Long and spatially variable Neolithic Demographic Transition in the North American Southwest

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In many places of the world, a Neolithic Demographic Transition (NDT) is visible as a several-hundred-year period of increased birth rates coupled with stable mortality rates, resulting in dramatic population growth that is eventually curtailed by increased mortality. Similar processes can be reconstructed in particular detail for the North American Southwest, revealing an anomalously long and spatially variable NDT. Irrigation-dependent societies experienced relatively low birth rates but were quick to achieve a high degree of sociopolitical complexity, whereas societies dependent on dry or rainfed farming experienced higher birth rates but less initial sociopolitical complexity. Low birth rates after A.D. 1200 mark the beginning of the decline of the Hohokam. Overall in the Southwest, birth rates increased slowly from 1100 B.C. to A.D. 500, and remained at high levels with some fluctuation until decreasing rapidly beginning A.D. 1300. Life expectancy at 15 increased slowly from 900 B.C. to A.D. 700, and then increased rapidly for 200 y before fluctuating and then declining after A.D. 1400. Life expectancy at birth, on the other hand, generally declined from 1100 B.C. to A.D. 1100/1200, before rebounding. Farmers took two millennia (~1100 B.C. to ~A.D. 1000) to reach the carrying capacity of the agricultural niche in the Southwest.

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Significance

Population size greatly affects the human condition but is difficult for archaeologists to estimate. For the Neolithic North American Southwest, we use indirect methods to estimate birth rate and life expectancy, two major factors determining population size. The population boom usually accompanying the introduction of cultivated plants and animals, the “Neolithic Demographic Transition,” was slow to emerge and was marked by considerable subregional variability in birth rate. This variability is likely related to differing morbidities and availability of agricultural lands in various subregions. In common with many Neolithic peoples, pre-Hispanic Puebloans experienced very high birth rates, especially between A.D. 500 and 1300 when they possibly exceeded the highest in the world today, and quite low life expectancy at birth.
and likely more productive races of maize [Maíz Blando and Harinosa de Ocho (Maíz de Ocho)] ~A.D. 600 (23); the appearance between A.D. 600 and 800 on the Colorado Plateau of villages consisting of many households together in a single site, often accompanied by public structures such as great kivas or large courtyards (24, 25); and the pitthouse-to-pueblo transition between about A.D. 700 and 800, which allowed for, and signals, greatly increased storage of maize (26).

That pilot study (20) revealed considerable contemporaneous variability in the juvenility index, some of which seemed to be related to subregion. Here, we present juvenility indices from 194 sites and composite samples consisting of 10,199 sets of human remains, including those tallied in ref. 20. This larger sample allows us to partition $^{15}$P$_{5}$ values by subregion, revealing unsuspected spatial and temporal variability that affects our understanding of the causes of variability in CBR, and therefore the sources of culture change in the pre-Hispanic US Southwest. In addition, we make a preliminary calculation of regional life expectancies that reveals unsuspected temporal variability.

Results and Discussion

For the sample of human remains in Tables S1 and S2, we apply a nonparametric method for estimating local regression surfaces to fit the relationship between $^{15}$P$_{5}$ and calendar years for assemblages from 10 subregions (Fig. 1) (SI Text, Sources of Data and Coding Conventions). This method allows us to identify temporal trends in admittedly noisy data. Results are shown in Fig. 2 (SI Text, Statistical and Graphic Conventions).

