Bayesian Probability Density Analysis and Population History at San Marcos Pueblo, New Mexico

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A common situation faced by archaeologists is one where the researcher would like to estimate the resident population of a site over the course of its occupation, but all one has to work with is the overall size of its architectural footprint and a tabulation of the various types of pottery found on the surface. Fairly sophisticated models can be developed when one also has knowledge of the production histories of pottery types (see, for example, Ortman et al. 2007) or suites of absolute dates tied to construction events in various portions of the site (see, for example, Dean 1969; Eighmy 1979; Graves 1983), but in most cases all one has to work with are estimates of the overall production span (or more precisely, deposition span) of various pottery types. In this paper I develop a method for estimating the population histories of archaeological sites in such situations and test this model against the data from San Marcos Pueblo, an ancestral Pueblo settlement in the Galisteo Basin of north-central New Mexico.

San Marcos presents a good test case for this method. The site is so large that it will never be feasible to reconstruct its population history directly from excavation results, but the surface of the site is well-preserved and has been documented in great detail as a result of recent research directed by Ann Ramenofsky. In addition, the stratigraphic histories of at least two room blocks are known thanks to Ariane Pinson's (In Prep.) work on the arroyo that cuts across a portion of the site. Records from Nelson's early excavations (Nelson 1912-1915) provide a minimal basis for translating adobe mound areas into room counts, and estimates of the 17th century population appear in two Spanish census documents, thus providing some basis for checking archaeological interpretations against historic records. Finally, substantial effort has already been devoted to characterizing the settlement history of San Marcos (Ramenofsky, et al. 2009), and this work provides a useful means of checking how well a general method for estimating population histories can account for the history of a settlement that has already been studied in detail.

This chapter thus utilizes data from San Marcos Pueblo to develop generally-applicable methods for reconstructing population histories in the northern Rio Grande and other settings with similar characteristics. I first discuss previous approaches taken by northern Rio Grande archaeologists to estimating the population histories of settlements, emphasizing their strengths and weaknesses, to highlight the various parameters one should attempt to control in estimating these histories. Then, I present a new, two-step method that attempts to control these parameters. The first step combines a total site surface pottery assemblage with the local pottery chronology using Bayes' Theorem to estimate a probability density curve for the occupation of San Marcos; and the second step links results of this analysis to estimates of roofed living space during specific pottery periods to reconstruct the overall population history of a settlement. I will use the data from San Marcos to illustrate this method, and will judge its effectiveness by comparing the results with those from previous studies at this site.

Methods for estimating population in archaeology

All methods of estimating population combine measures of the living space in a settlement with data on the chronology of use of that space. The simplest approach employed in the northern Rio Grande has involved apportioning the total living space uniformly across the periods of occupation suggested by the surface pottery assemblage (see Dickson 1979; Maxwell 1994; Orcutt 1999a, b). To do this, one first defines pottery periods based on the beginning and end dates of the pottery types found in a region and then determines the phases of occupation for a specific site from the range of types in its pottery assemblage. Then, one allocates the total roofed living space at that site proportionately across pottery periods, taking variation in the lengths of the pottery periods and the average use-life of a structure into account.

Although this approach has the benefit of simplicity, it makes several unrealistic assumptions. First, it assumes that living space accumulates the same way as pot sherds or stone flakes, such that the occupancy rate of the total architectural footprint at a site is no greater than one over the periods of occupation. Excavations in northern Rio Grande villages demonstrate that this assumption is unrealistic. In fact, excavation results suggest that in most cases nearly the entire architectural footprint of a site was inhabited during the period of peak occupancy (see Creamer 1993; Fallon and Wening 1987; Greenlee 1933; Kohler and Root 2004; Luebben 1953; Peckham 1981; Snow 1963; Vierra, et al. 2003; Wendorf 1953).

Second, this approach assumes that each square meter of an architectural mound was inhabited only for the use-life of a single room. It is almost certainly the case that the use-life of individual adobe rooms in northern Rio Grande sites was short. For example, Snow (1963) inferred that the average use-life of an adobe room was about 25 years based on the number of plaster layers on the walls of excavated rooms and the rate of replastering in historic pueblos. By comparison, the duration of the pottery periods into which living space is apportioned are often 50 years or more. Nevertheless, excavations indicate that a given square meter of mound area was often used for much longer than 25 years. For example, excavated or otherwise exposed rooms at many sites contain multiple floors, floor levels that vary across stratigraphic sections, and cultural fill consisting of melted adobe construction material and mixed refuse beneath the walls (Greenlee 1933; Pinson, this volume; Stubbs and Stallings 1953:2-8; Wendorf 1953:36-42). Snow (1963) also observed that adobe walls were often rebuilt on existing wall stubs using chunks of adobe from previous, disintegrated walls set in adobe mortar, and the same pattern was observed at San Marcos in Roomblock 13 (Pinson, In Prep.). These results indicate that standardizing the roofed living space at a site to the average use-life of individual structures is not realistic.

An alternative approach that overcomes these issues to some extent involves apportioning the total living space across periods of occupation using a settlement history function representing the typical population trajectory of such settlements. Hill and others (2004) followed this strategy in their study of late prehistoric settlements across the U.S. Southwest (also see Wilcox, et al. 2007), as did I in a recent study of northern Rio Grande settlements (Ortman 2012:Chapter 4). This approach improves upon earlier methods because it models the population history of a site in such a way that most of the architectural footprint was occupied at some point, and it recognizes that most settlements start small and grow in size over time. Indeed, many studies of villages for which construction sequences and absolute dates are available suggest that villages typically grow in a logistic fashion (for examples, see Eighmy 1979; Graves 1983; Ortman 2012:Chapter 4). Thus, applying a settlement history function to the total architectural footprint of a site is much more realistic than dividing the total roofed living space by the number of periods of occupation. This approach also allows a given square meter of ground to have been inhabited for a much longer period than the use-life of any single structure.

Still, this approach is not ideal because it imposes a life history on a settlement when in fact this is what one would most like to reconstruct, and excavations make clear that the shapes of settlement histories can vary substantially. For example, Tijeras Pueblo started small and gradually grew to encompass the final architectural footprint one can see today (Cordell and Damp 2010), whereas the entire footprint of Arroyo Hondo Pueblo was established early in its occupation, after which a smaller population lingered for several decades (Creamer 1993). A more realistic way to generate a settlement history curve from surface evidence would incorporate the relative frequencies of pottery types found at the site. But this brings up the issue posed at the outset; namely, that in the northern Rio Grande there is little empirical basis for estimating the frequency distributions of pottery types over time. There are a number of well-dated, short-duration contexts dating to the Coalition (A.D. 1200-1350) period (see Orcutt 1999a,b), but there are precious few for the Classic (A.D. 1350-1540) and Historic (A.D. 1540-1760) periods, when most of the large settlements like San Marcos were inhabited.

