# REVISITING HOHOKAM PALEODEMOGRAPHY

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*Archaeological evidence documents apparent depopulation of the Hohokam region of Southern Arizona at the end of the Classic period (A.D. 1150–1450). Major population centers were no longer occupied, and many distinctive material culture traits associated with the Hohokam tradition seem to disappear. Proposed explanations include migration, dispersion of the population into less archaeologically visible settlements, and wholesale population decline. The latter hypothesis is attractive partly because of a seminal study of paleodemography and health at the Classic-period site of Pueblo Grande in the Phoenix Basin. That study suggested that the population was not sustainable due to very low life expectancy, a very high dependency ratio of juveniles to adults, and other indicators of biological stress. A hazards analysis of the published demographic data reveals life expectancy at birth in the expected range for prehistoric populations with no evidence of a dependency crisis. Population decline at the end of the Classic period is more likely explained by reduced fertility than by increased mortality. Birth rates are sensitive to cultural and economic forces, and we should look beyond health factors in trying to account for the disappearance of Hohokam traditions.*

*La evidencia arqueológica documenta una aparente despoblación de la región Hohokam del sur de Arizona a finales del período clásico (1150–1450 d.C.). Los principales centros de población ya no estaban ocupadas y muchos de los rasgos culturales distintivos materiales asociados con la tradición Hohokam parecen desaparecer. Explicaciones propuestas incluyen la migración, la dispersión de la población en los asentamientos arqueológicamente menos visibles y disminución de la población mayor. Esta última hipótesis es atractiva debido en parte a un estudio seminal de paleodemografía y la salud en el lugar de Período Clásico de Pueblo Grande en la cuenca de Phoenix. Ese estudio sugiere que la población no era sostenible debido a la muy baja esperanza de vida, una proporción muy alta dependencia de los menores a los adultos y otros indicadores de estrés biológico. Un análisis de los peligros de los datos demográficos publicados utilizando un modelo mixto Makeham revela la esperanza de vida al nacer en el rango esperado para las poblaciones prehistóricas sin evidencia de una crisis de dependencia. Las muestras de los sitios Hohokam contemporáneas en regiones cercanas siguen un patrón demográfico similar. Disminución de la población al final del período clásico es más probable explica por la reducción de la fertilidad que por el aumento de la mortalidad. Las tasas de natalidad son sensibles a las fuerzas culturales y económicas y debemos mirar más allá de los factores de salud para tratar de dar cuenta de la desaparición de las tradiciones Hohokam.*

The O'odham of southern Arizona have long used the term *Huhugam* to refer to the people who once inhabited their region and who are now "all gone" (Lopez 2007). Inspired by this term, Harold Gladwin (Gladwin and Gladwin 1934) chose the name Hohokam for a cultural phenomenon that endured in the southern deserts from about A.D. 500 to A.D. 1450, ending shortly before the arrival of Europeans in North America (Fish and Fish 2007). This archaeological culture is recognized by characteristic material culture traits, including distinctive ceramics, marine shell ornaments, ground stone palettes, ceramic and stone censers, and specific forms of residential and monumental architecture. Perhaps the greatest technical achievement of the Hohokam consisted of extensive irrigation systems fed by perennial rivers in the Phoenix Basin (Bayman 2001; Doyel 1987; Doyel et al. 2000; Fish and Fish 2007; Gumerman 1991; Haury 1976). While the most intensive occupation was located in the Salt/Gila River core area, the Hohokam phenomenon extended into peripheral regions from the Verde River Valley in the north to the Papagueria spanning the Mexican border in the South. The ingenuity of the Hohokam permitted substantial pop-

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*American Antiquity* 80(3), 2015, pp. 492–510
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DOI: 10.7183/0002-7316.80.3.492



https://doi.org/10.7183/0002-7316.80.3.492 Published online by Cambridge University Press

ulations to inhabit a land of extreme temperatures and sparse precipitation for centuries, but before the close of the fifteenth century, the archaeological complex or way of life referred to as Hohokam was no longer evident.

Archaeologists have proposed many hypotheses to account for the Hohokam "collapse," including social conflict, warfare, disease, or disruption of irrigation systems due to flooding, soil depletion, or salinization (Bayman 2001:291–292). Abbott (2003) emphasizes that the decline was a long-term process involving not only environmental problems, but also social fragmentation, disrupted trade networks, political strife, and unsustainable demographics. The most forceful argument for decline resulted from an investigation of Pueblo Grande (AZ U:9:1[ASM]), one of the largest Classic-period Hohokam sites in the Phoenix Basin. Citing evidence of poor health and high mortality, Van Gerven and Sheridan (1994a:128) concluded that, by the close of the Classic period, the Pueblo Grande population was "living on the edge of survival, nutritionally and reproductively stressed and struggling to maintain their numbers." Sheridan (2003:106) concluded that "biocultural adaptation during the Classic period can clearly be seen as marginal at best, doomed to failure." Abbott et al. (2003:5) remarked that the Hohokam Classic period should be viewed as a period "of widespread decline, and a precipitous slide toward the eventual abandonment of a homeland that had been occupied for approximately fifteen hundred years." They (Abbott et al. 2003:18–19) cautioned against extending the specific findings of the Pueblo Grande study to the Hohokam region as a whole, although they suggested that similar conditions may have extended to other settlements supplied by the same canal system and possibly to the lower Salt River Basin as a whole. Nevertheless, others have invoked evidence of declining health and increased mortality to explain the disappearance of the Hohokam tradition (Lekson 2006, 2009:201–202) or depopulation (Cordell and McBrinn 2012:234; Hill et al 2004:707) more generally and we must ask whether there is evidence to support this hypothesis.

In this study, I reexamine bioarchaeological evidence from the Van Gerven and Sheridan (1994a) study and conclude that the hypothesis of a demographic crisis is not supported. Furthermore, a review of bioarchaeological evidence from contemporaneous sites in the Hohokam region reveals that the pattern of high mortality suggested for Pueblo Grande is not replicated elsewhere.

## The Hohokam

Very high average temperatures and aridity characterize the climate of the Sonoran Desert of southern Arizona and northern Mexico, but the region nevertheless offers abundant natural resources for desert-adapted people (Fish and Nabhan 1991; Rea 1997). As a consequence of the basin and range topography of this region, a variety of ecosystems coexist in close proximity, affording a wide variety of wild plants and animals. Until relatively recent times, water flowed perennially along at least some sections of the major rivers. Seasonal rains fill the dry riverbeds, especially during summer months, permitting floodwater or channeled irrigation systems. Desert dwellers in southern Arizona utilized irrigated fields as early as 1250 B.C. (Mabry 2008), growing an early variety of maize, which likely supplemented a diet of non-domesticated foods. Archaeologists view the Hohokam tradition as having its roots in these early settlements (Bayman 2001; Mabry 2000; Wallace 2007).