Subregional Analysis, Southern Southwest. The earliest assemblages large enough to include in this analysis are from the Sonoran Desert. Although maize was introduced to this area from the south by ~2100 B.C. (18, 21, 27), birth rates as proxied by $^{15}$P$_{5}$ remained below what Bocquet-Appel considered zero growth ($^{15}$P$_{5} = 0.18$; but see SI Text, Statistical and Graphic Conventions) until ~A.D. 1 (Fig. 2). (Contemporaneous $^{15}$P$_{5}$ values for the Kayenta area are similar but do not begin as early.) Although some researchers have argued for relatively sedentary occupations in the Sonoran Desert during the Early Agricultural period (2000 B.C. to A.D. 50) coupled with an intensive agricultural system producing most of the food (19, 28, 29), the low juvenility indices reported here favor suggestions that these occupations tended to be short-lived (30, 31) or part of a seasonal round (27), and perhaps most important, because this also affects mobility, focused on varieties of maize that were not yet very productive (32). Values for $^{15}$P$_{5}$ plateaued in the Sonoran area between about A.D. 500 and 1000, during the late Formative and early pre-Classic (or the late Pioneer and early Colonial) periods in the Hohokam sequence. An extensive canal system allowing production of at least two maize crops per year was in place by the middle of this period (33), and not coincidentally Hohokam settlements spread far north of their core riverine zone in the Sonoran desert into the Flagstaff area, and into uplands south and west of Tucson and Phoenix during this same interval (33). A large-scale system of exchange, perhaps linked to ball court events, apparently developed into a market system from about A.D. 1000 to 1100 (34). Around that time, however, $^{15}$P$_{5}$ values began to decrease as populations reconcentrated in river valleys, especially in the Phoenix Basin, forming large platform mound communities. The very low $^{15}$P$_{5}$ values from about A.D. 1200 until the end of this sequence complement declines in population...
visible in architectural data (12) and suggest a proximate cause for the “core decay” (35) long noted for this area and for the eventual disappearance of the Hohokam.

The Tonto Basin and Verde Valley areas, aggregated here, are marked by anomalously low \( 1_{SP} \) values throughout their entire sequence (Fig. 2). Heavy reliance on a canal system in the Tonto Basin (as in the Sonoran Desert just to the south) may be partly responsible for these low \( 1_{SP} \) values. Fink (36) has suggested that waterborne transmission of pathogens, including a variety of bacteria, viruses, protozoa, helminths, and fungi, may have elevated morbidity and mortality, particularly among infants and children. If this resulted in differentially depressing the size of 0- to 5-y-old cohorts, it would then have depressed the size of the 5- to 19-y-old cohort, ultimately reducing both the computed \( 1_{SP} \) values and, of course, long-term population growth.

Cremation appears to have been more common in the Sonoran Desert and Tonto Basin/Verde Valley areas than elsewhere in the Southwest, although high proportions of cremations appear elsewhere occasionally [e.g., at Gran Quivira in the middle Rio Grande, where cremations account for 27% of all burials (37)]. Theoretically, this body treatment could affect \( 1_{SP} \) values if cremations were more common for some age categories than for others, and if cremated bodies were unable to be aged more frequently than uncremated bodies. Although there is evidence for the second proposition, there is no evidence that cremation is significantly associated with age (38) (SI Text, Cremation Analysis).

The Mogollon subregion is large and contains both upland and lowland settings (Fig. 1), undoubtedly influencing its variability in \( 1_{SP} \) values through time (Fig. 2). Juvenility indices peak somewhat later here than in most other subregions, boosted by large assemblages with high \( 1_{SP} \) values (Paquimé in Chihuahua and Grasshopper Pueblo in the Mountain Mogollon area of Arizona) dating to the early A.D. 1300s. Several contemporaneous sites in the Mountain Mogollon area, including Grasshopper, apparently received influxes of women and children from the north in the late A.D. 1200s or early 1300s, possibly as refugees (39, 40). Such an influx could inflate \( 1_{SP} \) values both immediately, because of the children, and over time if female immigrants were predominately of child-bearing age.

The middle Rio Grande subregion has few assemblages predating ~A.D. 1200 and was apparently lightly occupied before that time. Birth rates declined slowly and almost linearly from the A.D. 1200s through the 1500s, with the latest assemblage from Pueblo de las Humanas (Gran Quivira) late enough to have been influenced by Spanish introduction of diseases (Table S1) (37).

Subregional Analysis, Northern Southwest. Except for the northern Rio Grande (Fig. 1), the remaining six areas in Fig. 2 are completely or mostly on the Colorado Plateau, a physiographic province that in late pre-Hispanic times was associated with Pueblo societies and the Fremont of Utah. These societies relied on rainfed farming or on dry farming (21), with various water-harvesting techniques and small-scale irrigation important in the northern Rio Grande after ~A.D. 1300.

In general, these six northern sequences are marked by higher \( 1_{SP} \) values than are the four southern areas, although the Kayenta and Fremont/Virgin regions are intermediate in this respect, presumably because their generally lower elevation and greater aridity relative to the San Juan Basin and the Northern San Juan limited maize production (Fig. 2 and Fig. S1). The exception to lower \( 1_{SP} \) values in the western portions of the Southwest (the left-hand columns in Fig. 2) is the Sinagua area near Flagstaff, Arizona. All but the earliest site in this series postdate the eruption of nearby Sunset Crater, traditionally dated to A.D. 1065 but now believed to be closer to 1090 (41). It has long been proposed that this eruption created propitious agricultural conditions (42), and this is supported by the Sinagua’s high posterosption \( 1_{SP} \) values (Fig. 2).