In the absence of such information, researchers have often assumed that the deposition histories of pottery types follow normal or Gaussian distributions, and have used this model to assess the relative intensity of occupation through time following an approach known as *mean ceramic dating* (Christenson 1994; South 1972; Steponaitis and Kintigh 1993). This approach has been used in previous studies of San Marcos (Ramenofsky et al. 2008). Yet, imposing a bell-shaped frequency distribution on the pottery types in an assemblage is in reality no better than imposing a logistic growth model on the settlement overall because both are *a priori* distributions that surely misrepresent at least some cases. It is thus more desirable to reconstruct the population history of a settlement without having to specify the shape of the frequency distributions for pottery types or the growth pattern of the architectural footprint beforehand. The method presented below enables one to do this while making fewer assumptions than settlement history models or mean ceramic dating. This method works from the initial assumption that each pottery type was deposited at a uniform rate across its production span and combines this model with the site pottery assemblage to produce an initial assessment of the relative rate of sherd deposition through time. It then modifies this initial assessment using Bayes' Theorem to produce a refined assessment. Finally, information on the sizes of architectural mounds and the spatial distributions of pottery types are used to calibrate these refined sherd deposition rates, thus translating them into estimates of the resident population.

Bayesian probability density analysis

The approach presented here is a form of probability density analysis as developed in my previous work (Ortman 2003:39-65; Ortman, et al. 2007; Varien and Ortman 2005). However, instead of using empirical probability density distributions derived from calibration data, or theoretical distributions as in mean ceramic dating, this method begins by apportioning the probability of deposition of a sherd of a given type uniformly over the entire production span of that type, based on absolute dates and stratigraphic evidence from a given region. In statistical jargon, such distributions are referred to as *uniform distributions*. Table 1 presents uniform distributions for local pottery types of the Galisteo Basin, within which San Marcos Pueblo occurs. The rows of the table list the pottery types, along with their beginning and end dates of production based on recent assessments (Dyer 2008; Wilson 2006). The columns present a series of 18 pottery periods defined on the basis of the beginning and end dates of these types, such that each period is characterized by a distinct assemblage (in other words, no two pottery periods are associated with the same list of types present). Finally, the cell values represent the number of years in each pottery period divided by the total range of each type. These values are between zero and one, and the values in each row sum to one. The values in each row thus represent the proportion of the total range of each type corresponding to each pottery period, or the probability that a sherd of that type was deposited at a site during each of these periods. Note that the bottom row of the table also sums the total probability assigned to each pottery period based on the typology. These values will come into play later in the analysis.

The rows of Table 1 represent uniform distributions because the probability of deposition of a sherd of a given type in any given year is equal over the entire span of production of each type. The probability of deposition during a given period varies with the length of the period, but this is reasonable because, in the absence of any additional information on the shape of the production curve, a sherd is more likely to have been deposited during a period representing a larger proportion of its total production span than during a period corresponding to a shorter proportion of this span.

The initial step in the analysis combine these uniform distributions with the surface pottery assemblage to calculate a probability density distribution representing the relative rate of sherd deposition at the site through time. This is accomplished by (1) multiplying the uniform distribution for each pottery type by the number of sherds of that type in the site assemblage, (2) summing the resulting distributions together, and then (3) dividing by the sample size. Table 2 presents these calculations for the San Marcos Pueblo assemblage. For example, the value in the cell corresponding to Galisteo Black-on-white and A.D. 1275-1315 (18.56) in Table 2 represents the number of Galisteo Black-on-white sherds in the assemblage (58) multiplied by the proportion in the corresponding cell of Table 1 (.320); the column total for this row reflects the sum of these values for Galisteo Black-on-white, Santa Fe Black-on-white, Indented Corrugated, and Smeared Indented Corrugated; and the "prior" represents this column total divided by the overall assemblage size. This "prior" distribution is a probability density distribution for which the area under the curve equals one and the height represents the relative probability of occupation during each of the pottery periods. These values can also be interpreted as relative rates of sherd deposition, or the relative intensity of occupation, during each period.

A primary shortcoming of this initial analysis is that it does not take information on the relative frequencies of pottery types that co-occur during certain periods into account. For example, in the San Marcos assemblage there are a small number of Santa Fe Black-on-white sherds and a large number of Glaze A sherds. Given that both types were produced between A.D. 1315 and 1350, and that Glaze A is much more frequent, the Santa Fe Black-on-white sherds may well have been deposited primarily during the period of overlap with Glaze A (A.D. 1315-1350), instead of being deposited uniformly over its entire production span (A.D. 1175-1350). Yet the probability density analysis discussed above apportions Santa Fe Black-on-white uniformly across its entire production span, thus imparting a greater probability of occupation to periods prior to the production of Glaze A than may be reasonable. This example illustrates that it would be desirable to modify the uniform distribution for each type based on the way the observed proportions of that type interact with expectations of the uniform deposition model. In terms of this specific example, it would be desirable to adjust the shape of the uniform deposition model so that Santa Fe Black-on-white was deposited more often during the period of overlap in production with Glaze A, and less often in periods prior to the production of Glaze A.

The second step in the analysis accomplishes this using Bayes' Theorem. This theorem can be written a number of ways, but its simplest form is:

$$P(H|D) \propto P(H) * P(D|H).$$

The theorem states that the probability (P) of a hypothesis (H), given a specific piece of data (D), is proportional to the probability of the hypothesis before the data are known times the probability of the data if the hypothesis were true. The terms on the right-hand side of the equation are known as the *prior probability* and *conditional probability*, respectively. Bayes' Theorem provides a systematic way of combining these two parameters to produce a *posterior probability* of the hypothesis, which is given on the left-hand side of the equation (For additional background on Bayes' Theorem, see Iversen (1984); and for applications to archaeological data see Buck et al. (1996), Robertson (1999) and Ortman et al. (2007), among others).

Bayes' Theorem is often adapted to situations where the hypothesis to be examined is actually a series of related hypotheses, such as the relative probability of occupation during each of a series of pottery periods. In this case, Bayes' Theorem for the discrete case of k related hypotheses can be written as:

$$P(H_i|D) = \frac{P(H_i) * P(D|H_i)}{\sum_{i=1}^{k} P(H_i) * P(D|H_i)} \quad (1)$$

Equation 1 states that one can examine the relative probability of each of a series of related hypotheses by combining prior knowledge of the relative probability of each hypothesis with the probability of obtaining the observed sample data if each of the available alternatives were true. In this case, Bayes' Theorem is invoked to evaluate the probability that a site was inhabited during each of a series of pottery periods, given the prior probability of occupation for each period (from the probability density analysis) and the conditional probability of obtaining the sample data from that site based on the uniform deposition model. The resulting posterior distribution presents a view of the occupational history of the site that takes both the probability density analysis and the relative frequencies of types in the assemblage into account.