Settlements during the Preclassic Hohokam period (A.D. 500–1150) consisted of pithouse villages arranged around courtyards and many included large oval depressions referred to as ball courts. The Hohokam world reached its greatest geographic extent near the end of this era (Fish and Fish 2007:9). During the Classic period (A.D. 1150–1450), monumental architecture consisted of platform mounds rather than ball courts, and pithouse structures were arranged within adobe-walled compounds. At this time, population was consolidated into fewer larger settlements in the core region (Doyel 2007:88). Throughout the Hohokam era, extensive irrigation systems supported an intensive agricultural subsistence pattern focused primarily on maize, but still supplemented with wild plants and game (Bayman 2001). The canal systems in the Phoenix Basin were the most elaborate, totaling an estimated 483 km (300 mi) in length (Doyel 2007). Irrigation systems were also found in the Tucson, Tonto, and Safford Basins and along most secondary watercourses

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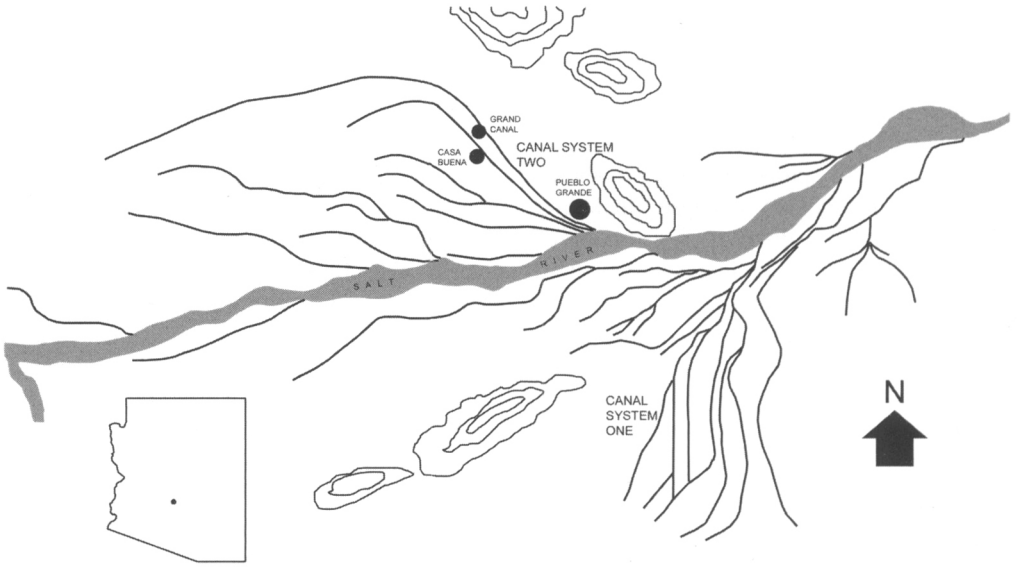



**Figure 1. Map of the Phoenix Basin Hohokam canal system (after Turney 1929).**

of southern and central Arizona (Dart 1989). Many distinctive material culture traits disappear after about A.D. 1450–1500, and all the large Hohokam sites appear to have been abandoned. In the sixteenth and seventeenth centuries, Spanish explorers found smaller settlements of O'odham speakers living along the rivers (Doelle 1984).

Hill et al. (2004) summarized explanations offered for the apparent population decline, including migration, dispersion of the population into small scattered settlements, or a demographic collapse resulting from increased mortality and/or declining fertility. Other regions of the Southwest experienced depopulation prior to A.D. 1450/1500. For example, population centers in the Four Corners region had been abandoned by A.D. 1300, and there is strong evidence that populations in that region migrated to the upper Rio Grande region. Occupants of the mountainous region of east central Arizona likely migrated to the Hopi mesas and to the Zuni region. However, there are no large post-A.D. 1500 population centers adjacent to the Hohokam region to support the migration alternative. It is possible that people dispersed into very small settlements of ephemeral structures and returned to hunting and gathering, supplemented with small-scale floodwater farming. Such settlements might leave few archaeological traces (Craig 2011). The demographic collapse hypothesis has received more attention, especially due to a bioarchaeological study of human skeletal remains from the Classic-period Hohokam site of Pueblo Grande (AZ U:9:1[ASM]) in the Phoenix Basin (Van Gerven and Sheridan, eds. 1994).

## Pueblo Grande

Pueblo Grande, near the head of Canal System Two on the north bank of the Salt River (Figure 1), was one of the largest Hohokam settlements in the Salt River Valley of the Phoenix Basin. Initial settlement began in the Preclassic Pioneer period, but maximum population size was reached during the Classic period. Based on habitation area, Abbott and Foster (2003:44) estimate approximately 632 inhabitants per generation for the entire settlement during the Early Classic period (A.D. 1150–1275). Estimates for the Civano phase of the Late Classic period (A.D. 1275–1350) vary from 504 (a 20-percent decline) to 1,134 inhabitants per generation (a 79-percent increase). Variation is due to differing assumptions about house use life in adobe compounds. A decline to about 180 persons per generation is suggested for the final Polvorón phase (approximately A.D. 1350–1450).

Soil Systems, Inc., excavated approximately 20 percent of the site during 1989–1990 as mitigation for planned highway construction (hereafter

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Table 1. Number of Individuals from Burial Features at Pueblo Grande (Hohokam Expressway Excavations).

| Burial Type | Early Classic | Late Classic | Subtotal Dated | Classic Undated | Total |
|---|---|---|---|---|---|
| Inhumation | 269 | 171 | 440 | 194 | 634 |
| Cremation | 90 | 23 | 113 | 77 | 190 |
| Total | 359 | 194 | 553 | 271 | 824 |

*Note*: Totals from Mitchell (1994c) are shown in lieu of those provided by Van Gerven and Sheridan (eds. 1994) because the table in the former has more temporal assignments. The undated burials have no temporal assignment but are most likely Classic period.

referred to as the Hohokam Expressway excavations). The excavated portion of the Classic-period settlement contained 14 habitation areas, 17 burial areas (Mitchell 1994a:1), and extramural pits. The most prominent architectural feature at Pueblo Grande was a large platform mound, situated west of the area excavated during the Hohokam Expressway project.

The skeletal sample was the largest to be documented in modern times at any Classic-period Hohokam site (Breternitz 1994:ix). A total of 836 burial features were discovered, including 644 inhumation features and 192 cremation features (Mitchell 1994b:74), representing 634 inhumed and 190 cremated individuals (Table 1). The decline in the number of individuals from the Early to Late Classic periods suggests that the population during the Late Classic period was closer to the low end of the range estimated by Abbott and Foster (2003:44).

The decline in the number of cremations during the Late Classic period is much sharper than for the inhumations. The difference in the proportion of inhumations and cremations is significant ($\chi^2 = 13.53$, $df = 1$, $p = .0002$), with more cremations than expected in the Early Classic and fewer in the Late Classic. Hohokam cremations typically consist of secondary deposits containing highly fragmented remains (Haury 1976; McGuire 1992; Wallace and Swartz 2012), with much less bone than expected for a single individual. At Pueblo Grande, the average amount of bone per deposit was only 191 g (Fink 1994:190). Various processes have been suggested to account for this. Remains may have been subdivided and placed in multiple secondary contexts. Multiple deposits of variable bone quantity also might represent different stages of the mortuary process. I agree with Haury (1976:171) that it is not safe to equate the number of cremation deposits with the number of individuals represented. These deposits should not be used in paleodemographic reconstruction unless the underlying formation processes are fully understood.