The high \( 1_{SP} \) values early in the Northern San Juan sequence are especially remarkable and unlike anything seen contemporaneously in the southern Southwest. The San Juan Basin sequence also appears to start with high values, but this is based on only one small assemblage. From ~A.D. 700 to 1100, however, the San Juan Basin rates are among the highest in the Southwest. Although \( 1_{SP} \) values were declining slightly in the San Juan Basin after ~A.D. 1200, they remained relatively high there and in the northern San Juan. Whatever the causes of the depopulation of the northern Southwest during the A.D. 1200s, they seem not to have greatly affected \( 1_{SP} \) values in these two growth centers.

Possible Explanations for the Plateau/Desert Valley Contrast. The contrast between the generally higher \( 1_{SP} \) values for dry/rainfed farming areas in the north and the lower values for the Sonoran Desert and Tonto Basin that were more dependent on irrigation is surprising and previously unrecognized. From the intensity of Hohokam agricultural systems and their early sociopolitical complexity (25, 43), one might predict rapid population growth and therefore high \( 1_{SP} \) values. However, in fact, households in the irrigation-dependent south were apparently having fewer offspring than the dry farmers to the north and east. (That these societies might have been exporting their offspring to other subregions seems implausible, although it could be explored with stable isotope analyses.) In addition to the possibility that increased pathogen loads in irrigation systems depressed \( 1_{SP} \) values, we suggest that the differing distributions of potential agricultural land in the two areas contributed to this pattern.

In many portions of the Colorado Plateau, extensive tracts of productive lands became available when precipitation and temperature patterns were favorable, making it possible for families to export numerous offspring to other favorable areas. However, irrigation systems can expand only with great difficulty. In many cases, topography or vested interests make it impractical to expand or reorient irrigation networks. Theory explaining why sociopolitical complexity should develop first in circumscribed areas such as the Phoenix Basin has long been available (44), and in light of this results may be applicable to the north/south contrast in rate of political evolution in the Southwest. A possible consequence of this social hierarchy is that opportunities for reproduction may have monopolized by fewer, richer households in irrigation-dominant societies but shared more equally in the north, with the net result at the population level being higher juvenility indices in the north, and lower indices in the south.

This expectation—consistent with reproductive skew theory (45)—could be tested by comparing burial assemblages from Classic period platform mounds advantageously located on the canal system against more peripheral contemporaneous assemblages—a task not attempted here. Regardless of such possible variability within subregions, the distribution of \( 1_{SP} \) values across the Southwest (Fig. 2) suggests that pioneer southwestern archaeologist A. V. Kidder (46) was quite literally correct when he identified the San Juan (in which he included the Northern San Juan, San Juan, and Kayenta areas) as “the breeding ground for many of the basic traits of Southwestern culture and center of dissemination.”

Combined Southwest: Crude Birth Rates and Life Expectancies. The \( 1_{SP} \) values for all 10 subregions are combined and converted to CBR in Fig. 3 (SI Text, Crude Birth Rates). This reveals an almost linear trend from around 0.02 at ~1100 B.C. to a peak ~A.D. 500 at rates exceeding 0.05. Birth rates then leveled off, with some variability including a slight dip in the mid-A.D. 1100s, until about A.D. 1300. After that, CBR declined rapidly across the Southwest, to levels not experienced for the previous 1500 y.
Overall, the birth rates for these populations appear to be very high. The mean value of the fitted CBR for all assemblages in this sequence is 0.049 ($s = 0.006$), above the highest value reported in the world today (Niger, 0.047; Fig. 3) (47).

For 36–40 assemblages that are relatively large (minimum, 24 individuals; mean, 98) and for which life tables are available or can be constructed, Fig. 4 reports life expectancies at age 15 ($e_{15} + 15$), and two measures for life expectancy at birth ($e_0$) (SI Text, Life Expectancy Calculations).