For these calculations, the prior probability of occupation during each of a series of pottery periods is the value of the prior probability density distribution for that period. These values are given for San Marcos on the bottom row of Table 2. The conditional probability of occupation, given the model of uniform deposition, is estimated using the normal distribution. First, the proportion of the total probability for period *i* provided by type *j* ($p_{i,j}$) is calculated from the results of the probability density analysis. These values are presented for the San Marcos assemblage in Table 3. Second, a normal distribution is defined for each pottery type and period based on the pottery typology. The means of these distributions ($\mu_{i,j}$) are the proportion of the total probability for period *j* accounted for by pottery type *i* in the uniform distributions specified by the typology (Table 4); and standard deviations are estimated using the standard errors of these proportions, with sample sizes equal to the number of years in period *j*, as given by equation 2, below:

$$\sigma_{i,j} = \sqrt{\frac{\mu_{i,j} * (1 - \mu_{i,j})}{Y_j}} \qquad (2)$$

Third, these normal distributions are used to estimate the probability of obtaining $p_{i,j}$ (the values in Table 3) which is to say, a sample in which the observed proportion of the total probability for period *i* is provided by type *j*, given the hypothesis of uniform deposition of that type across its production span. These conditional probabilities are calculated following equation 3:

$$C_{i,j} = \frac{1}{\sigma_{i,j}\sqrt{2\pi}} * \exp\left\{-\frac{(p_{i,j} - \mu_{i,j})^2}{2\sigma_{i,j}^{\ 2}}\right\}. \qquad (3)$$

Fourth, these values are averaged across types for each period to generate a mean conditional probability distribution:

$$C_j = \frac{\sum_{j=1}^{n} C_i}{n_j}, \qquad (4)$$

Finally, the prior and mean conditional distributions are combined using Bayes' Theorem (Eq. 1) to generate a posterior probability distribution that specifies the relative intensity of occupation during each pottery period. Figure 1 presents the prior, conditional, and posterior probability distributions for San Marcos Pueblo in graphical form. This figure illustrates the effect of this application of Bayes' Theorem on the results. Specifically, it illustrates that the posterior probability distribution has a larger value than the prior probability distribution for periods corresponding to relatively high conditional probabilities, and vise versa for periods corresponding to relatively low conditional probabilities. In effect, this analysis has weighted the uniform distribution model in accordance with the likelihood of obtaining the observed sample from San Marcos, given the uniform deposition model assumed at the outset. The result is a refined view of the relative rate of sherd deposition at San Marcos through time. To the extent that that (1) the total pottery assemblage from San Marcos is representative of the total sherd population at the site, and (2) per capita sherd deposition rates were consistent through time, these differences in deposition rates should be proportional to the number of people who used and broke pottery vessels at the site during each period. If these assumptions are reasonable, the posterior probability density distribution provides an estimate of the shape of the population history of the site. Given this, the remaining task is to calibrate the posterior distribution to population levels. I discuss this final stage of the analysis below.

From probability density to population

To the extent that the posterior probability density distribution represents the shape of San Marcos' population history, this distribution suggests a much more dynamic history than the prior distribution, and this raises the question of whether the posterior distribution provides a better representation of this history. Stratigraphic evidence from the arroyo cut-bank documented by Pinson (In Prep.) suggests that it does. The cut-bank exposes two occupational layers in room blocks 28 and 29 that are separated by a period of disuse. The initial occupation represents single story architecture associated with Glaze A sherds that fell into disuse by the late A.D. 1300s based on a radiocarbon date from an intrusive burial pit. The second occupation, consisting of two-story architecture associated with Glaze B-D sherds, was established in the early A.D. 1400s, based on a second radiocarbon date. This sequence, with the second component being significantly larger than the first, is reflected in the posterior probability distribution but not the prior distribution. This correspondence thus provides a check on the analysis, and supports the inference that the posterior distribution does in fact represent the shape of the population history of San Marcos.

If in fact the height of the posterior distribution is proportional to the resident population, it should also be possible to calibrate this curve to estimate the resident population during each period. To accomplish this, one needs to estimate the population of a site during certain pottery periods independent of the probability density analysis. Fortunately, such estimates can be made for four periods in the history of San Marcos. Two of these are provided by Spanish census documents, which record a population of 777 "neophytes" in A.D. 1641 and 600 "neophytes" in A.D. 1680 (Hodge, et al. 1945). I assigned these estimates to the 1625-1650 and 1650-1680 periods, respectively.

I also estimated population for two additional periods based on estimates of the numbers of rooms in architectural mounds associated with specific pottery types. Nels Nelson (1912-1915) documented the surface area and number of stories represented by each architectural mound as part of his early work at San Marcos. Recent work by Duwe (2011) further suggests that adobe rooms in prehispanic northern Rio Grande villages melt down to encompass an area of 4.5 x 5 meters per room. I used this conversion in conjunction with Nelson's data to estimate the total rooms represented by each architectural mound at San Marcos. I then translated the estimated room counts into estimates of the population that would have inhabited those rooms at full occupancy. To accomplish this, I multiplied the estimated room count for each mound by the ratio of the average floor area of ground floor rooms excavated by Nelson ($7.36m^2$, N=171) to the average floor area per person in traditional architecture, based on Brown's (1987) re-study of Naroll's constant ($6m^2$ per person). These data and calculations are presented in Table 5.

I used these figures to estimate population for two periods in the history of San Marcos. First, I estimated the population of the initial settlement based on the data for mounds associated with Coalition Period pottery. There are only three middens at San Marcos (16, 17 and 18) in which appreciable amounts of Clapboard Corrugated, Indented Corrugated, Santa Fe Black-on-white and Galisteo Black-on-white occur. All of these types were manufactured prior to the introduction of Glaze A pottery to the San Marcos area around A.D. 1315. I thus summed the peak populations of the three architectural mounds associated with these middens (Nelson mounds 37, 38, and 39-43) to estimate the A.D. 1275-1315 population (359 persons). Second, I estimated the peak population of San Marcos overall based on the estimated populations of mounds associated with Glaze B, the type most characteristic of the A.D. 1425-1450 period corresponding to the peak of the posterior probability distribution. Glaze B occurs in every midden at San Marcos, so I summed the estimated populations of all architectural mounds to estimate the A.D. 1425-1450 population (2,621 persons). In essence, I assume, based on the widespread distribution of Glaze B sherds, that the entire architectural footprint of San Marcos was inhabited during the period corresponding to the peak of the posterior distribution. As mentioned earlier, this assumption is consistent with excavation results from other Classic Period northern Rio Grande villages.

One could certainly raise objections to the estimates made above, as they incorporate a number of assumptions about relationships between roofed space and people, middens and room blocks, and sherd deposition and occupancy rates that are almost certainly inaccurate in at least some cases. Nevertheless, these four estimates of population during specific pottery periods are strongly correlated with the height of the posterior distribution for those same periods, even though the estimates derive from different data sources, both of which are independent of the probability density analysis. This is illustrated by the linear regression in Figure 2. This chart also illustrates that the posterior distribution predicts population for these four periods better than the prior distribution. It would clearly be preferable to have population estimates for more of the periods represented in the posterior distribution; but nevertheless, the strong correlation between the four population estimates that are available and the posterior distribution suggests that the height of the posterior distribution is in fact proportional to population, and that the estimates discussed above provide a reasonable basis for calibrating this distribution.

