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Report

Modeling, simulating, and comparing biased archaeological mortuary assemblages

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Abstract

This paper uses a novel approach to compensate for inherent sampling biases and to compare the age profiles of two ancient Maya sacrificial assemblages to expectations from a model life table for traditional horticultural populations. It seeks to statistically rule out the possibility that either site is accumulated due to a standard mortality process experienced in horticulturalist populations. This analysis utilizes data from Midnight Terror Cave (MTC), Belize and Chichén Itzá (CI), Mexico to compare the observed versus expected death counts by age. Monte-Carlo based estimates of preservation bias were modeled assuming a normal distribution with mean and variance based on expert opinion. This model was used to up-adjust age-specific death counts for both sites to make more robust sample sizes, which were compared to those expected from a model life table at the 5th, 50th, and 95th percentiles of the resampled distribution of preservation bias. At low levels of estimated bias (5th percentile), neither MTC nor CI assemblages could be distinguished from the null-mortality model. At average to higher levels of estimated bias (50th and 95th percentiles), both populations could be statistically distinguished from the null mortality model either across all age intervals or within specific age ranges. After accounting for preservation bias, the findings suggest that both MTC and CI assemblages were unlikely to have accumulated due to a normal mortality pattern experienced within traditional horticulturalist populations, further supporting the ethnographic and archaeological evidence that indicates that the sites are accumulated due to cultural practices related to human sacrifice.

Keywords: Mortuary assemblages; Siler model; Monte Carlo simulation; Preservation bias; Sampling bias; Sacrifice; Maya Bioarchaeology

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1. Introduction

The previous examinations of the Midnight Terror Cave (MTC) site, Belize, have concluded that there is strong archaeological evidence suggesting that the assemblage is accumulated due to cultural practices associated with human sacrifice (Kieffer, 2011; 2015; 2018). The assemblage associated with Chichén Itzá (CI), Mexico, is widely considered being accumulated primarily due to human sacrifice practices (de Anda Alanís, 2007; Tozzer, 1941; Tiesler, 2005). However, to date no research has ruled out the possibility that either site is accumulated due to a typical mortality pattern associated with horticultural populations. This study fills the existing gap in the literature by making a statistical comparison between sacrificial assemblages and normal mortuary assemblages and asking the question of whether the MTC and CI assemblages are clearly different from a horticulturalist model life table, thus ruling out the simplest possible alternative explanation for their accumulation. The focus of the paper is to test the null hypothesis that these assemblages accumulated through such a standard mortality process. A rejection of this null hypothesis would securely establish the standing of these sites as examples of assemblages accumulated due to human sacrifice.

1.2. Background

1.2.1. Mortuary assemblages

Mortuary assemblages from archaeological sites should not be assumed to reflect the typical J-curve age at death distributions that is expected in the mortuary assemblages of living populations (Chamberlain, 2006; Weiss, 1973). Differences may exist due to unanticipated disasters such as epidemics, warfare, and human sacrifice (Chamberlain, 2006) or they may accumulate for taphonomic reasons related to culture-specific mortuary practices (Saunders *et al.*, 1992; Scrimshaw, 1984), soil conditions (Gordon & Buikstra, 1981; Haglund & Sorg, 1997; 2002) or even as artifacts of excavation methods (Paine & Harpending 1998). For all of these reasons, bioarchaeologists have long been suspicious about the assumption that mortuary assemblages directly represent mortality processes (Angel, 1966; Bocquet-Appel & Massett, 1982; Weiss, 1973). McCaa (2002) goes as far as to call this the "Whopper Assumption."

In addition to the challenges associated with differential preservation of materials, mortality analysis often makes very specific assumptions about demographic non-stationarity, differences in frailty across subsets of the population, and the role of selective mortality (Wood *et al.*, 1992) that is not always acknowledged in any given analysis in the literature of bioarchaeology and paleodemography (Keckler, 1997). A common approach has been to use the strategy of "model life-tables" (Bocquet-Appel & Massett, 1982; Paine & Harpending, 1996) to correct for deficiencies in bioarchaeological data. This approach is common in demographic approaches to population analysis with incomplete data (Coale & Demeny, 1966; Preston *et al.* 1994; Shryock *et al.*, 1980); however, the choice of an acceptable model can have important impacts on any analysis (Hill & Hurtado, 1996; Howell, 1976; Keckler, 1997).