Van Gerven and Sheridan (1994b) provided age assessments for 620 of the 634 inhumed individuals, although many were assigned only general age categories, such as infant or adult, due to incomplete preservation. The authors constructed a life table from 361 of the more precisely aged individuals from inhumations to estimate demographic parameters, such as life expectancy at birth, mortality rates, and birth rates. They reported life expectancy at birth of 16.6 years for the Early Classic period, 14.5 for the Late Classic period, and 15.17 years for the combined sample. In a stationary population, the crude birth rate (CBR) equals the crude death rate (CDR) and is equal to the reciprocal of life expectancy at birth. The reported CBR/CDR for the combined sample was .066. Van Gerven and Sheridan (1994b:14) noted that this exceeds rates observed in modern populations and suggested that continuous immigration would have been required to maintain population levels (Van Gerven and Sheridan 1994a:123–124).

As further evidence of a population under stress, the authors pointed to an elevated dependency ratio. This statistic is defined by Weiss (1973) as the ratio of individuals from birth to 15 years, plus individuals older than 50 years to the number of individuals in the 15 to 50 age group (see Supplemental Information). Van Gerven and Sheridan (1994b:17) reported a dependency ratio of 1.230 for the Pueblo Grande Classic period as a whole and suggested that younger adults would have been significantly stressed in caring for less productive members of the population. In subsequent chapters in the same volume, the authors made the case that the Pueblo Grande population experienced high levels of nutritional stress or

https://doi.org/10.7183/0002-7316.80.3.492 Published online by Cambridge University Press

disease and that the situation worsened from the Early to Late Classic settlement, mirroring the increased mortality suggested by the demographic analysis. This overall picture of Classic-period Hohokam health appeared to support the demographic collapse hypothesis.

In assessing what role declining health may have played in the disappearance of the Hohokam archaeological tradition, we would like to know whether these conditions were matched at contemporaneous sites in the Phoenix Basin and adjacent regions, and to compare Preclassic period samples with Classic period samples. Unfortunately, there are no large comparative samples from the Preclassic period, as the dominant mortuary pattern during that period was cremation (Fink 1988:795; Mitchell and Brunson-Hadley 2001:48). Suitable Classic-period comparative samples from elsewhere in the Salt River Basin and adjacent regions are considered below. However, I begin with reexamination of paleodemographic evidence from Pueblo Grande itself.

Mitchell (1992) conducted demographic analyses of a subset of the sample used by Van Gerven and Sheridan (1994b), with 218 individuals from two burial groups. He used a life table to estimate life expectancy at birth as approximately 28 years. He attributed the difference between his figure and the estimate of 15 years from Van Gerven and Sheridan (1994b) partly to different analytical methods. Mitchell included more adults in his life table analysis by adding the imprecisely aged individuals in proportion to those that were in discrete age intervals and including cremated individuals.

The Hohokam Expressway excavations were not the only large-scale investigations of Pueblo Grande (Supplemental Table 1). Soil Systems, Inc., obtained another large sample, including at least 568 inhumed individuals, during excavations from 1997 to 2002 on another portion of the same site.[1] Life expectancies were estimated from life tables to vary from 24.7 to 28.9 years for the Early and Late Classic periods respectively (Rebecca Hill, personal communication 2014).

With two independent studies reporting life expectancies at birth greatly at odds with the Hohokam Expressway study, a reexamination of the life tables provided by Van Gerven and Sheridan (1994b) is in order. First, it is evident that life table calculations presented in that study deviated from standard practice, significantly underestimating life expectancy at birth. As shown in Supplemental Table 2, employing conventional methods results in life expectancy at birth of 22.4 years. The second factor in the underestimation of life expectancy is that Van Gerven and Sheridan (1994b) used a subset of the complete inhumation sample, excluding individuals with less precise age estimates (Supplemental Table 3). Since a majority of the less precisely aged individuals were adults, excluding them skews the age distribution to the juvenile end of the curve, contributing to the underestimation of life expectancy at birth and overstating the case for a demographic decline.[2]

The imprecisely aged individuals may be added back into a life table, as was done by Mitchell (1992), but paleodemographers have now largely moved beyond the life table method in favor of hazards analysis, which employs mortality models and can easily accommodate age estimates of varying precision (see Supplemental Information). Here, I employ a mixed-Makeham model (Wood et al. 2002), which assumes that a population has two subgroups, each with a different constant hazard, and a senescent component. The group with the higher risk of death, due either to greater innate frailty or to greater exposure to risk factors, will be disproportionately represented in the juvenile portion of the mortality curve because hazard of death is typically very high at birth (Chamberlain 2006).[3] As the curve reaches older childhood and adolescence, hazard of death reaches a minimum constant rate. Risk of death rises exponentially in the senescent phase.

This method allows inclusion of all 620 age-assessed individuals listed in Van Gerven and Sheridan (eds. 1994:Appendix B). The survivorship curve for combined Early and Late Classic periods is shown in Figure 2. Life expectancy at birth is 27.12 years, close to the estimates reported by Mitchell (1992) and by Hill and Lincoln-Babb (2008). The crude birth/death rate is .037, well within the range for known human populations. A range of 20 to 30 years for life expectancy is typical for prehistoric populations (Acsádi and Nemeskéri 1970; Howell 1976; Weiss 1973:50). To place this in perspective, fertility rates in much of the world in 1947 ranged between .040 and .045 (Dumond 1965:303).

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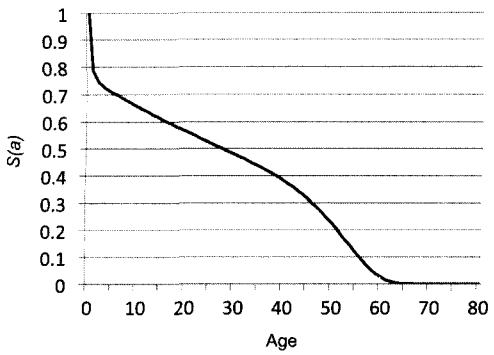



**Figure 2. Survivorship function curve for the combined Early and Late Classic-period sample from Pueblo Grande.**

Table 2. Comparison of Life Expectancies for Early Classic, Late Classic, and Undated Samples at Pueblo Grande.

| Period | $n^a$ | $e^0$ | CBR/CDR |
|---|---|---|---|
| Early Classic | 266 | 26.66 | .0375 |
| Late Classic | 170 | 30.94 | .0323 |
| Undated | 184 | 23.16 | .0432 |
| Early Classic, adjusted[b] | 391.91 | 25.64 | .0390 |
| Late Classic, adjusted[b] | 228.09 | 29.77 | .0336 |

[a]Number of individuals from inhumation burials (Hohokam Expressway Excavations).
[b]Totals adjusted by adding individuals in undated burials to each group in the same proportions as the dated burials.

It is important to recall that a portion of the burial sample at Pueblo Grande—those represented by cremation deposits—is still missing from the demographic analysis. This is significant because Hohokam cremations in general, and those at Pueblo Grande in particular, overwhelmingly represented adult individuals. Fink (1994:191) reported that only six percent of cremation deposits held non-adult individuals. If these were included in demographic analyses, life expectancy would be yet higher. However, because we cannot assume a one-to-one relationship between cremation deposits and individuals, we cannot assess the magnitude of the underestimation.