Consequently, I use the regression equation in Figure 2 in combination with the posterior distribution to provide estimates of the momentary population of San Marcos Pueblo during each of seventeen pottery periods spanning A.D. 1050-1760. Note that I did not assign any population to periods with posterior probabilities lower than A.D. 1275-1315, due to the evidence discussed earlier which suggests that this was the initial period of occupation. The resulting estimates suggest that San Marcos was established as a village of some 400 people during the late A.D. 1200s, and that the settlement grew to encompass more than 2,000 persons during the A.D. 1400s. In the A.D. 1500s the site population dwindled towards its initial size, and then grew again during the A.D. 1600s until it was abandoned during the Pueblo Revolt.

Comparison with previous studies at San Marcos

How does the population history of San Marcos developed in this paper compare with previous models of this history? A recent treatment by Ramenofsky and others (Ramenofsky et al. 2009) used a combination of frequency seriation, correspondence analysis, and mean ceramic dating to define five periods of occupation. The overall shape of this history corresponds quite well to the model developed here. For example, Ramenofsky and others' (2009) Period 1 corresponds to the initial period of occupation suggested by the posterior distribution in Figure 2, and their Periods 2-5 correspond to the four peaks of the posterior distribution. In addition, Ramenofsky and others' (2009:521) summary of population trends, based on 32-year standard deviation surrounding the mean ceramic date for each midden, bears a close resemblance to the results of the analysis presented here: “The 32-year kernel reveals that the population increased through the fourteenth century and peaked in the early fifteenth century. A population decline began in the middle of the fifteenth century and ended in the late fifteenth century. A period of stability and perhaps even another increase occurred into the late sixteenth century, with final abandonment in the seventeenth century.”

Nevertheless, the two analyses differ in a number of ways. First, Ramenofsky and others suggest that population growth was consistent through the 14th century, whereas the posterior distribution calculated here suggests it was inconsistent. I believe the latter interpretation is more likely for two reasons. First, it matches the cultural stratigraphy in the arroyo cut bank. Second, the dip in the posterior distribution emerges through the application of Bayes’ Theorem. Let me explain why this happens and why it is justified. The uniform deposition model used to generate the prior distribution apportions the probability of deposition of each sherd uniformly across the deposition span of its corresponding type. If the population of San Marcos had been consistent across its entire history, and the rate of sherd deposition per capita was also consistent, one would expect the total probability represented by the resulting assemblage to be apportioned according to Table 4. Yet Table 3 illustrates that the proportion of the total probability contributed to A.D. 1350-1400 by Galisteo B/W and Smeared Indented Corrugated are less than expected, according to the uniform deposition model. In other words, if the population of San Marcos had been consistent between A.D. 1350 and 1400, relative to adjacent periods, there should be higher proportions of Galisteo Black-on-white and Smeared Indented Corrugated sherds in the total site assemblage. Thus, the rate of sherd deposition, and hence population, was probably not consistent across this period. This is reflected in the conditional probability distribution which suggests that the probability of occupation was lower between A.D. 1350 and 1400 than it was on either side of this interval. Thus, combining the conditional probability distribution with the prior distribution using Bayes’ Theorem produces a dip in posterior probability, and hence sherd deposition and population, during this period.

A second difference between this and previous studies is that the posterior distribution spreads out the various peaks in population over a longer time span than mean ceramic dating. To illustrate this, Table 7 compares the major occupational periods defined by Ramenofsky and others (2009:521) to the pottery periods corresponding to peaks in the posterior distribution resulting from this study. This comparison illustrates that the distribution used to represent the depositional histories of pottery types does impact the resulting population history. Specifically, it compresses this history in the case of mean ceramic dating (based on normal distributions) or spreads it out in the case of probability density analysis as implemented here (based on uniform distributions).

Although more work is needed in this area, two lines of evidence suggest that Bayesian probability density analysis using uniform distributions is superior to the use of normal distributions in mean ceramic dating. First, empirical studies of the frequency distributions of pottery types based on directly-dated assemblages (Orcutt 1999a, b; Ortman, et al. 2007) suggest that normal curves do not represent the frequency distributions of types that are characteristic of the initial or final periods in a pottery sequence very well. In most cases, pottery types characteristic of sites dating to the initial period are most frequent during the initial period, and types characteristic of sites dating to the final period are most frequent during the final period.

Thus, using normal distributions in any form of probability density analysis (including mean ceramic dating) will tend to compress the occupational histories of sites away from the "edges" of the local pottery sequence. This effect is apparent in the specific case of San Marcos from Table 7. Second, in the specific case of San Marcos, the posterior distribution suggests increased population levels for the 17th century that are closely mirrored in Spanish census documents, whereas the mean ceramic dating model presented by Ramenofsky and others (2009: Figure 12) suggests gradual decline from the late 16th century. The picture suggested by the posterior distribution is more consistent with historic documents related to San Marcos and with the fact that a mission was established there in the 17th century. San Marcos appears to have been one of the villages into which Pueblo populations coalesced during the early historic period, and Bayesian probability density analysis reflects this history better than mean ceramic dating.

A third difference between this and previous studies of San Marcos lies in their data requirements. Ramenofsky and others' reconstruction focuses on dating each midden individually, and thus requires a representative sample of sherds from each midden. The method developed here, in contrast, only requires a representative sample of the total sherd population and an accounting of the living space encompassed by various elements of the architectural footprint. As such, it could be applied to a simple random sample of sherds from the site surface. One of the most important benefits of the intensive surface work conducted by Ramenofsky and others at San Marcos is that it allows one to compare several different methods for estimating the population history of the site. That the method developed here reproduces the results generated from a more detailed analysis, and also extends them in certain ways, suggests that it may be applicable to the types of data typically collected in settlement pattern surveys, where less effort is invested in any given site.

A final difference between the two methods is that the Bayesian probability density analysis developed here allows one to estimate the magnitude as well as the shape of the population history curve, whereas Ramenofsky and others' methods only estimate its shape. In this study, estimates of population for certain pottery periods are used to calibrate the posterior distribution in order to translate probabilities into people. In contrast, Ramenofsky and others (2009) refrain from estimating actual human populations. This is reasonable, given the methods they utilize, because at San Marcos there is no necessary relationship between type frequencies in a given midden and the number of residents of a given roomblock through time. Indeed, residents of adjacent roomblocks likely contributed sherds to shared middens in varying proportions over the occupational history of each mound, and the visibility of surface artifacts varies across the site due to the taphonomic processes involved in the devolution of adobe architecture (see Pinson, in prep.). The method developed here removes this problem by looking at the history of sherd deposition across the site as a whole. It does not attempt to date specific architectural features or to specify the layout of the village at any given moment; but it does enable one to estimate the number of people who resided at a site during each of a series of chronological periods. To determine the accuracy or precision of these estimates, one would need to delve further into the assumptions incorporated into this analysis. For example, if artifacts from early occupations are significantly under-represented on the modern ground surface one would need to derive some sort of period weighting function and incorporate this into the probability density analysis to control for this bias. Also, if per capita sherd deposition rates varied through time, one would need to modify the uniform accumulation model to reflect this fact. Finally, if the peak occupancy rate of the architectural footprint was significantly less than one, the posterior distribution would need to be recalibrated. I believe estimating a peak occupancy rate close to one is reasonable given the current state of knowledge of San Marcos because it reflects the widespread distribution of the pottery type corresponding to the period of peak probability and it leads to a stronger calibration when combined with population estimates for other periods. But this assumption should be investigated further in future research at San Marcos and other northern Rio Grande villages.