Total life expectancies at 15 increased very slowly from around 35 y at ~900 B.C. to about 37 y at ~A.D. 600, and then more rapidly to almost 40 y ~A.D. 1000, after which they declined markedly, bottoming out near 35 y ~A.D. 1150 (Fig. 3). Values increased again until ~A.D. 1400, and then decreased. The mean fitted value for $e_{15}$ values is 37.2 y ($s = 1.1$).

We acknowledge a number of potential problems with the $e_{15}$ estimate and the $e_0$ estimate based on life tables ($e_0LT$), including both underenumeration of infants and children, and underestimation of older-adult ages (48). Given the nature of the data, trends through time are more credible than are the absolute estimates. Comparisons with modern populations for which life tables are not reconstructed from death assemblages are especially problematic, and in fact the $e_{15}$ values we estimate are much lower than some modern hunter-gatherer groups with $e_{15}$ values between about 51 and 58 y (thus, average total life spans of six or seven decades for those surviving to 15) (49). More to the point are comparisons (below) with other ancient populations, because the biases introduced by the archaeological record and the problems inherent in building life tables from osteological samples are shared.

![Crude Birth Rate](image1)

**Fig. 3.** Crude birth rate (green, $n$ assemblages = 133) through time, entire Southwest (loess fit with 90% CI). Symbol size is proportional to number of individuals 5 y or older in each assemblage. Horizontal reference lines mark current estimated CBR for the world and for the nation with the highest current CBR, Niger. Vertical reference lines at A.D. 1 and 1280.

![Life Expectancy](image2)

**Fig. 4.** Life expectancy at 15 from life tables (red, $n$ assemblages = 36) through time, entire Southwest (loess fit with 90% CI); life expectancy at birth from life tables (dashed blue line, $n$ assemblages = 40) through time, entire Southwest (loess fit with 90% CI); life expectancy at birth from juvenility indices (solid blue line, $n$ assemblages = 120) through time, entire Southwest (loess fit, no CI). Symbol size is proportional to the number of individuals 5 y or older in each assemblage; red symbols represent assemblages used to estimate $e_{15}LT$; blue symbols, $e_0LT$. Vertical reference lines at A.D. 1 and 1280.
The two estimates of life expectancy at birth (Fig. 4) both suggest declines from ∼1100 B.C. until A.D. 500/600, followed by an increase till A.D. 700/1000, a sharp decline bottoming out A.D. 1100/1200, with post-A.D. 1300 increases. Overall, by either measure the life expectancy at birth of these southwestern populations was quite short (mean fitted value of $e_{0\text{LT}} = 22.1$, $s = 2.1$; mean fitted value of $e_{0\text{BA}} = 22.8$, $s = 3.1$).

**Summary and Conclusions**

Using proxies derived from excavated assemblages of human remains we have estimated juvenility indices (convertible to birth rates) for 10 subregions, and birth rates for the entire North American Southwest, for ∼2,500 y beginning ∼1000 B.C. We also used two techniques to provide preliminary estimates of life expectancies through time at birth and at age 15 for the Southwest as a whole (SI Text, Life Expectancy Calculations).

Table S3 assembles some comparative data for the three life expectancies estimated here. Estimates for life expectancy at birth in this southwestern series are somewhat below the mean of the other series in this table, whereas the mean fitted value for $e_{15}$ in the Southwest is well above the average for the other series. We can tentatively conclude that in the Southwest chances of dying before age 15 were somewhat higher than was typical in the post-Pleistocene, premodern world, but those surviving to age 15 could expect somewhat longer lives than in many contemporaneous societies. The widening gap between our two measures of $e_{0}$ and $e_{15}$ from ∼1000 B.C. to A.D. 400/500 seems to suggest an increasing proportion of mortality in prereproductive ages over this period as sedentism and reliance on maize also generally increased.

The NDT in the Southwest was less a revolution than a slowly accelerating demographic process in which birth rates increased steadily for some 1,600 y beginning no later than ∼1100 B.C. Birth rates leveled off (with some fluctuation) at high values ∼A.D. 500 and eventually declined rapidly beginning A.D. 1300. This is a long time for such high rates to be maintained (50); the mean duration of the “boom” phase of the NDT in 11 subregions of Europe is 600 y (51). This long expansion may have been possible because climates permitted Fremont farmers to intensively use large portions of the Great Basin between ∼A.D. 700 and 1200 (although colonization began earlier) (52), and farmers were also able to expand into large portions of the middle and northern Rio Grande after A.D. 900 (53). Nevertheless, the decline in $e_{15}$ after A.D. 1000 may have been due to density-dependent compensation. By A.D. 1000, life expectancy at 15 had been increasing (slowly at first, and then more rapidly) for some 1,900 y.