With birth and mortality rates now shown to be within normal ranges, it is no longer necessary to invoke continuous immigration to account for a stable population level during the Early Classic period. Nevertheless, is there still evidence that productive-aged individuals were burdened with caring for large numbers of juveniles and the elderly? The dependency ratio can be a useful measure of well-being, especially in assessing the capacity of households to invest in child health and nourishment (Hadley et al. 2011; Reyna 1976). Hadley et al. (2011) examined Ethiopian youths in rural, semi-urban, and urban communities with dependency ratios of 1.16, .94, and .72, respectively. Those in the highest dependency ratio group had the lowest nutritional status, as indicated by weight. As noted above, a dependency ratio of 1.23 was reported in the Hohokam Expressway study.

In order to reevaluate the dependency ratio for Pueblo Grande using the results from hazards analysis, a table was generated from the survivorship function, and the proportion of the living population in each age interval was calculated using the method described by Frankenberg and Konigsberg (2006:237) and Weiss (1973:38). The dependency ratio for the Classic-period sample as a whole is .789, substantially lower than reported by Van Gerven and Sheridan (1994b). This is closest to that represented by the urban group in the Ethiopian study (Hadley et al. 2011), which experienced the best nutritional levels. There is no evidence that adults at Pueblo Grande would have been unduly burdened with caring for the young and old.

Van Gerven and Sheridan (1994b) reported a slight decrease in life expectancy from Early to Late Classic. Reanalysis using the complete sample reverses this finding. As shown in Table 2, life expectancy increases in the Late Classic. Notably, the undated burials have the lowest of the three groups. It is likely that the undated burials lacked temporally diagnostic ceramics. Since these are more likely to be absent with juvenile burials, it is not surprising that life expectancy is lower for this subset. Hill and Lincoln-Babb (2008) reported a similar finding from their sample. If the undated burials are added to the Early and Late Classic samples proportionally for each age interval, there is still a greater life expectancy in the Late Classic period, but the difference is diminished. A significant increase in life expectancy would indicate decreased birth and mortality rates, assuming a population growth rate of zero.

Figure 3 compares survivorship curves for Early and Late Classic burials. The Late Classic

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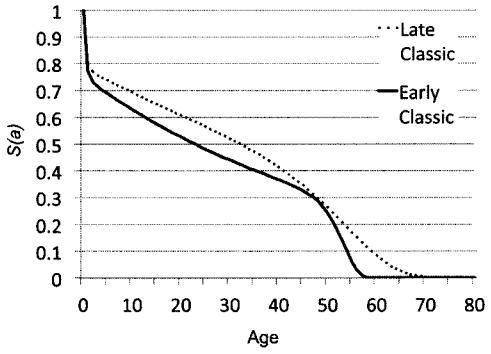



**Figure 3. Comparison of survivorship curves for Early and Late Classic burials at Pueblo Grande.**

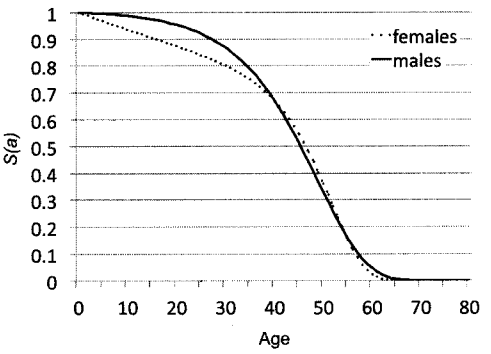



**Figure 4. Comparison of survivorship curves for males and females at Pueblo Grande.**

period has a slightly higher rate of survivorship from childhood to late middle age, where the curves meet. The Late Classic diverges again with higher survivorship from about age 55 on. Differences in age distribution of two samples may be tested for significance using nonparametric tests, such as a Mann-Whitney test of summed ranks or a Kolmogorov-Smirnov test of shape divergence in survivorship curves (Chamberlain 2006:43–44). Survivorship estimates at five-year intervals were obtained from the survivorship function for each sample and tested for significance using PAST, 3.0 (Hammer et al. 2001). The differences do not reach statistical significance (Mann-Whitney $U$ = 173.5, $p$ = .24142; Kolmogorov-Smirnov $D$ = .33333, $p$ = .15449).

It is also possible to compare survivorship of males and females at Pueblo Grande, although because sex assessment is not possible for infants and children, life expectancies are overestimated. Nevertheless, survivorship curves can be compared for the period from 12 years forward. A minimum sample size of 100 individuals is recommended for paleodemographic reconstruction (Hoppa and Saunders 1998; Paine and Harpending 1996). Due to the limited number of sex-assessed individuals, dividing the sample further into Early and Late Classic samples would yield samples well below this threshold. Consequently, I compare the combined sample of males ($n$ = 144) and females ($n$ = 154). Male life expectancy at birth is 43.31 years, compared with 40.89 years for females. The survivorship curves are shown in Figure 4. Females experienced slightly lower survivorship up to about 40 years, but this difference is not significant (Mann-Whitney $U$ = 195.5, $p$ = .53765; Kolmogorov-Smirnov $D$ = .14286, $p$ = .97279).

Hazards analysis of the paleodemographic variables of the complete Pueblo Grande sample indicates that life expectancy at birth was not abnormally low. Reanalysis brings estimates into line with those obtained by others for the same site. This dramatically reduces the estimated fertility rate and brings the dependency ratio into line with expected values from modern populations. I see no basis for concluding that continuous immigration would have been required to maintain population during the Early Classic period. Assuming a stationary population, the crude death rate is also significantly less than initially reported. However, it is currently the consensus view that life expectancy at birth is much more sensitive to fertility rates than mortality rates, especially when there is a non-zero population growth rate (Frankenberg and Konigsberg 2006:247–248; McCaa 2002; Sattenspiel and Harpending 1983). Thus, it is necessary to consider the implications of a nonstationary population.

Alternate means for evaluating fertility in prehistoric populations are not constrained by the assumption of stationarity or classification of individuals into narrowly defined age intervals. These involve various proportions of juveniles to adults, which have been demonstrated to have high correlations with birth rates, population growth rates, or mortality rates (Bocquet-Appel 2002; Bocquet-Appel and Naji 2006; Buikstra et al. 1986; Jackes 2011). They typically exclude individuals younger than five years old because of frequent under-numeration of infants due to poor preservation or

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Table 3. Demographic Variables Estimated from the Proportion of Juveniles to Adults at Pueblo Grande.

| Sample | 5–19 yrs[a] | 5+ yrs[a] | P (5–19) | $b$[b] | $r$[c] |
|---|---|---|---|---|---|
| PG all periods | 67 | 423 | .15839 | .03345 | -.00184 |
| PG Early Classic | 46.342 | 259.939 | .17828 | .03675 | .00118 |
| PG Late Classic | 20.658 | 163.060 | .12669 | .02809 | -.00711 |

[a]Numbers of individuals from inhumation features. Early and Late Classic-period totals are adjusted by adding counts from undated Classic-period inhumations.
[b]b = birth rate; S.E. .00304.
[c]r = growth rate; S.E. .00534.

differential deposition. Errors in adult age assessment are also avoided by the use of broad age categories. Bocquet-Appel (2002) proposed the use of P(5–19), the proportion of deaths from 5–19 years to all deaths from 5 years through adulthood. Using model life tables, he demonstrated high positive correlations with birth rate and population growth rate and provided regression formulae for estimating these rates from archaeological samples. Estimates for Pueblo Grande using this method are shown in Table 3.