What we observe in a mortuary assemblage is not mortality; rather, it reflects a proportional relationship between mortality and the probability that we observe any specific death in the context of bioarchaeological investigation (Wood *et al.*, 1994; 2002). This relationship is viewed through a specific filter introduced by the choice of a model life table and specific demographic model by which to analyze these data (Hill & Hurtado, 1996; Keckler, 1997; Wood *et al.*, 1994).

An acceptable consideration of the relationship between what we observe in a mortuary assemblage and what we expect must, therefore, present a specific strategy for dealing with bias in the probability of observing deaths and the utilization of a model life table with high plausibility. In this paper, we address both concerns in comparing the MTC and CI assemblages to a reference mortality process associated with traditional, horticulturalist populations. First, an expert-based model of preservation bias was employed that explicitly addresses the probability of observation of each death in the assemblage. This model includes an examination of both the average anticipated probability of observation as well as high and low variants that capture a range of uncertainty. These estimates were combined in the context of a normal distributed Monte Carlo model (Graham & Talay, 2013; LeMieux, 2009) of the probability of observations that is reported in this paper and, therefore, could plausibly be re-adjusted by readers using our tables if they prefer to explore different levels. The model grows out of the work of Saunders *et al.* (1992; 2002) in which comparisons of cemetery populations and parish records were made that provided explicit starting estimates for considering these issues. It is based in the theory behind Horvitz-Thompson estimators (Horvitz & Thompson, 1952), in which observed data may be up-weighted to reflect unobserved data in calculating summary statistics (Longford, 2005) Here, fellow colleagues experienced in bioarchaeology and paleodemography were consulted by the author to form estimates of the average, high, and low ranges of bias that could be present and these estimates formed the basis of our analysis.

To adequately choose a model life table for developing expected distribution of age at death for each site, this method built upon the analysis of traditional horticulturalist mortality patterns presented by Gurven & Kaplan (2007). Their model comprehensively reviews what is known about mortality in traditional, horticulturalist populations and estimates the mortality schedule using the Siler competing hazards model (Siler, 1979; 1983), which parameterizes the life table by estimating effects associated with known differences in early-life, adult, and old-age mortality patterns. As such, the Siler model provides a biologically plausible basis for a model life table that speaks to species-specific mortality patterns experienced as part of the human life course (Hill &

Hurtado, 1996; Siler, 1979; 1983). This model also has been argued to be the most biologically plausible mortality model for traditional anthropological populations (Gage, 1988; Wood *et al.*, 2002).

By choosing model parameters based on Gurven & Kaplan's (2007) average for horticulturalist populations, we arrive at the most plausible model life table for use in discriminating sacrifice-related assemblage formations from a background mortality process that characterized the populations from which the MTC and CI assemblages were most likely to be drawn. When combined with the explicit modeling of the probability of observing a death using the Monte-Carlo approach described above, this paper not only provides a significant step forward in understanding the MTC and CI assemblages, but it also provides new tools for bioarchaeologists and paleodemographers seeking to understand the anthropology of similar groups. The approach is general and paleodemographers who implement this method may adjust estimates of preservation bias or the specific model life table chosen to fit their purpose. As such, this paper provides both new insights and new methods to the bioarchaeological and paleodemographic literature.

1.2.2. Demographic patterns of Central America

In addition to the archaeological evidence at the site, the known normal burial patterns in the Maya area further suggest that the MTC assemblage resulted from human sacrifice. While caves have been documented as locations of ossuary assemblages, this pattern is primarily restricted temporally to the Postclassic (950 CE-1539 CE) and spatially to the southern periphery of the Maya area in Honduras and western periphery in Chiapas, Mexico (Blom, 1954; Ruz, 1968:165). This type of cave burials was suggested by many to be an elite privilege (Dahlgren de Jordan, 1966; Moser, 1975). This elite appropriation of caves for tombs and elite burial has been documented throughout Guatemala and Mexico (e.g., Brady, 1989:348; Burgoa, 1934; Dahlgren de Jordan, 1966; Moser, 1975; 1976; Kieffer, 2009; Thompson, 1938). Ruz Lhuillier (1965) also noted secondary burials at cave sites in Guatemala and Yucatan, Mexico. Caves in the Southern Lowlands and Peten, Guatemala, were commonly used for sacrifice (Gibbs, 1997; Owen, 2005; Moyes & Gibbs, 2000; Saldana & Kieffer, 2009; Scott & Brady, 2005;). Commoner burials are typically found in house mounds (Rathje, 1970) and rockshelters (Bonor Villarejo, 1995; Bonor Villarejo & Martínez Klemm, 1995; Glassman & Bonor Villarejo, 2005; Prufer, 2002; Saul *et al.*, 2005).