Although we do not attempt to translate these indices into population sizes or growth rates, a plausible interpretation is that populations increased in size in the Southwest for ∼2,200 y, from no later than 1100 B.C. to ∼A.D. 1100, stabilizing or declining after that time. A Southwest-wide population decline beginning ∼A.D. 1100 has been suggested (11); others have reconstructed declines in the northern Southwest after A.D. 1250 and in the southern Southwest after A.D. 1350 (12). The rates reconstructed here suggest that population increases were probably most rapid between ∼A.D. 500 and 1000, the period in which values for both birth rate and $e_{15}$ were at or near their peaks. We suggest that the close of this interval, also marked by the increasing appearance of durable masonry architecture in many subregions, signals the effective end of territorial expansion as a way of accommodating more offspring, although in some subregions population increases could still be supported via increases in sociopolitical complexity.

The CBR and all three estimates of life expectancy record a pronounced dip some time between the late 1000s and late 1100s. Given the extreme dependence on maize in nearly all of the Southwest after ∼300 B.C. (54, 55), these declines may have been partly in response to the megadrought centered on A.D. 1150 affecting large portions of the West (56). It is possible that other variability in CBR between about A.D. 900 and 1300 reflects other droughts centered on A.D. 936, 1034, and 1253 (56). In northern and upland portions of the Southwest, the progressive cooling of the northern hemisphere in the Little Ice Age (57) may also have decreased maize production after A.D. 1200 (58, 59). Although there is considerable variability in birth rates through time in specific subregions (Fig. 2), the small increases in CBR for the first 2000 years of this record suggest that local climatic downturns could be buffered by interregional movements until toward the end of the first millennium A.D. This in turn suggests that southwestern maize farmers took over 2,000 y to fill up their agricultural niche and become regionally susceptible to climatic variability.

Bocquet-Appel (60) suggested that initial population increases in the NDT were driven solely by increases in natality, with lagged increases in mortality eventually returning farming populations to a stable state. In the Southwest, by contrast, increasing life expectancy during reproductive years probably had a positive although minor role in initial NDT population growth, and decreased CBR contributed importantly to eventual population stabilization (or possibly decline). None of this calls into question Bocquet-Appel’s conclusions concerning the centrality of the relationship between increased sedentism and increased natality—conditions that slowly coevolved in the Southwest, not resulting in relatively stable sedentism in most subregions until ∼A.D. 600.

The slow demographic processes reconstructed here hardly seem like a Childean “Neolithic Revolution” (61). We argue although that populations crossed a critical threshold in the middle of the first millennium A.D. when “more” became “different” (62). At that point, for the first time in 1,600 y, birth rates plateaued, at high levels, and even declined slightly as opportunities for colonization began to decrease. For most groups, increasing birth rates was no longer a viable strategy. Instead, groups began to exploit smaller territories more intensively, as seems to have happened in the Natufian Near East (63). Community sizes began to increase (64), plausibly in response to intergroup competition as having more members improved chances for acquiring or retaining superior territories. Larger social groups favored novel sociopolitical arrangements and investments in architectural features such as ball courts in the south and great kivas elsewhere that could coordinate large numbers of participants. Across much of the northern Southwest, this macroevolutionary transition (65) is recognized as the beginning of the Basketmaker III period. More generally, this A.D. 500–700 period marked increased internal codification and external differentiation of the Ancestral Pueblo, Mogollon, and Hohokam traditions.

**Materials and Methods**

Data on human remains were acquired from a number of primary and secondary sources (SI Text, Sources of Data) and coded following practices developed in previous NDT research (SI Text, Coding Conventions, and ref. 20). Figs. 2 and 3 use loess smoothing of demographic proxies against the absolute date of the assemblages from which they were developed (SI Text, Statistical and Graphic Conventions). We examined, and rejected, the possibility that cremations might be significantly affecting $\nu_{PS}$ values (SI Text, Cremation Analysis). Values for $\nu_{PS}$ were converted to CBR following ref. 13 (SI Text, Crude Birth Rates). Life expectancies at birth and at 15 were drawn from the literature or computed from life tables generated from the literature as explained in SI Text, Life Expectancy Calculations, where we also describe an alternative estimate for $e_{0}$ ($e_{BA}$) derived from ref. 13.

