.2	2.3	11.6	.4	.042
1060	1100	1.2	1.6	6.3	2.5	15.9	.6	.05
1100	1140	1.7	4.4	9.5	4.4	13.5	.7	.057
1140	1180	.9	5.9	10.5	4.3	11.4	.9	.062
1180	1225	.5	3.4	10.3	4.2	9.9	.9	.064
1225	1260	1.2	7.0	14.3	4.1	14.3	1.0	.066
1260	1280	.5	5.7	10.9	4.2	15.5	.8	.067

[a] Kohler and Reese (2014).

Table 5.

Population Growth Rates (percent per year) from one period midpoint to the next. Values > |.7| (bold) are suggestive of migration (following Cowgill 1975).

From (year A.D.)	To (year A.D.)	Dolores	Hovenweep	McElmo	Mesa Verde Landform	Mesa Verde National Park	Ute Piedmont	Study Area Overall
663	763	**.8**	.3	.0	−.2	.2	**−.7**	.2
763	820	**2.0**	**2.5**	**1.7**	**3.4**	**1.4**	**1.8**	**1.9**
820	860	.4	**−.9**	.5	**−1.7**	.7	**−1.4**	.2
860	900	**−.8**	**−4.5**	**−3.4**	**−1.3**	**−2.6**	**−1.4**	**−2.2**
900	950	**−2.5**	**1.6**	**.7**	**.8**	.2	**1.5**	−.3
950	1000	−.1	.2	**1.3**	**2.4**	**2.0**	**2.2**	**1.5**
1000	1040	**1.2**	**1.1**	.1	−.4	.4	**1.0**	.2
1040	1080	.6	**1.2**	**1.7**	.2	.8	**.7**	**1.1**
1080	1120	**.9**	**2.6**	1.0	**1.4**	−.4	.6	.9
1120	1160	**−1.7**	**.7**	.2	−.1	−.4	.3	.0
1160	1203	**−1.2**	**−1.3**	.0	.0	−.3	.1	−.2
1203	1243	**2.1**	**1.8**	**.8**	−.1	**.9**	.3	.8
1243	1270	**−3.6**	**−.8**	**−1.0**	.1	.3	**−.8**	**−.7**