There are several Maya cave sites that have been interpreted as including sacrificed individuals. These sites include Eduardo Quiroz Cave (Pendergast, 1971), Naj Tunich, Guatemala (Brady, 1989), Petroglyph Cave, Belize (Reents-Budet & MacLeod, 1986), Actun Tunichil Muknal, Belize (Gibbs, 2000), Cueva de Sangre, Guatemala (Scott & Brady, 2005), La Iluminada and Hun Nal Ye, Guatemala (Woodfill, 2007). However, many of these sites only have a few individuals, which make any statistical comparison to them difficult if not impossible. Only the Cenote Saratoga at CI, Mexico, has a large enough assemblage to be used for statistical purposes. What is unique about this site and what makes it an ideal example for the expected demography of sacrifice is the ethnohistoric literature that documents sacrifice occurring there (Tozzer, 1941).

2. Methods

2.1. Data sources

Numerous studies on the CI assemblage, Mexico, demonstrated large percentages of infants and men were recovered at the site (de Anda Alanís, 2007; Hooton, 1940; Tiesler, 2007). At least 127 individuals have been recovered, 88 were children or juveniles under 18 years of age (de Anda Alanís, 2007). Unfortunately, this dataset could not be used in this study because de Anda Alanís has not yet published the exact age distribution of his reanalysis. Therefore, the original analysis conducted by Hooton (1940) was used as the dataset in this study. Demographic data used for MTC consists of the 118 individuals (the majority were young adults and children between 5 and 12 years of age) that have been previously published by the author (Kieffer, 2015; 2018).

2.2. Age adjustments and sample characteristics

Methods for assigning ages to skeletal remains are not without uncertainties (Bass, 1995; Sattenspiel & Harpending, 1983; Saunders *et al.*, 1992; 2002) and this often allows interval-based estimates of age as the only available option. Since demographic analyses of mortality are facilitated by assignment of individuals to more fine-grained groupings, such as 5-year age intervals, data utilized in this analysis were subjected to the method of rectangular proration (Brass, 1960; Shryock *et al.*, 1980). Rectangular proration is built upon the assumption of rectangularity which assumes that within a 5-year age group, every year has equal proportional distribution (Shryock *et al.*, 1980). In this analysis, rectangular proration was utilized to assign individuals to 5-year age categories from more coarse-grained ones and the summarized counts of deaths by age utilized in the remainder of the analysis. The resulting "observed" death counts for both the MTC and CI assemblages are reported in Table 1.

2.3. A Horticulturalist model life table using the Siler competing hazards method

The Siler model is a competing hazards approach to life-table estimation, with each individual potentially dying from forces associated with infant mortality, initial adult mortality, and shifts in the force of mortality as senescence occurs (Siler, 1979; 1983). In formulaic terms, the Siler model formulates the force of mortality as:

$$\mu(a) = \alpha_1 e^{-\beta_1 \alpha} + \alpha_2 + \alpha_2 e^{\beta_3 \alpha}$$

Here, β_1 represents the rate of decline in early mortality with age, associated with the parameter α_1, which represents the force of mortality associated with neonatal life, together this represents a term that reflects early-life mortality risk that is decelerating with age (Siler, 1979; 1983). The second term parameter α_2 reflects a constant force of mortality across the life span (Makeham, 1860). The third term-- $\alpha_2 e^{\beta_3 \alpha}$ —reflects the senescent component of mortality which is the constant force of mortality (α_2) with an acceleration component ($e^{\beta_3 \alpha}$) reflecting increased risks of mortality across the aging spectrum (Gompertz, 1825). The model is reviewed in greater detail in Gage and Dyke (1989), Gurven & Kaplan (2007), and Wood *et al.* (2002), to which interested readers with an inclination for mathematics are referred. In this analysis, we used the parameters suggested by Gurven & Kaplan (2007): $\alpha_1 = 0.2798$, $\beta_1 = 1.1037$, $\alpha_2 = 0.0223$, and $\beta_3 = 0.1274$ as a model life table, predicting the anticipated number of deaths in each age interval, we would expect to see within the MTC and CI assemblages.