The birth rate for the combined Early and Late Classic sample is .03345, slightly less than the hazards analysis estimate of .0369. Also consistent with hazards analysis, it appears that birth rates declined from Early to Late Classic. Estimated population growth rate for the combined Classic period is a slightly negative -.00184. If we assume a stable negative growth rate for the entire Classic period at Pueblo Grande (A.D. 1150–1450) with a starting population of 632, the ending population is 363 individuals.[4] However, if we examine the Early and Late Classic periods separately, we find a slight positive growth rate during the former period and a negative growth rate during the latter period. Population projection with a beginning level of 632 results in an increase to 733 persons at the beginning of the Late Classic, with a terminal population of 211 in A.D. 1450. These estimates are within the range estimated from architecture by Abbott and Foster (2003).

## Comparison with Contemporaneous Populations

As noted previously, the authors were cautious in extending the implications of the Hohokam Expressway study beyond the Phoenix Basin as a whole, much less to the entire Hohokam region. Others, however, have concluded that disease and nutritional stress were endemic in the prehistoric Southwest, and some suggest that these factors worsened as populations became more sedentary and more reliant on agriculture, and population density increased (Cordell and McBrinn 2012:234; Martin 1994; Merbs 1989; Palkovich 1984; Stodder and Martin 1992). A reasonable question to ask is whether this pattern has been replicated at contemporaneous sites in the same or neighboring regions.

Data are available for two sites in the Salt River Basin located downstream in the same canal system as Pueblo Grande. These are Casa Buena (AZ T:12:37[ASM]) and Grand Canal (AZ T:12:256[ASM]) (See Figure 1 and Table 4). Both were occupied during the Classic period, A.D. 1100–1450. Casa Buena was a major village site that experienced rapid growth in population at the beginning of the Classic period (Howard and Wilcox 1988). Excavations were conducted in 1985, and a total of 56 individuals are listed in the table of inhumation burials (Barnes 1988). Grand Canal was also a major village site, and 82 individuals were recovered from inhumations during excavations in 1986. Although each sample is

Table 4. Phoenix Basin Comparative Samples.

| Collection | Site number (ASM) | Period | Reference | $n$[a] | $e^0$ |
|---|---|---|---|---|---|
| Casa Buena | AZ T:12:37 | AD 1100–1450 | Barnes (1988) | 56 | |
| Grand Canal | AZ T:12:256 | AD 1100–1450 | Fink (1989) | 79 | |
| Combined sample | | | | 135 | 33.18 |

[a]Number of individuals from inhumation features.

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**Figure 5. Survivorship function curve for the combined Casa Buena and Grande Canal samples.**

below the threshold of 100 individuals, there is justification for combining them for demographic analysis. Considering the close proximity of the two sites and their contemporaneity, it is likely that these populations interacted (Howard and Wilcox 1988:913). Excluding fetal remains, the total number of inhumed individuals in the combined sample is 135.

A survivorship curve for the combined Casa Buena and Grand Canal sample is shown in Figure 5. Life expectancy at birth is 33.18 years, about 6 years greater than for Pueblo Grande. This is quite similar to an estimate of 32.44 years obtained by Fink (1989:639) from a life table for the combined Casa Buena and Grand Canal sample, although his sample included individuals from cremations, despite the acknowledged problems of counting individuals from such deposits. A partial explanation for the disparity in life expectancies between Pueblo Grande and the two downstream sites is the likelihood of underrepresentation of infants in the Grand Canal sample. Fink (1989:636) explains that, in many other Hohokam sites, infants were frequently interred in residential areas below the floors of dwellings or adjacent to the enclosing walls. Only one room block was encountered during the 1986 excavations at Grand Canal, and there were no inhumations discovered in association. However, many residential structures were encountered at Casa Buena (Howard 1988), and the skeletal collections included relatively more juveniles. Therefore, incomplete recovery, by itself, may not explain the disparity.

There are additional comparative samples from sites in the Tonto Basin and Globe Highlands (Figure 6). This region is located to the northeast of the Salt-Gila Basin and the sites were occupied

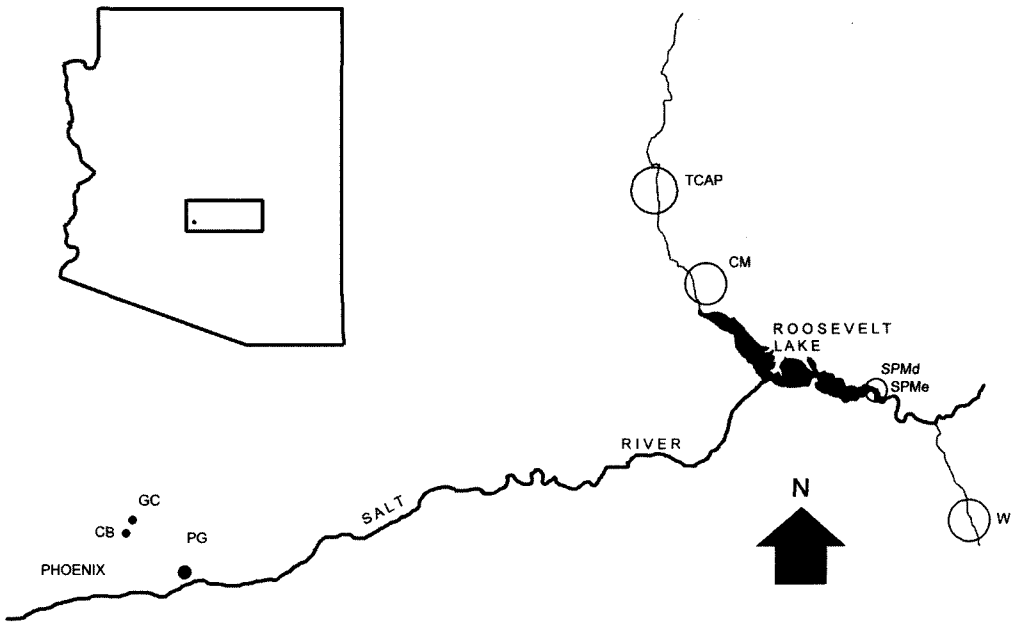



**Figure 6. Map of comparative sites in the Tonto Basin and Globe Highlands (PG = Pueblo Grande, CB = Casa Buena, GC = Grand Canal, TCAP = Tonto Creek Archaeological Project, CM = Cline Mesa, SPMd = Schoolhouse Point Mound, SPMe = Schoolhouse Point Mesa, W = Wheatfields).**

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Table 5. Comparative Collections from the Tonto Basin and Globe Highlands.

| Sample | Site Numbers (ASM) | Period | Reference | $n^a$ | $e^0$ |
|---|---|---|---|---|---|
| Cline Mesa | AZ U:3:128, 133, 139; U:4:7, 9,10,11, 12, 13, 29, 32, 60, 62, 75, 77 | A.D. 1225–1450 | Regan (1997) | 105 | 22.66 |
| Schoolhouse Point Mound | AZ U:8:24 | A.D. 1210–1430 | Regan et al (1996) | 214 | 17.39 |
| Schoolhouse Point Mesa | AZ U:8:25, 159, 385, 450, 451, 453, 454, 456, 458, 527; V:5, 137, 138 | A.D. 1225–1350 | Regan and Turner (1997) | 116 | 24.23 |
| Tonto Creek | AZ U:3:5, 224, 277, 289, 294, 297, 298, 299, 300 | A.D. 1200–1325 | Minturn (2001) | 290 | 27.34 |
| Wheatfields | AZ V:5:220, 223; V:9:325, 365, 367 | A.D. 1275–1450 | Hurlbut (2003) | 120 | 25.16 |

[a]Number of individuals from inhumation features.