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SI Text

Sources of Data
This expansion to ref. 1 extends the spatial window within which \(^{13}P_3\) values were collected or calculated to encompass the entirety of the pre-Hispanic Southwest. We also assembled life table data within this window where we could find it. We attempted to locate assemblages collectively spanning as much of the total occupation span for the region as possible. Although we looked for assemblages predating \(\sim 1100\) B.C., we could not generate an adequate sample, which argues for high mobility and low population sizes before that date. Mortuary assemblage data were collected from as many sources as could be located, including published articles, journals, volumes, published and unpublished site reports, and databases provided by colleagues. We accepted all data from these sources with the following exceptions:

- We excluded assemblages where we could not estimate their dates or age distributions to our satisfaction;
- We excluded assemblages obviously affected by massacres or extreme perimortem processing possibly indicating cannibalism;
- Unless they could be used as part of a composite assemblage, we generally excluded isolated burials;
- We excluded one \(^{13}P_3\) value of 0.954 from a large assemblage (Snaaketown, A.D. 1000; Table S1) as an extreme positive outlier (Fig. S1).

In the northern Southwest, the dates we assign to assemblages are typically derived directly (or indirectly, via ceramics that have previously been calibrated) from tree-ring chronologies. In the desert Southwest, most dates are directly or indirectly from \(^{14}C\) determinations. There is no standard repository for archaeological or bioarchaeological data so it is impossible to census the population of excavated pre-Hispanic skeletal materials or to estimate its size. Most of these materials have been repatriated and are unavailable for new study. This study increases the number of sites/composite assemblages by 380% and the number of human remains by 230% relative to ref. 1.

Coding Conventions
Tables S1 and S2 contain many entries for skeletal counts that are not integers. Many sources offered age estimates cross-cutting the age categories we used (5–19 and \(\geq 20\)). In those cases, their counts were distributed proportionately among our age ranges. For example, an individual aged 18–21 would be distributed as 0.5 individuals in the 5–19 category and 0.5 individuals in the \(\geq 20\) category. We attempted to accurately interpret an individual’s actual age when researchers used non-quantitative characterizations such as infant, adolescent, etc., using other information specific to each source. All analyses include both aged cremations and aged inhumations. Cremations are most common in the Sonoran Desert and Tonto Basin sequences, between \(~\)A.D. 700 and 1300.

Statistical and Graphic Conventions
Although the original presentation of the Neolithic Demographic Transition for Europe and the Levant assigned assemblages a chronological placement relative to the local assumption of a Neolithic way of life (2), here we use absolute dates. This is possible because of the smaller area examined, and results in a clearer presentation.

In Fig. 1, site/composite sample symbols are proportional in size to number of individuals aged \(\geq 5\). Regional affiliations of sites were assigned using information in each source. Composite data points were only generated from assemblages within a single region, and close together in time. Their coordinates were found by locating each contributing site and assigning the composite an average location, weighted according to the sample sizes of each contributing site.

Loess analyses (Figs. 2–4) were weighted by number of individuals aged \(\geq 5\) in each assemblage, making aggregation or deletion of small assemblages less critical than for an analysis not so weighted. The date assigned to each assemblage was the midpoint assigned to that assemblage in each source, or our best estimate of what that midpoint would be when the source was not explicit. The analyses in Fig. 2 used all samples with \(\geq 5\) individuals aged \(\geq 5\) y and a smoothing parameter \(\alpha = 0.45\). The analyses in Fig. 3 and the analysis generating \(e_{BA}\) in Fig. 4 used all samples with \(\geq 10\) individuals and a smoothing parameter of 0.35. All loess fits used degree = 1 (linear) for the local polynomials in each local regression, and cubic interpolation for blending local polynomial fits at the kd tree vertices. Confidence intervals in Figs. 2–4 are 90% around the fit. These intervals integrate the effects of uncertainty due to variable and often small sample sizes and sample variability in values for the dependent variable that are close together in time.