Table 1. Age-adjusted (post rectangular proration) datasets utilized in this analysis

Age (year)	Midnight Terror Cave	Chichen Itza
0 – 1	6	7
2 – 4	18	7
5 – 9	17	2
10 – 14	5	8
15 – 19	3	5
20 – 24	15	2
25 – 29	12	2
30 – 34	12	2
35 – 39	12	2
40 – 44	4	2
45 – 49	4	2
> 50	4	2

2.4. A Monte-Carlo model of preservation bias and statistical comparisons

Expert-based ranges for the analysis of preservation bias utilized in this study are reported in Table 2. The approach builds out of results from the study of Saunders *et al.* (2002), who compared cemetery assemblages to parish records and record discrepancies that suggest a proportionality between observed cemetery assemblages and those expected in a register-type tracking of deaths (Saunders *et al.*, 2002, p144: Figure 5.4). Using this as an initial basis, interviews with several experienced bioarchaeologists were conducted to arrive at best-guess estimates of observability bias by age, including both a most-likely “average” as well as the upper and lower bounds of the distribution. This approach is commonly utilized in stochastic simulation studies where estimates of a phenomenon are not available, when a research topic is new, and when a paucity of literature exists (Graham & Talay, 2013; LeMieux, 2009). They are presented for each 5-year age category, truncated at the 50 Plus years due to a paucity of available individuals beyond this age. These values were used to operationalize a set of Monte Carlo based estimates of the probability of observing a death. The basis for the Monte Carlo model was a random resampling of rates under a binomial probability model (Chiang, 1964; 1984), operationalized as a normal random variable (Graham & Talay, 2013; LeMieux, 2009). Each Monte Carlo experiment resampled the assumed distribution 1,000 times and we accounted for autocorrelation in random number generation (“burn-in” bias) by excluding the first 500 resampled estimates and thinning to each 100th iteration (LeMieux, 2009; Linstrom

Table 2. The ranges of observability bias utilized in the Monte-Carlo simulations to determine if differential preservation may exist within an assemblage

Age Cohort (year)	5th Percentile	50th Percentile	95th Percentile
0 – 1	0.05	0.43	0.80
2 – 4	0.07	0.31	0.55
5 – 9	0.03	0.19	0.35
10 – 14	0.03	0.09	0.15
15 – 19	0.03	0.07	0.10
20 – 24	0.03	0.07	0.10
25 – 29	0.03	0.07	0.10
30 – 34	0.03	0.07	0.10
35 – 39	0.03	0.09	0.15
40 – 44	0.03	0.14	0.25
45 – 49	0.07	0.21	0.35
> 50	0.07	0.26	0.45

et al., 2010). These distributions were utilized in the analysis at the 5th, 50th, and 95th percentiles to account for uncertainty in the expert-based judgments (Graham & Talay, 2013). Graphically, this produced survival plots that were visually inspected (Figures 1 and 2) to qualitatively assess the impact of the Monte Carlo based adjustments. In both cases, the adjusted datasets appear to be significantly different from the observed age-distribution once the Siler model is fit to both using maximum likelihood methods with code custom-written in the R software package (r-project.org). These qualitative observations suggest that if preservation is present in these assemblages, which is a significant likelihood, directly modeling should impact our assessment of hypotheses.

To test the null hypothesis of no differences in the age at death structure between null models and adjusted death counts by age for the MTC and CI assemblages, we employed simple categorical and parametric data analysis.

3. Results

Tables 3-5 present the results of statistical comparisons of the adjusted age-specific death counts to those expected under the null model of horticulturalist mortality. Table 3 captures analyses made using the 5th percentile of the modeled distribution of observability bias, Table 4 those from the 50th percentile (the average and "most-likely" value), and Table 5 reviews results associated with comparisons at the 95th percentile. Across all age intervals, statistically significant differences are observed at the 50th and 95th percentiles only for the CI assemblage (50th percentile: Chi-square = 25.18, $P = 0.02$; 95th percentile: Chi-square = 149.27, $P = 0.001$). Overall, only a weak significant difference was observed for the MTC site at the 95th percentile (Chi-square = 15.88, $P = 0.1$).