Table 6. Comparison of Birth Rates and Population Growth Rates.

| Sample | 5–19 yrs[a] | 5+ yrs[a] | P (5–19) | $b$ | $r$ |
|---|---|---|---|---|---|
| Casa Buena and Grand Canal | 10 | 120 | .08333 | .02051 | -.01559 |
| TCAP | 37 | 226 | .16372 | .03434 | -.00102 |
| Cline Mesa | 6 | 67 | .08955 | .02162 | -.01426 |
| Wheatfields | 6 | 84 | .07143 | .01836 | -.01832 |
| Schoolhouse Pt. Mound | 24 | 113 | .21239 | .04232 | .00599 |
| Schoolhouse Pt. Mesa | 11 | 82 | .13415 | .02937 | -.00582 |

[a]Number of individuals from inhumation features.

throughout the Classic period.[5] These collections are listed in Table 5, and the far right column gives the estimate for life expectancy at birth for each assemblage obtained from hazards analysis. The lowest figure is 17.39 years at Schoolhouse Mound. Regan et al. (1996:792) noted that adults are under-numerated partly due to heavy vandalism disproportionately affecting adult graves because of the greater likelihood that they contained decorated ceramic vessels. Figure 7 compares the survivorship curves for each sample. The greatest difference is between the Tonto Creek Archaeology Project collection and Schoolhouse Mound, although the comparison just falls short of statistical significance (Mann-Whitney $U = 152.5, p = .0884$, Kolmogorov-Smirnov $D = .38095$, $p = .0706$). If we exclude the collection that may have been affected by uneven sampling, all of the estimates for life expectancy at birth fall into a range of 20 to 30 years.

Birth rates and population growth rates are compared in Table 6. Birth rates range from a low of .018 in the Wheatfields sample to a high of .042 for Schoolhouse Point Mound. All the samples appear to have experienced a negative growth rate, with the exception of Schoolhouse Point Mound, but the latter may not be a reliable figure due to the possibility of sample bias, as mentioned previously. Hence, all the comparative Classic-period sites appear to have negative population growth in the range of about -.001 to -.018. These results are plotted, along with those for the Early and Late Classic periods at Pueblo Grande, in Figures 8 and 9. Birth rates for the combined Casa Buena and Grand Canal sample, Cline Mesa, and Wheatfields are significantly lower than the estimated birth rates for the Early Classic period at Pueblo Grande, the Tonto Creek sample, and Schoolhouse Point Mound. Confidence intervals for estimated population growth rates in all the samples overlap, with the exception of Schoolhouse Point Mound relative to Wheatfields or the combined Casa Buena/Grand Canal samples. Most of the range of variation is below the zero growth rate line, and only the Early Classic period at Pueblo Grande, Schoolhouse Point Mound, and the Tonto Creek sample have mean values at or above the line.

Overall, paleodemographic analysis indicates broad similarities between Pueblo Grande and other Classic-period sites in the Salt River Basin,

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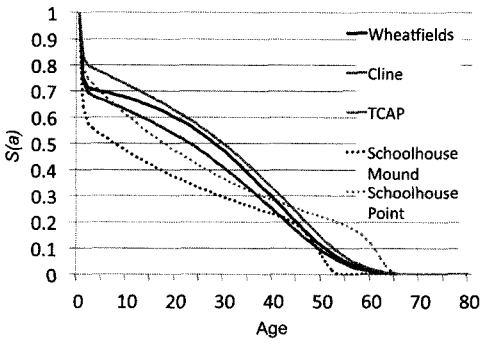



**Figure 7. Survivorship curves for the Tonto Basin and Globe Highlands collections.**

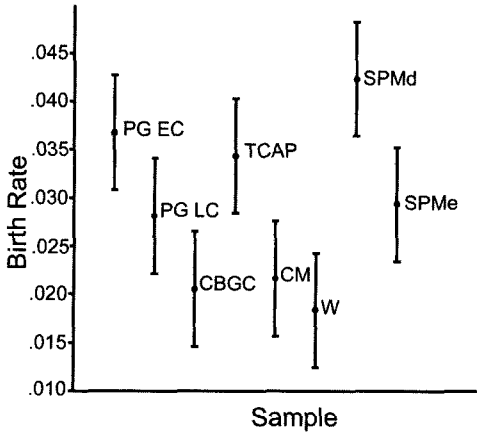



**Figure 8. Estimated birth rates with 95 percent confidence intervals.**

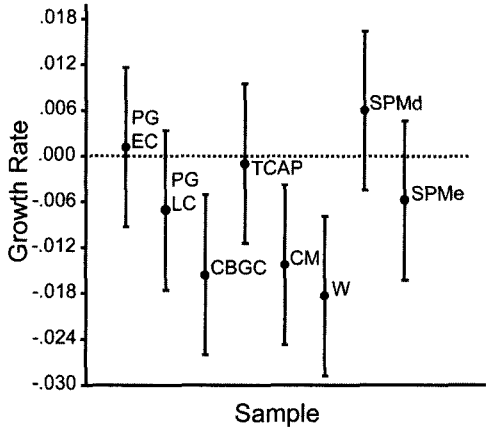



**Figure 9. Estimated population growth rates with 95 percent confidence intervals.**

Tonto Basin, and Globe Highlands. There is no evidence that fertility or mortality rates were excessively high. The age proportions in the cemetery populations suggest that all these Classic-period sites experienced slightly negative growth rates. The decline in population during the terminal occupation stage at Pueblo Grande is consistent with independent population estimates based on habitation areas.

## Paleopathological Inference

Sheridan attributed difficulties faced by the Pueblo Grande community to inadequacies of the subsistence system and a deteriorating local environment (Sheridan 2003:106). It was argued that nutritional stress and disease led to failure of the community to maintain itself, despite an excessively high birth rate (Van Gerven and Sheridan 1994a). Evidence for the impact of these factors was presented in several chapters of the original report, including dental enamel hypoplasia (Karhu and Amon 1994), porotic hyperostosis and diploic thickening (Mittler and Van Gerven 1994), cortical bone maintenance and long bone growth (Van Gerven and Sheridan 1994c), osteopenia (Kuzawa and Van Gerven 1994), and osteoarthritis (McCafferty and Mittler 1994). A detailed examination of these studies is beyond the scope of this paper. But with life expectancies revised significantly upward, there is now a disconnect between the paleopathological and paleodemographic evidence from Pueblo Grande. A comparison with other sites in the region is in order.

In Table 7, I compare reported frequencies of enamel hypoplasia and porotic hyperostosis in the regional sample described above.[6] Enamel hypoplasia is an enamel defect linked to discrete episodes of interrupted growth, acute disease, or nutritional deprivation (Goodman and Rose 1990). Hypoplasia frequencies in the comparative sample vary from 18 percent to 100 percent affected individuals. Most notable is the difference between the earlier and later Pueblo Grande studies.