Despite the specific differences generated through the two approaches compared here, the overall shapes of the population histories suggested by Ramenofsky and others (2009) and this study correspond quite well. This is encouraging as it suggests that, given the available data, a variety of methods can lead to similar interpretations. The results presented here generally support Ramenofsky and others' subdivision of the occupation at San Marcos into five chronological periods, and also reinforce the general shape of the population history of the settlement. In this light, the primary contribution of this study is that it presents a simpler means of calculating an overall population history curve that appears consistent with more of the available data from the site and which allows one to translate probability densities into estimates of actual human populations. It does not radically change the overall picture of the history of San Marcos; rather, it refines this picture at certain points.

Conclusions

In this paper I have reviewed methods employed in previous studies to assess the population histories of northern Rio Grande settlements; developed a new method which I call *Bayesian probability density analysis* for assessing these histories; and compared the population history suggested by this method for San Marcos Pueblo with the results of previous studies of this history. The method makes relatively few assumptions about the surface pottery assemblage from a site and it allows these assumptions to be modulated to some extent through the use of Bayes' Theorem. The method also does a surprisingly good job of generating a probability density distribution for San Marcos Pueblo that is consistent with previous more intensive studies of the site and also appears consistent with independent stratigraphic and documentary evidence. These results suggest that Bayesian probability density analysis has significant potential for the purpose of reconstructing the population histories of archaeological sites when all one has to work with are the production spans of local pottery types, a representative surface pottery assemblage, and an estimate of the living space represented by the total architectural footprint.

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References Cited

Brown, B. M.

1987 Population Estimation from Floor Area: A Restudy of "Naroll's Constant.". *Behavior Science Research* 22(1-4):1-49.

Buck, C. E., W. G. Cavanaugh and C. D. Linton

1996 *Bayesian Approach to Interpreting Archaeological Data*. John Wiley and Sons, New York.

Christenson, A. L.

1994 A test of mean ceramic dating using well-dated Kayenta Anasazi sites. *Kiva* 59:297-317.

Cordell, L. S. and N. E. Damp

2010 Adobe Melt-down. In *Threads, Tints, and Edification, Papers in Honor of Glenna Dean*, edited by E. J. Brown, K. Armstrong, D. M. Brugge and C. J. Condie, pp. 49-59. Papers of the Archaeological Society of New Mexico 36, Albuquerque.

Creamer, W.

1993 *The Architecture of Arroyo Hondo Pueblo, New Mexico*. Arroyo Hondo Archaeological Series 7. School of American Research Press, Santa Fe.

Dean, J. S.

1969 *Chronological Analysis of Tsegi Phase Sites in Northeastern Arizona*. Laboratory of Tree-Ring Research, Tucson.

Dickson, D. B., Jr.

1979 *Prehistoric Pueblo Settlement Patterns: The Arroyo Hondo, New Mexico, Site Survey*. School of American Research, Santa Fe.

Duwe, S. G.

2011 *The Prehispanic Tewa World: Space, Time and Becoming in the Pueblo Southwest.* Ph.D. Dissertation, University of Arizona.

Dyer, J. B.

2008 *Middle Rio Grande Ceramic Reference Manual, Volume I: Cochiti Pueblo to Socorro, New Mexico*. Bureau of Reclamation, Albuquerque.

Eighmy, J. L.

1979 Logistic trends in Southwest population growth. In *Transformations: Mathematical approaches to culture*, edited by C. Renfrew and K. L. Cooke, pp. 205-220. Academic Press, New York.

Fallon, D. and K. Wening

1987 *Howiri: Excavation at a Northern Rio Grande Biscuit Ware Site*. Laboratory of Anthropology Notes 261b. Museum of New Mexico, Santa Fe.

Graves, M. W.

1983 Growth and Aggregation at Canyon Creek Ruin: Implications for Evolutionary Change in East-Central Arizona. *American Antiquity* 48(2):290-315.

Greenlee, R.

1933 *Archaeological Sites in the Chama Valley, and Report on Excavations at Tsama, 1929-1933.* Manuscript on file (P651), Laboratory of Anthropology, Museum of New Mexico, Santa Fe.

Hill, J. B., J. J. Clark, W. H. Doelle and P. D. Lyons

2004 Prehistoric Demography in the Southwest: Migration, Coalescence, and Hohokam Population Decline. *American Antiquity* 69(4):689-716.

Hodge, F. W., G. P. Hammond and A. Rey

1945 *Fray Alonso de Benavides' Revised Memorial of 1634*. Coronado Cuarto Centennial Publications, 1540-1940, Vol., IV. University of New Mexico Press, Albuquerque.

Iversen, G. R.

1984 *Bayesian statistical inference*. Sage Publications, Newbury Park, California.

Kohler, T. A. and M. J. Root

2004 The Late Coalition and Earliest Classic on the Pajarito Plateau (A.D. 1250-1375). In *Archaeology of Bandelier National Monument: Village formation on the Pajarito Plateau, New Mexico*, edited by T. A. Kohler, pp. 173-214. University of New Mexico Press, Albuquerque.

Luebben, R. A.

1953 Leaf Water Site. In *Salvage Archaeology in the Chama Valley, New Mexico*, edited by F. Wendorf, pp. 9-33. Monographs of the School of American Research No. 17, Santa Fe.

Maxwell, T. D.

1994 Prehistoric Population Change in the Lower Rio Chama Valley, Northwestern New Mexico. Paper presented at the 59th Annual Meeting of the Society for American Archaeology, Anaheim. CA.

Nelson, N. C.

1912-1915 *Field notes of the excavations at San Marcos Pueblo*. American Museum of Natural History, New York.

Orcutt, J. D.

1999a Chronology. In *The Bandelier Archaeological Survey: volume I*, edited by R. P. Powers and J. D. Orcutt, pp. 85-116. Intermountain Cultural Resource Management Professional Paper 57, Santa Fe.

1999b Demography, Settlement, and Agriculture. In *The Bandelier Archaeological Survey: volume I*, edited by R. P. Powers and J. D. Orcutt, pp. 219-308. Intermountain Cultural Resource Management Professional Paper 57, Santa Fe.

Ortman, S. G.

2003 Artifacts. In *The archaeology of Yellow Jacket Pueblo: excavations at a large community center in southwestern Colorado [HTML Title]*, edited by K. A. Kuckelman. Available: http://www.crowcanyon.org/yellowjacket.

2012 *Winds from the North: Tewa Origins and Historical Anthropology*. University of Utah Press, Salt Lake City.

Ortman, S. G., M. Varien and T. L. Gripp
2007 Empirical Bayesian Methods for Archaeological Survey Data: An Example from the Mesa Verde Region. *American Antiquity* 72(1):241-272.