Within specific age-intervals, however, both sites deviate significantly from the horticultural model life table, but those deviations depend upon levels of observability bias incorporated into the estimation. At the 5th percentile of the modeled distribution for MTC significant differences were noted for newborns to 1 year of age ($P = 0.007$), 11 – 15 years old ($P = 0.005$), and 36 – 40 years old ($P = 0.008$). At the 50th and 95th percentiles, the 11 – 15 ($P = 0.002$) and 36 – 40 ($P = 0.005$) age intervals demonstrated significant differences. At the 50th percentile of the modeled distribution, a significant difference was noted for the 6 – 10 age intervals for CI ($P < 0.001$). At the 95th percentile, significant differences were noted for the 11 – 15 ($P < 0.001$), 16 – 20 ($P = 0.002$), and 36 – 40 ($P = 0.003$) age intervals for the MTC models. While the CI models at the 95th percentile had significant differences for the newborn to one ($P < 0.001$), 6 – 10 ($P < 0.001$), and 51 and above ($P = 0.01$) age intervals.

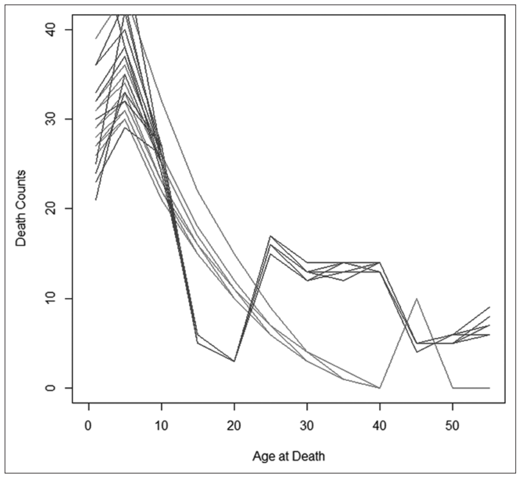

Figure 1. Graphical depiction of a Siler Model for the Midnight Terror Cave assemblage based on adjusted (black)) (a steep spike composed of multiple lines that range along the Y axis at just under 30 individuals and over 40 at 5 years of age along the X axis, then dramatically dropping to ~5 individuals at 15 – 20 years of age, followed by a slight peak of ~15 individuals at ~25 – 40 years of age, before dropping to ~5 individuals at 45 years of age) and unadjusted (grey) (a steep slope of multiple lines that range along the Y axis from ~25 to a little under 40 individuals at birth, that increases by 5 individuals at 5 years of age before sloping down to ~10 at 20 years of age, then almost no individuals at 40 and 50-years-old, with a brief spike of 10 individuals at 45 years of age) datasets.

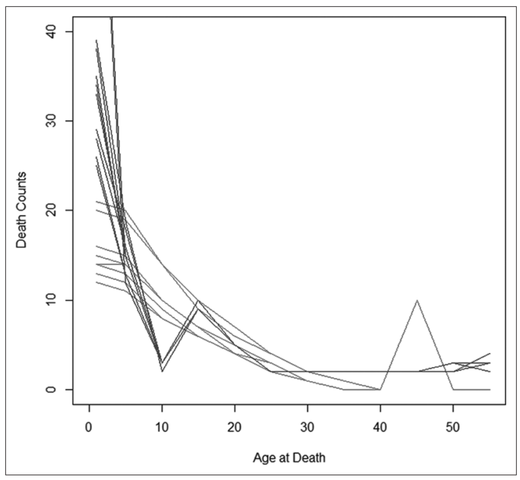

Figure 2. Graphical depiction of adjusted (black) (a steep curve composed of multiple lines that range along the y axis at ~25 to over 40 individuals at birth along the beginning of the x axis, then dramatically dropping to <5 individuals at 10 years of age, followed by a slight peak of ~10 individuals at ~15 years of age, then flattens to ~3 individuals from 25 – 50 years of age before a slight increase in death counts) and unadjusted (gray) Siler curves (a gradual slope of multiple lines that range along the y axis from ~11 to a little over 20 individuals at birth, then decreases to a range of 5 – 10 individuals by 20 years old, almost no individuals at 40 and 50 years old, with a brief spike of 10 individuals at 45 years of age) for CI.