In Figs. 2–4, we place vertical reference lines at A.D. 1 and 1280 to mark the beginning of the first millennium A.D. and the time by which the depopulation of the northern Southwest was essentially complete. In Fig. 2, the horizontal reference lines at \(^{13}P_3 = 0.18\) mark Bocquet-Appel’s estimate for the value of \(^{13}P_3\) in a stationary population. This estimate is probably too high for the Southwest, because the Sonoran Desert populations were obviously surviving, and probably growing slowly, despite the fact that that their \(^{13}P_3\) values did not exceed 0.18 on average until nearly A.D. 1.

Flows of populations between subregions, likely large in the A.D. 1200s, might subtly affect the juvenility indices in Fig. 2 by depression in the source area and inflation in the sink. However, the Kayenta region is a probable source for migration to the Tonto Basin and Sonoran Desert, and yet those destinations evidence very low juvenility indices in the 1200s and early 1300s. In any case, these effects, if they exist, should largely disappear when the Southwest is considered in its entirety (Fig. 3), assuming that immigration into and out of the entire region was minimal.

Cremation Analysis
To assess whether the proportion of cremations in some of these assemblages affects their \(^{13}P_3\) values, we regressed \(^{13}P_3\) on proportion cremations \([n\text{ cremations}/(n\text{ cremations} + n\text{ inhumations})]\) where both quantities include only individuals \(\geq 5\) y old, using the 15 sites with at least 1 aged cremation identified in Table S1. We used weighted least squares with weights proportional to sample size (total aged burials \(\geq 5\) old, both cremations and inhumations). There is no significant linear relationship between the two quantities \((^{13}P_3 = 0.288–0.123 \times \text{ proportion cremations} ; r^2 = 0.07; P > F = 0.33)\).

Crude Birth Rates
For compatibility with earlier research (2), we define the crude birth rate (CBR) as the number of living births per year divided by the current population size (births per person per year). We estimate birth rate from \(^{13}P_3\) according to the formula provided in ref. 2, table 2:
CBR = 0.00375 + 0.15334(15P5)0.89074.

CBR is more often presented as births per 1,000 people per year. The CBR we estimate at the beginning of our sequence (0.02) is equivalent to 20 births per 1,000, slightly above the estimated world rate of 18.9 births per 1,000 in 2013 (3). Our estimated Southwest-wide CBR for the A.D. 500–1100 period exceeds, although its confidence interval includes, CBR estimates for the fastest-growing countries in the world in 2013, Niger (46.8) and Zambia (42.8) (3).

Life Expectancy Calculations
In addition to the relatively random processes affecting recovery of all materials from the archaeological record, life expectancy calculations based on death assemblages are beset by systematic biases. They depend on life tables that assume stable populations, a single population, equal probability of enumeration in all age categories (hence, good preservation of younger individuals) and accurate aging. All of these assumptions are potentially problematic here and for most other skeletal populations (4, 5). Proposed remedies for older-adult age underestimation (6) require reanalysis of collections, an impossibility here. In most cases, e15 values presented here (e15LT where LT indicates they were calculated from life tables) were obtained directly from the literature. For four sites noted in Table S1, we computed e0LT and e15LT from age distributions given in the reports using the R program ArchLT(), provided by its author, Tim Riffe (Department of Demography, University of California, Berkeley). For Snaketown, we used values of e15 computed by this program using ages recently estimated from Native American Graves Protection and Repatriation Act forms from the American Museum of Natural History rather than those available for this site in (7).

Because of these problems, we also present a calculation of life expectancy at birth (e0LT), where LT indicates that it was calculated in the standard way, from life tables, and add an alternative estimate for life expectancy at birth, e0BA, based not on life tables but computed from the juvenility index using the relationship between that index, e0, and r computed from 45 reference life tables from various world locations in the 17th to 20th centuries (2). The advantages of this approach are that it avoids the infant underestimation and adult-age underestimation affecting life table approaches. The disadvantages are that we must assume that mortality patterns in these relatively recent populations are similar to those in the US Southwest in much more ancient times, and that we must hypothesize a value for r. We assumed r = 0.005 before A.D. 1300, and r = 0 after that. Although these two estimates for e0 often agree in direction of trend, e0BA is more variable through time.


Fig. S1. Box plot, 15P5 values by region. Width of boxes is proportional to number of assemblages in each region. Named outliers are more than 1.5 mid-spreads above the upper hinge. Snaketown is the most extreme outlier in the dataset and was eliminated from other calculations in this paper.
Other Supporting Information Files

Table S1 (DOCX)
Table S2 (DOCX)
Table S3 (DOCX)