Porotic hyperostosis has long been ascribed to iron-deficiency anemia, resulting from deficient diets or a response to infectious disease (Martin and Goodman 2002). Walker et al. (2009) dispute the relationship with iron deficiency and attribute the condition to megaloblastic or hemolytic ane-

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Table 7. Comparison of Enamel Hypoplasia and Porotic Hyperostosis Frequencies.

| | Enamel Hypoplasia | | Porotic Hyperostosis | |
|---|---|---|---|---|
| Sample | $n^c$ | Percent Affected | $n^c$ | Percent Affected |
| PG EC[a] | 47 | 97.9 | - | 59 |
| PG LC[a] | 38 | 100.0 | - | 51 |
| PG EC[b] | 99 | 37.4 | - | - |
| PG LC[b] | 38 | 31.6 | - | - |
| CB | 26 | 34.6 | 24 | 50.0 |
| GC | 89 | 18.0 | 61 | 37.7 |
| TCAP | - | 21.9 | 308 | 9.4 |
| CM | - | - | 105 | 3.8 |
| W | - | 55.0 | - | - |
| SPMd | 138 | 54.3 | - | - |
| SPMe | - | - | 116 | 6.0 |

[a]Hohokam Expressway excavations (Van Gerven and Sheridan 1994d).
[b]1997–2002 excavations (Hill and Lincoln-Babb 2008).
[c]Number of observable individuals in the sample.

mia, possibly reflective of vitamin B12 deficiency. In the comparative sample, this disorder varies from 3.8 percent to 59 percent affected individuals.[7]

Given rather similar demographic patterns for the comparative samples, we must conclude that either there is a weak relationship among the variables or there are significant interobserver differences in scoring of the indicators. In either case, we are still faced with the fact that the demographic evidence does not reinforce the paleopathological findings of the Van Gerven and Sheridan (eds. 1994) study and that the more recent study (Hill and Lincoln-Babb 2008) does not support the finding with regard to enamel hypoplasia. Whether or not these pathologies were endemic at Pueblo Grande, there is no basis for extending the paleopathological findings of the Hohokam Expressway study to the rest of the Hohokam region.

## Mortality, Fertility, and Growth Rates under Nutritional Stress

Another approach is to look for expected health and demographic consequences of suboptimal nutrition from examination of historically documented cases. There are numerous case studies of the health and demographic consequences of famine in the modern world, including Iceland 1784–1785 (Vasey 1991), Ireland 1845–1849 (Mokyr and Ó Gráda 2001), Leningrad 1941–1943 (Antonov 1947), the Netherlands 1944–1945 (Hart 1993), China 1959–1961 (Kane 1987), and Bangladesh 1974 (Alamgir 1980). The severity of nutritional deprivation and impact on health varied, but, typically, famine was associated with increased mortality, especially among the young and old, and a significant reduction in birth rate. After a famine, however, birth rates frequently rebound, as they did in the Netherlands (Hart 1993), Iceland (Vasey 1991), and Bangladesh (Kane 1987). Another consequence may be a significant post-famine reduction in mortality, as the individuals at greatest risk of dying have already been eliminated from the population (Bongaarts and Cain 1982:45). The same effect has been noted subsequent to epidemics and is referred to as a "harvesting" effect (Sawchuk et al. 2013). The rate at which a population recovers depends on the underlying rate of population growth. For example, with a growth rate of one percent, a population will recover in ten years, but with more moderate growth rates, it may take many years for previous levels to be attained (Dyson and Ó Gráda 2001:12). Conversely, if a population was in decline, we would not expect a return to the pre-famine population level, but rather a return to previous mortality and fertility rates. Famines are typically short-term events, and the fluctuations in fertility and mortality would likely not be detectable in paleodemographic analyses. Skeletal collections are an aggregate sample, including many generations with low chronological resolution. It is possible that Hohokam societies may have experienced famines, but the paleodemographic evidence can neither confirm nor refute such a hypothesis.

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Table 8. Comparison of Long Bone Lengths.

| | Female Humerus | Female Femur | Female Tibia | Male Humerus | Male Femur | Male Tibia |
|---|---|---|---|---|---|---|
| EC n | 21 | 22 | 16 | 24 | 26 | 14 |
| EC Range | 250–330 | 310–430 | 320–370 | 247–355 | 392–485 | 325–410 |
| EC Mean | 291.52 | 402.27 | 349.97 | 312.88 | 439.42 | 368.50 |
| EC SD | 17.23 | 24.13 | 14.12 | 22.62 | 19.75 | 26.25 |
| LC n | 23 | 19 | 12 | 12 | 12 | 12 |
| LC Range | 280–328 | 380–448 | 305–390 | 270–347 | 411–470 | 320–399 |
| LC Mean | 292.52 | 401.74 | 345.83 | 315.58 | 441.75 | 372.67 |
| LC SD | 11.20 | 18.97 | 22.19 | 21.66 | 20.35 | 23.07 |
| T | -.22979 | .078124 | .60226 | -.34327 | -.33442 | -.42634 |
| p | .819 | .938 | .552 | .734 | .740 | .674 |

*Note*: All measurements in mm. Comparisons limited to elements with sample size greater than 10.

Chronic malnutrition is also unlikely to leave a unique paleodemographic signature. Bongaarts (1980) found a slight but not statistically significant reduction in fecundity when malnourished and adequately fed groups were compared. However, there is good evidence linking suboptimal growth or stunting with chronic malnutrition (Saunders and Hoppa 1993). In conditions of marginal subsistence, the capacity to reduce body size is likely a selective advantage (Stini 1975, 1988). Data concerning adult stature or long bone lengths are not included in the Van Gerven and Sheridan (eds. 1994) study, but some postcranial measurements were taken in the field.[8] Table 8 compares long bone lengths by sex and time period. Early and Late Classic mean female humerus and femur lengths are virtually identical, and mean tibia length is about 4 mm less in the Late Classic period. Mean male long bone lengths are slightly greater in the Late Classic period. None of the differences are statistically significant. Based on the mean tibia and femur lengths, female stature may be estimated between 151.5 and 156.5 cm, with male stature between 163 and 164 cm. These were a small-bodied people, but estimated stature is well within the range expected for prehistoric southwestern populations (cf. Auerbach and Ruff 2010:196; McClelland 2008; Stodder 2010). Whether small body size reflects successful adaptation to a subsistence pattern vulnerable to periodic disruption, a diet with marginal protein levels, or chronic malnutrition, body size does not suggest a significant change in nutritional status in the Late Classic period at Pueblo Grande.