Table 3. Comparisons of sacrifice assemblages to reference mortality schedule of small-scale horticulturalists at the 5th percentile of the Monte-Carlo modeled p. Observed and expected counts are given for every age cohort and Z-score and *P* values given for the statistical differences between observed and expected

Age	5th percentile monte-carlo modeled *P* (observation)	Gurven-Kaplan Reference Mortality				Midnight Terror Cave				Chichen Itza			
		n expected MTC	Proportion expected MTC	n expected Chichen Itza	Proportion expected Chichen Itza	n observed	Proportion	Z	*P*-value	n observed	Proportion	Z	*P*-value
0 – 1	3.29	28	0.262	13	0.262	20	0.128	2.703	0.007	23	0.335	−0.860	0.390
3 – 5	1.70	26	0.245	12	0.245	31	0.198	0.802	0.424	12	0.173	0.887	0.373
6 – 10	1.42	19	0.176	9	0.176	24	0.157	0.465	0.638	3	0.041	2.441	0.015
11 – 15	1.10	13	0.124	6	0.124	5	0.036	2.792	0.005	9	0.128	−0.169	0.865
16 – 20	1.06	9	0.085	4	0.085	3	0.021	2.452	0.014	5	0.077	0.154	0.881
21 – 25	1.06	6	0.054	3	0.054	16	0.103	−1.368	0.171	2	0.031	0.832	0.407
26 – 30	1.05	3	0.031	2	0.031	13	0.082	−1.867	0.061	2	0.031	0.329	0.741
31 – 35	1.06	2	0.015	1	0.015	13	0.082	−2.244	0.025	2	0.031	−0.309	0.757
36 – 40	1.10	1	0.006	0	0.006	13	0.086	−2.647	0.008	2	0.032	−1.214	0.226
41 – 45	1.27	0	0.001	0	0.001	5	0.033	−1.882	0.060	3	0.037	−1.493	0.136
46 – 50	1.35	0	0.000	0	0.000	5	0.035	−1.882	0.060	3	0.039	−1.493	0.136
>51	1.57	0	0.000	0	0.000	6	0.041	−2.066	0.038	3	0.046	−1.493	0.136
						Chi-square		12.418		Chi-square		8.840	
						P-value		0.400		*P*-value		0.700	

Table 4. Comparisons of sacrifice assemblages to reference mortality schedule of small-scale horticulturalists at the 50th percentile of the Monte-Carlo modeled p. Observed and expected counts are given for every age cohort and Z-score and *P* values given for the statistical differences between observed and expected

Age	50th percentile monte-carlo modeled *P* (observation)	Gurven-Kaplan reference mortality				Midnight Terror Cave				Chichen Itza			
		n expected MTC	Proportion expected MTC	n expected Chichen Itza	Proportion expected Chichen Itza	n observed	Proportion	Z	*P*-value	n observed	Proportion	Z	*P*-value
0 – 1	5.05	33	0.262	24	0.262	30	0.166	1.979	0.048	35.349	0.402	−1.963	0.050
3 – 5	2.28	31	0.245	22	0.245	41	0.224	0.321	0.749	15.979	0.182	0.942	0.347
6 – 10	1.53	23	0.176	16	0.176	26	0.142	0.854	0.395	3.061	0.035	4.122	0.000
11 – 15	1.18	16	0.124	11	0.124	6	0.032	3.093	0.002	9.431	0.107	1.389	0.165
16 – 20	1.12	11	0.085	8	0.085	3	0.018	2.888	0.004	5.601	0.064	1.178	0.238
21 – 25	1.12	7	0.054	5	0.054	17	0.092	−1.269	0.204	2.240	0.025	1.642	0.101
26 – 30	1.11	4	0.031	3	0.031	13	0.073	−1.541	0.124	2.226	0.025	0.775	0.441
31 – 35	1.12	2	0.015	1	0.015	13	0.073	−2.264	0.024	2.231	0.025	−0.046	0.960
36 – 40	1.17	1	0.006	1	0.006	14	0.077	−2.802	0.005	2.344	0.027	−0.622	0.535
41 – 45	1.33	0	0.001	0	0.001	5	0.029	−1.896	0.057	2.669	0.030	−1.787	0.073
46 – 50	1.53	0	0.000	0	0.000	6	0.033	−2.080	0.038	3.061	0.035	−1.787	0.073
>51	1.83	0	0.000	0	0.000	7	0.040	−2.251	0.024	3.669	0.042	−2.069	0.038
						Chi-square		15.375		Chi-square		25.178	
						P-value		0.200		*P*-value		0.010	