Peckham, S. L.
1981 The Palisade Ruin. In *Collected Papers in Honor of Erik Kellerman Reed*, edited by A. H. Schroeder, pp. 113-148. Papers of the Archaeological Society of New Mexico. vol. 6. Albuquerque Archaeological Society, Albuquerque.

Pinson, A. O.
In Prep. Room Blocks as Tells: The Devolution of Adobe Buildings and the Formation of the Surface Archaeological Record. In *The Archaeology and History of San Marcos Pueblo in north Central New Mexico*, edited by A. F. Ramenofsky and K. M. Schleher. American Museum of Natural History, New York.

Ramenofsky, A. F., F. D. Neiman and C. D. Pierce
2009 Measuring Time, Population and Residential Mobility from the Surface at San Marcos Pueblo, North Central New Mexico. *American Antiquity* 74(3):505-530.

Robertson, I. G.
1999 Spatial and multivariate analysis, random sampling error, and analytical noise: empirical Bayesian methods at Teotihucan, Mexico. *American Antiquity* 64:137-152.

Snow, D. H.
1963 *A Preliminary Report on Excavations at Sapawe New Mexico.* . Manuscript on File. Laboratory of Anthropology, Santa Fe.

South, S.
1972 Evolution and Horizon as Revealed in Ceramic Analysis in Historical Archaeology. *The Conference on Historic Site Archaeology Papers* 6(2):71-116.

Steponaitis, V. P. and K. W. Kintigh
1993 Estimating site occupation spans from dated artifact types: some new approaches. In *Archaeology of eastern North America: papers in honor of Stephen Williams*, edited by J. B. Stoltman, pp. 349-361. Archaeological Report, no. 25. Mississippi Department of Archives and History, Jackson.

Stubbs, S. A. and W. S. Stallings, Jr.
1953 *The Excavation of Pindi Pueblo, New Mexico*. Monographs of the School for American Research and the Laboratory of Anthropology, No. 18, Santa Fe.

Varien, M. D. and S. G. Ortman
2005 Accumulations research in the southwest United States: middle-range theory for big-picture problems. *World archaeology* 37(1):132-155.

Vierra, B. J., L. Nordby and G. Martinez
2003 Nake'muu: Village on the Edge. In *Anasazi Archaeology at the Millennium*, edited by P. F. Reed, pp. 137-144. Proceedings of the Sixth Occasional Anasazi Symposium. Center for Desert Archaeology, Tucson.

Wendorf, F.
1953 Excavations at Te'ewi. In *Salvage Archaeology in the Chama Valley, New Mexico*, edited by F. Wendorf, pp. 34-93. Monographs of the School of American Research No. 17, Santa Fe.

Wilcox, D. R., D. A. Gregory and J. B. Hill
2007 Zuni in the Puebloan and Southwestern Worlds. In *Zuni Origins: Toward a New Synthesis of Southwestern Archaeology*, edited by D. A. Gregory and D. R. Wilcox, pp. 165-209. University of Arizona Press, Tucson.

Wilson, G. P.
2006 *Guide to Ceramic Identification: Northern Rio Grande and Galisteo Basin to A.D. 1700*. 2nd ed. Technical Series, Bulletin 12. Laboratory of Anthropology, Santa Fe.

Table 1. Uniform distributions and pottery periods based on local pottery types in the Galisteo Basin.

			Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
			Begin	1050	1175	1200	1250	1275	1315	1350	1400	1425	1450	1490	1515	1550	1600	1625	1650	1700	1050
			End	1175	1200	1250	1275	1315	1350	1400	1425	1450	1490	1515	1550	1600	1625	1650	1700	1760	1760
Type	Begin	End	Span	125	25	50	25	40	35	50	25	25	40	25	35	50	25	25	50	60	710
Kwahe'e B/W	1050	1200	150	.833	.167	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Santa Fe B/W	1175	1350	175	0	.143	.286	.143	.229	.200	0	0	0	0	0	0	0	0	0	0	0	1
Galisteo B/W	1275	1400	125	0	0	0	0	.320	.280	.400	0	0	0	0	0	0	0	0	0	0	1
Glaze A	1315	1425	110	0	0	0	0	0	.318	.455	.227	0	0	0	0	0	0	0	0	0	1
Glaze AB	1315	1450	135	0	0	0	0	0	.259	.370	.185	.185	0	0	0	0	0	0	0	0	1
Glaze B	1400	1450	50	0	0	0	0	0	0	0	.500	.500	0	0	0	0	0	0	0	0	1
Glaze BC	1400	1490	90	0	0	0	0	0	0	0	.278	.278	.444	0	0	0	0	0	0	0	1
Glaze C	1425	1490	65	0	0	0	0	0	0	0	0	.385	.615	0	0	0	0	0	0	0	1
Glaze CD	1425	1515	90	0	0	0	0	0	0	0	0	.278	.444	.278	0	0	0	0	0	0	1
Glaze D	1490	1515	25	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
Glaze DE	1490	1650	160	0	0	0	0	0	0	0	0	0	0	.156	.219	.313	.156	.156	0	0	1
Glaze E	1515	1650	135	0	0	0	0	0	0	0	0	0	0	0	.259	.370	.185	.185	0	0	1
Glaze EF	1515	1700	185	0	0	0	0	0	0	0	0	0	0	0	.189	.270	.135	.135	.270	0	1
Glaze F	1625	1700	75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	.333	.667	0	1
Kapo Black	1625	1760	135	0	0	0	0	0	0	0	0	0	0	0	0	0	0	.185	.370	.444	1
Indented Corr.	1050	1315	265	.472	.094	.189	.094	.151	0	0	0	0	0	0	0	0	0	0	0	0	1
Smeared Ind. Corr.	1250	1400	150	0	0	0	.167	.267	.233	.333	0	0	0	0	0	0	0	0	0	0	1
Micaceous/plain	1400	1600	200	0	0	0	0	0	0	0	.125	.125	.200	.125	.175	.250	0	0	0	0	1
Striated	1600	1760	160	0	0	0	0	0	0	0	0	0	0	0	0	0	.156	.156	.313	.375	1
Total				1.31	0.40	0.47	0.40	0.97	1.29	1.56	1.32	1.75	1.70	1.56	0.84	1.20	0.63	1.15	1.62	0.82	14

Table 2. Prior probability calculation for San Marcos Pueblo.

	Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
	Begin	1050	1175	1200	1250	1275	1315	1350	1400	1425	1450	1490	1515	1550	1600	1625	1650	1700
	End	1175	1200	1250	1275	1315	1350	1400	1425	1450	1490	1515	1550	1600	1625	1650	1700	1760
	Span	125	25	50	25	40	35	50	25	25	40	25	35	50	25	25	50	60
Type	Sample																	
Kwahe'e B/W	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Santa Fe B/W	58	0	8.29	16.57	8.29	13.26	11.60	0	0	0	0	0	0	0	0	0	0	0
Galisteo B/W	58	0	0	0	0	18.56	16.24	23.20	0	0	0	0	0	0	0	0	0	0
Glaze A	1570	0	0	0	0	0	499.55	713.64	356.82	0	0	0	0	0	0	0	0	0
Glaze AB	244	0	0	0	0	0	63.26	90.37	45.19	45.19	0	0	0	0	0	0	0	0
Glaze B	811	0	0	0	0	0	0	0	405.50	405.50	0	0	0	0	0	0	0	0
Glaze BC	107	0	0	0	0	0	0	0	29.72	29.72	47.56	0	0	0	0	0	0	0
Glaze C	712	0	0	0	0	0	0	0	0	273.85	438.15	0	0	0	0	0	0	0
Glaze CD	288	0	0	0	0	0	0	0	0	80.00	128.00	80.00	0	0	0	0	0	0
Glaze D	404	0	0	0	0	0	0	0	0	0	0	404.00	0	0	0	0	0	0
Glaze DE	35	0	0	0	0	0	0	0	0	0	0	5.47	7.66	10.94	5.47	5.47	0	0
Glaze E	181	0	0	0	0	0	0	0	0	0	0	0	46.93	67.04	33.52	33.52	0	0
Glaze EF	99	0	0	0	0	0	0	0	0	0	0	0	18.73	26.76	13.38	13.38	26.76	0
Glaze F	258	0	0	0	0	0	0	0	0	0	0	0	0	0	0	86.00	172.00	0
Kapo Black	37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6.85	13.70	16.44
Indented Corr.	26	12.26	2.45	4.91	2.45	3.92	0	0	0	0	0	0	0	0	0	0	0	0
Smeared Ind. Corr.	272	0	0	0	45.33	72.53	63.47	90.67	0	0	0	0	0	0	0	0	0	0
Micaceous/plain	772	0	0	0	0	0	0	0	96.50	96.50	154.40	96.50	135.10	193.00	0	0	0	0
Striated	70	0	0	0	0	0	0	0	0	0	0	0	0	0	10.94	10.94	21.88	26.25
Total	6002	12.26	10.74	21.48	56.07	108.28	654.11	917.87	933.73	930.75	768.11	585.97	208.41	297.73	63.30	156.15	234.34	42.69
Prior	1	.0020	.0018	.0036	.0093	.0180	.1090	.1529	.1556	.1551	.1280	.0976	.0347	.0496	.0105	.0260	.0390	.0071

Table 3. Proportion of period probability provided by each type in the San Marcos assemblage.

		Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
		Begin	1050	1175	1200	1250	1275	1315	1350	1400	1425	1450	1490	1515	1550	1600	1625	1650	1700
		End	1175	1200	1250	1275	1315	1350	1400	1425	1450	1490	1515	1550	1600	1625	1650	1700	1760
		Span	125	25	50	25	40	35	50	25	25	40	25	35	50	25	25	50	60
Type	Sample	Proportion																	
Kwahe'e B/W	0	.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Santa Fe B/W	58	.010	0	.772	.772	.148	.122	.018	0	0	0	0	0	0	0	0	0	0	0
Galisteo B/W	58	.010	0	0	0	0	.171	.025	.025	0	0	0	0	0	0	0	0	0	0
Glaze A	1570	.262	0	0	0	0	0	.764	.777	.382	0	0	0	0	0	0	0	0	0
Glaze AB	244	.041	0	0	0	0	0	.097	.098	.048	.049	0	0	0	0	0	0	0	0
Glaze B	811	.135	0	0	0	0	0	0	0	.434	.436	0	0	0	0	0	0	0	0
Glaze BC	107	.018	0	0	0	0	0	0	0	.032	.032	.062	0	0	0	0	0	0	0
Glaze C	712	.119	0	0	0	0	0	0	0	0	.294	.570	0	0	0	0	0	0	0
Glaze CD	288	.048	0	0	0	0	0	0	0	0	.086	.167	.137	0	0	0	0	0	0
Glaze D	404	.067	0	0	0	0	0	0	0	0	0	0	.689	0	0	0	0	0	0
Glaze DE	35	.006	0	0	0	0	0	0	0	0	0	0	.009	.037	.037	.086	.035	0	0
Glaze E	181	.030	0	0	0	0	0	0	0	0	0	0	0	.225	.225	.529	.215	0	0
Glaze EF	99	.016	0	0	0	0	0	0	0	0	0	0	0	.090	.090	.211	.086	.114	0
Glaze F	258	.043	0	0	0	0	0	0	0	0	0	0	0	0	0	0	.551	.734	0
Kapo Black	37	.006	0	0	0	0	0	0	0	0	0	0	0	0	0	0	.044	.058	.385
Indented Corr.	26	.004	1	.228	.228	.044	.036	0	0	0	0	0	0	0	0	0	0	0	0
Smeared Ind. Corr.	272	.045	0	0	0	.808	.670	.097	.099	0	0	0	0	0	0	0	0	0	0
Micaceous/plain	772	.129	0	0	0	0	0	0	0	.103	.104	.201	.165	.648	.648	0	0	0	0
Striated	70	.012	0	0	0	0	0	0	0	0	0	0	0	0	0	.173	.070	.093	.615
Total	6002	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 4. Proportion of period probability suggested by the uniform deposition model.

	Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
	Begin	1050	1175	1200	1250	1275	1315	1350	1400	1425	1450	1490	1515	1550	1600	1625	1650	1700
	End	1175	1200	1250	1275	1315	1350	1400	1425	1450	1490	1515	1550	1600	1625	1650	1700	1760
Type	Span	125	25	50	25	40	35	50	25	25	40	25	35	50	25	25	50	60
Kwahe'e B/W	150	.639	.413	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Santa Fe B/W	175	0	.354	.602	.354	.237	.155	0	0	0	0	0	0	0	0	0	0	0
Galisteo B/W	125	0	0	0	0	.331	.217	.257	0	0	0	0	0	0	0	0	0	0
Glaze A	110	0	0	0	0	0	.247	.292	.173	0	0	0	0	0	0	0	0	0
Glaze AB	135	0	0	0	0	0	.201	.238	.141	.106	0	0	0	0	0	0	0	0
Glaze B	50	0	0	0	0	0	0	0	.380	.286	0	0	0	0	0	0	0	0
Glaze BC	90	0	0	0	0	0	0	0	.211	.159	.261	0	0	0	0	0	0	0
Glaze C	65	0	0	0	0	0	0	0	0	.220	.361	0	0	0	0	0	0	0
Glaze CD	90	0	0	0	0	0	0	0	0	.159	.261	.178	0	0	0	0	0	0
Glaze D	25	0	0	0	0	0	0	0	0	0	0	.641	0	0	0	0	0	0
Glaze DE	160	0	0	0	0	0	0	0	0	0	0	.100	.260	.260	.247	.136	0	0
Glaze E	135	0	0	0	0	0	0	0	0	0	0	0	.308	.308	.293	.161	0	0
Glaze EF	185	0	0	0	0	0	0	0	0	0	0	0	.225	.225	.214	.117	.167	0
Glaze F	75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	.290	.412	0
Kapo Black	135	0	0	0	0	0	0	0	0	0	0	0	0	0	0	.161	.229	.542
Indented Corr.	265	.361	.234	.398	.234	.156	0	0	0	0	0	0	0	0	0	0	0	0
Smeared Ind. Corr.	150	0	0	0	.413	.276	.181	.214	0	0	0	0	0	0	0	0	0	0
Micaceous/plain	200	0	0	0	0	0	0	0	.095	.071	.117	.080	.208	.208	0	0	0	0
Striated	160	0	0	0	0	0	0	0	0	0	0	0	0	0	.247	.136	.193	.458
Sum		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 5. Estimated rooms and maximum population estimates for architectural mounds at San Marcos Pueblo.