Many cultural responses to famine have been documented (Kane 1987), but adjustments may occur well before famine arrives. For example, in 1983, a drought in Karnakata, India, led the population to adopt several strategies, including reduction in food consumption by women, children, and elderly, delayed marriage, going into debt, sale of livestock, and elective reduction in birth rate (Kane 1987). One of the most common responses historically has been to relocate (Bongaarts and Cain 1982). Migration has long been a central theme in Southwest prehistory, supported by archaeological studies (Spielmann 1998) and oral traditions of Native American tribes (Dongoske et al. 1993; Stevenson 1904). Migration has important implications for paleodemographic analyses because migrating groups may not have been a complete demographic cross section, thus skewing age distributions. Chamberlain (2006:39) noted that people on the move tend to be younger than average. The impact of migration on life expectancies is well illustrated by Jackes (2011) in an examination of a historic cemetery in Sydney, Australia. Furthermore, if a settlement loses reproductive-aged adults and their children disproportionately, we would expect a lowering of the fertility rate among the remaining population. Conversely, a net in-migration of younger adults would result in increased fertility rates and reduced life expectancy, since mortality is typically very high in the newborn age interval.

Declining fertility may also represent a choice driven by socioeconomic considerations, rather than a means of coping with hardship (Caldwell 1982). In the developed world, nutrition is inversely correlated with fertility, but the relationship is cultural, rather than biological. Fertility in the modern world has declined in concert with

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increased life expectancies and rising incomes (Lee 2003). One explanation is that parents choose to limit family size in order to focus their resources on a smaller number of offspring and maximize their future opportunities.[9]

## Conclusion

Reexamination of the complete burial sample from the Hohokam Expressway excavations at Pueblo Grande reveals that the case for a demographic collapse was overstated. Life expectancy at birth was in the expected range for prehistoric populations and the dependency ratio was within the range documented in the modern world. Estimated fertility rates indicate that the Early Classic period may have experienced a slight positive population growth rate and the Late Classic period a slight negative growth rate. Other contemporaneous sites in the region appear to have experienced a slight negative growth rate overall. These findings are in agreement with those of Kohler and Reese (2014), especially with regard to the Tonto Basin. They are also consistent with the argument by Hill et al. (2004) that the Hohokam region as a whole experienced a small negative population growth rate, which can result in significant population reduction over time.

The paleopathological findings of the Hohokam Expressway project at Pueblo Grande are not replicated at contemporary sites in the region, at least with respect to enamel defects and porotic hyperostosis. Hohokam populations undoubtedly experienced nutritional stress and disease, but the evidence is insufficient at present to explain the apparent decline in birth rates. Alternatively, reduced fertility may well have been a cultural response to changing environmental or socioeconomic conditions. If Hohokam populations faced periodic food shortages or political and economic disruption, reducing or delaying births would have been a rational response. Populations faced with famine, or even the possibility of famine, have adopted compensating strategies, including, ultimately, a decision to depart. If emigrants from the large Hohokam settlements included a disproportionate percentage of reproductive-aged adults, this is one possible explanation for reduced fertility. Dispersion of these groups into smaller, more transitory, and less visible settlements is one scenario. Hill et al (2004:694) consider this possibility, but are skeptical that very large numbers could disappear in this way.

While the exact nature of the demographic process is uncertain, it is clear that the major population centers were no longer occupied when Spanish Explorers arrived in the sixteenth century. The earliest accounts offer scant information about settlements, but some population estimates from the late seventeenth century are available (Doelle 1984). These suggest a population of about 5,500 for the region occupied by the O'odham from the Gila River south to the Mexican border. There was one large settlement at San Xavier del Bac, south of Tucson, and many smaller outlying settlements referred to as rancherías. These estimates cannot be considered a true census, and it is possible that more remote and dispersed settlements were missed. Habitations occupied during this period were much less substantial than those of the Hohokam period (Doelle 1984:200). The way of life referred to as Hohokam, or Huhugam, was no longer evident, but this does not necessarily mean that the people had all disappeared. The O'odham refer to the *Huhugam* as those who are "all gone," but they still recognize them as their ancestors (Lopez 2007). Recent material culture studies have suggested continuity between the Classic Hohokam and early historical periods in terms of raw material sourcing and trade networks (Eiselt et al. 2011; Loendorf et al. 2013). Whatever the fate of those who inhabited the large settlements of the Classic period, it is clear that people have continued to endure in this unforgiving land.

*Acknowledgments*. Research underlying this paper was originally funded by a grant from the Center for Desert Archaeology (now Archaeology Southwest) as part of a broader investigation of Hohokam health and demography. Lane Beck's insights on the demographics of Pueblo Grande were pivotal to this research. Thanks are also due to Rebecca Hill and Lorrie Lincoln-Babb for sharing their data from subsequent excavations, to David Abbott for thoughtful comments on an earlier draft, and to Paul and Suzanne Fish, Brett Hill, and two anonymous reviewers for their suggestions.

*Data Availability Statement*. Demographic analyses used published tables of burial features. Limited postcranial measurements for the Pueblo Grande burial sample were obtained from field notes curated at the Pueblo Grande Museum in Phoenix, Arizona. I am happy to share these data upon request.

https://doi.org/10.7183/0002-7316.80.3.492 Published online by Cambridge University Press

*Supplemental Materials*. Supplemental materials are linked to the online version of this paper, which is accessible via the SAA member login at www.saa.org/members-login:

Supplemental Table 1. Number of Individuals from Inhumation and Cremation Burials at Pueblo Grande.

Supplemental Table 2. Revised Life Table for Pueblo Grande Using the Same Sample as Van Gerven and Sheridan (1994).

Supplemental Table 3. Numbers of Individuals from Inhumation Burials According to Age Category and Time Period (Hohokam Expressway Excavations).

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## Notes

1. The project report for this work has not yet been published. A preliminary bioarchaeological report was provided by Hill and Lincoln-Babb (2008).

2. I would like to acknowledge Lane A. Beck for initially bringing this to my attention.

3. Since the hazard of death in human populations has typically been very high at birth, the observation by Van Gerven and Sheridan (1994b) that the modal age of death was birth is not as alarming as it sounds. This is why Acsádi and Nemeskéri (1970:14) exclude juveniles in determining the modal age of death.

4. Population projections were calculated with the formula $P_t = P_0 e^{rt}$.

5. Cultural affinity and archaeological classification of sites in the Tonto Basin is a matter of debate, with some preferring the term Salado and others including the region in the Hohokam sphere (Hill et al. 2004:703–706).

6. Due to inconsistency in reporting and unknown variation in preservation and observability, it is difficult to assess the significance of the differences in pathology frequencies. Additionally, interobserver differences in the scoring of these pathologies are a distinct possibility. For example, replicability of scoring enamel hypoplasia is impeded by the difficulty of defining the minimum level of expression of this defect for recording purposes (Hillson and Bond 1997).

7. Fink (1991) hypothesized that settlements on canals downstream from larger settlements would have been exposed to water-borne pathogens, suggesting that incidence of infectious disease should have been elevated relative to the upstream sites. Casa Buena and Grand Canal are located downstream from Pueblo Grande, but the incidence of porotic hyperostosis is no higher in one case and lower in the other. If this condition does indicate a response to infection, the comparison fails to support the Fink hypothesis.

8. These data were obtained by Lane Beck and John McClelland from field notes curated at the Pueblo Grande Museum, Phoenix, Arizona.

9. Hill et al. (2004:697) acknowledge that fertility is subject to socioeconomic considerations and may have been a factor in declining Hohokam populations, but appear to favor declining health as a more significant factor.

*Submitted May 25, 2014; Revised October 30, 2014; Revised January 11, 2015; Accepted January 15, 2015.*

https://doi.org/10.7183/0002-7316.80.3.492 Published online by Cambridge University Press