Table 5. Comparisons sacrifice assemblages to reference mortality schedule of small-scale horticulturalists at the 95th percentile of the Monte-Carlo modeled p. Observed and expected counts are given for every age cohort and Z-score and *P* values given for the statistical differences between observed and expected

Age	95th percentile monte-carlo modeled *P* (observation)	Gurven-Kaplan Reference Mortality				Midnight Terror Cave				Chichen Itza			
		n expected MTC	Proportion expected MTC	n expected Chichen Itza	Proportion expected Chichen Itza	n observed	Proportion	Z	*P*-value	n observed	Proportion	Z	*P*-value
0 – 1	9.057	41.334	0.262	51.857	0.262	54.343	0.240	0.459	0.646	63.401	0.515	−4.752	0.000
3 – 5	2.850	38.683	0.245	48.531	0.245	51.306	0.227	0.482	0.631	19.952	0.162	1.672	0.047
6 – 10	1.670	27.861	0.176	34.954	0.176	28.394	0.125	1.457	0.144	3.341	0.027	4.030	0.000
11 – 15	1.255	19.654	0.124	24.658	0.124	6.273	0.028	3.839	0.000	10.036	0.082	1.171	0.121
16 – 20	1.177	13.384	0.085	16.791	0.085	3.530	0.016	3.028	0.002	5.883	0.048	1.185	0.117
21 – 25	1.176	8.577	0.054	10.760	0.054	17.638	0.078	−0.856	0.390	2.352	0.019	1.690	0.046
26 – 30	1.190	4.957	0.031	6.219	0.031	14.283	0.063	−1.347	0.177	2.381	0.019	0.746	0.227
31 – 35	1.173	2.415	0.015	3.030	0.015	14.078	0.062	−2.379	0.017	2.346	0.019	−0.111	0.456
36 – 40	1.237	0.896	0.006	1.124	0.006	14.842	0.066	−2.898	0.004	2.474	0.020	−1.044	0.149
41 – 45	1.443	0.219	0.001	0.275	0.001	5.770	0.025	−2.064	0.039	2.885	0.023	−2.241	0.025
46 – 50	1.737	0.029	0.000	0.036	0.000	6.949	0.031	−2.233	0.026	3.474	0.028	−2.241	0.025
>51	2.240	0.002	0.000	0.002	0.000	8.959	0.040	−2.538	0.011	4.479	0.036	−2.592	0.010
						Chi-square		15.884		Chi-square		149.272	
						P-value		0.100		*P*-value		0.001	

If we relax the power level cut off for statistical significance to $P = 0.05$ or even $P = 0.1$ for the z-score test results at the level of age-groups, the number of age intervals that are statistically significant increases. This increase is more noticeable among the MTC cohorts, which would then have significant differences for more than half the age intervals in the 5^{th}, 50^{th}, and 95^{th} percentiles. Given the small sample sizes involved and the investigative nature of the analysis reported here, that relaxation may be justified.

4. Discussion

By examining which age cohorts have statistically significant differences, it becomes possible to rule out particular causes and further verify that these assemblages were most likely the work of sacrifice. Modern examples of warfare demography are seen in the cases of mass deaths in Palestine and Srebrenica (Bosnia), where civilian mortality was the greatest for individuals between the ages of 15 and 25, with the highest numbers being in 20s (Brunborg *et al.*, 2003; Radlauer, 2002). However, this does not explain the differences between children and adults. The elevated number of children is not typical for pre-industrial societies (Chamberlain, 2006, p64: Figure 2), nor is it expected for periods of famine (Chamberlain, 2006, p72: Figure 3).

For both the MTC and CI assemblages, at varying percentiles of the modeled distribution, we have noted statistical differences among the very young children, older children, young adults, and older adults. These age cohorts tend to be those ethnohistorically chosen for sacrifice (older children and young adults) (Fuentes & Guzmán, 1932; Roys, 1943; Scholes & Roys, 1968; Tozzer, 1941), and those not typically targeted for sacrifice (older adults). These cohort specific statistical differences indicate that their presence or absence in the assemblage is observable. However, these differences do not necessarily show levels of significance at high powers. This is especially when the models for the site of MTC are compared to each other.

The cohort-specific differences for MTC and CI also aid in ruling out the possibility that the bimodal age distribution of the assemblages is due to some sort of "accident hump" within the once living population that attributed to these assemblages. Gage and Mode (1993) note that when "accident humps" are noticeable they should only have miniscule mortality increases. As the simple Z-score test results indicate (Tables 3-5), there are statistically significant differences among specific cohorts for both MTC and CI compared to what a normal horticultural society should display. These significant differences rule out the possibility that these are miniscule mortality increases and thus dismisses the likelihood of an accident hump.