Nelson mounds	Area (m^2)	Ground floor rooms	Number of Stories	Total Rooms	Total Persons
3	182.6	8.1	1	8.1	10.0
1,2	821.6	36.5	1	36.5	44.8
8,9	1086.5	48.3	2	96.6	118.5
10	89.6	4.0	1	4.0	4.9
4,5,6	3360.1	149.3	2	298.7	366.4
7	305.3	13.6	2	27.1	33.3
15,16,17	1444.1	64.2	2	128.4	157.5
13	1635.0	72.7	2	145.3	178.3
18,19	2426.3	107.8	1	107.8	132.3
11	106.0	4.7	1	4.7	5.8
14	363.1	16.1	2	32.3	39.6
12	1617.6	71.9	2	143.8	176.4
Monastery Yard	1979.0	88.0	1	88.0	107.9
20,21,24,26,27	4072.4	181.0	1	181.0	222.0
22,23,25,28,29	5128.9	228.0	1	228.0	279.6
35,36	760.6	33.8	1	33.8	41.5
33,34	1578.8	70.2	2	140.3	172.1
39-43	2324.6	103.3	1	103.3	126.7
30-32	3150.2	140.0	1	140.0	171.7
38	1358.5	60.4	2	120.8	148.1
37	770.0	34.2	2	68.4	84.0

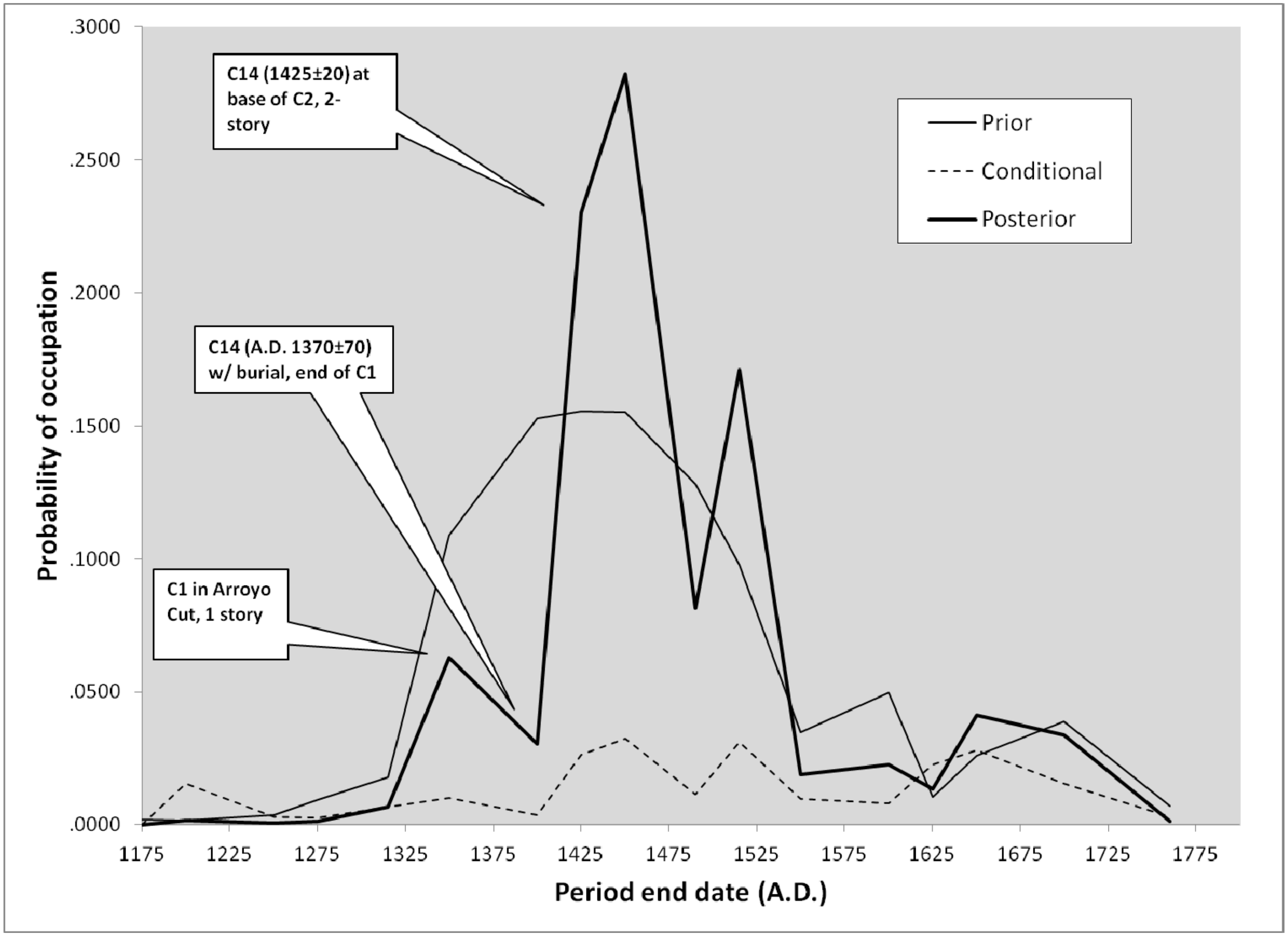
Table 6. Posterior probabilities and population estimates for San Marcos Pueblo.

Period	Dates	Posterior probability	Population Estimate
1	1050-1175	.000	0
2	1175-1200	.002	0
3	1200-1250	.001	0
4	1250-1275	.001	0
5	1275-1315	.007	412
6	1315-1350	.063	864
7	1350-1400	.031	603
8	1400-1425	.230	2217
9	1425-1450	.282	2636
10	1450-1490	.081	1014
11	1490-1515	.171	1737
12	1515-1550	.019	509
13	1550-1600	.023	539
14	1600-1625	.013	464
15	1625-1650	.041	688
16	1650-1700	.034	629
17	1700-1760	.001	0

Table 7. Comparison of population histories.

Temporal period (Ramenofsky et al. 2008:Table 5)	Mean MCD of period	Corresponding pottery period (this study)
1	1318	1275-1315
2	1370	1315-1350
3	1424	1425-1450
4	1496	1490-1515
5	1577	1625-1650

Figure 1. Prior, conditional, and posterior probability density distributions for San Marcos Pueblo.



Note: Annotations associate data from the arroyo cut-bank (see Pinson, In Prep.) with specific pottery periods.

Figure 2. Relationship between posterior probabilities and population estimates for selected periods at San Marcos.