It is interesting that the cohort specific differences documented for MTC do not correspond perfectly with the statistically significant differences for results from CI's demographic data. This indicates that preferred ages of sacrificial individuals may not be consistent throughout the Maya area. The weak difference noted between the MTC models could also be due to a variety of cultural choices relating to sacrifice at the site. For instance, if sacrificial preference changed over time or a more randomized selection process for sacrificial individuals, then these choices may be contributing to why the models are not different, but a number of differences are noted at specific age intervals.

Before the development of the types of statistical analysis employed in this research, bioarchaeologists could look at overall patterns of mortality curves and determine if mortality for a site was normal or not. Data that reflected a J-shaped or "bath-tub shaped" curve demonstrated a relatively normal distribution with high infant mortality that decreases before rising again for older individuals (Weiss, 1973). This pattern is seen in Mesoamerican mortuary assemblages interpreted as burials at Caves Branch Rockshelter, Belize (Glassman & Bonor Villarejo, 2005) and Teotihuacan, Mexico (Storey, 1992). However, this is not the type of pattern demonstrated by MTC or CI. The analysis and modeling introduced by this article provide a visual and statistical means to determine if an assemblage is normal for a horticultural society. The specific age intervals where statistical differences were noted also allowed for affirmation that sacrifice could have contributed to the formation of the assemblage.

Because the two different assemblages did not demonstrate the same statistical differences, it suggest that there may not always be an obvious way to statistically demonstrate differences between mortuary assemblages accumulated through natural processes and those that accumulate due to human sacrifice. Demographic relationships are complex, and not every site or assemblage is bound to be created or influenced by processes in the same manner. Overall, the number of statistical differences demonstrated across the percentiles of the modeled distributions at the age interval level as well as the comparison of models (Tables 3-5) leads us to reject the null hypothesis that either the MTC or CI assemblages accumulated as the result of a standard mortality process experienced within a traditional, horticulturalist population. Thus, the demographic analysis can be used to further support the archaeological and ethnohistoric evidence from these sites that indicate sacrifice as a contributing cause of death for the people represented by these assemblages.

Since this methodology is capable of correcting for preservation bias, it could be used to look at other perishable assemblages such as floral and faunal artifacts to gain insight into the degree of human interaction. Beyond archaeology, this statistical methodology could be useful in other fields of study (i.e., public health, political science, and retail science) where known or estimated inherent biases of over or under representation occur, the methodology used in this paper could be utilized to make more detailed and informed comparisons between large groups of individuals by age cohorts. Care should be taken in establishing estimates as well as basing conclusions on models that produce estimates that deviate significantly from the original data set, as they then may lead to inaccurate assumptions.

5. Conclusions

This paper examines differences in the distribution of age at death of two ancient Maya assemblages (MTC, Belize and CI, Mexico) and what would be expected from a normal mortality pattern for a horticultural population. A model life table suggested by Gurven & Kaplan (2007) in their summary of existing data on mortality in such populations was utilized as a null expectation against which death counts by age for each site were compared.

The fact that the Monte Carlo simulations correct for preservation bias and are significantly different in a variety of ways from the Siler modeled age distributions for MTC and CI indicates that these mortuary assemblages probably did not form from a normal horticultural population. This suggests that some factor (other than preservation bias) contributed to the mortality irregularities observed at these two sites.

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Conflict of interest

There is no conflict of interests to declare.

Author contributions

This is a single-authored paper.

Ethics approval and consent to participate

This study did not involve any living individuals. All data are from the archaeological record and no approval by an Institutional Review Board was needed. Research at the archaeological site of MTC, which allowed the author to conduct this analysis, was done under a permit granted by the Belize Institute of Archaeology.

Consent for publication

Not applicable.

Availability of data

Data from CI were obtained from previously published data. Data from MTC were obtained through analysis conducted by the author as part of her dissertation research. Raw data for how minimum number of individuals was calculated can be found in the author's dissertation, which can be downloaded at https://digitalrepository.unm.edu/anth_etds/145/. R Code is available in the author's dissertation Appendixes C and D. This research was done with the permission of the Belize Institute of Archaeology.

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