A Paleodemographic Assessment of Mortality and Fertility Rates during the Second Demographic Transition in Rural Central Indiana

Gretchen E. Zoeller[1], Brooke L. Drew[2], Christopher W. Schmidt[3],Ryan Peterson[4], Jeremy J. Wilson[5]

[1]Department of Anthropology, Indiana University-Purdue University Indianapolis
[2]Department of Earth and Environmental Systems, Indiana State University
[3]Department of Anthropology, University of Indianapolis
[4]Cardno
[5]Department of Anthropology, Indiana University-Purdue University Indianapolis

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Correspondence: 413 Cavanaugh Hall, 425 University Blvd. Indianapolis, IN 46202

Email: gezoelle@iu.edu

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Abstract

Objectives: Since its inception, skeletally based paleodemographic research has emphasized the utility of biocultural models for interpreting the dynamic relationship between the sociocultural and ecological forces accompanying demographic transitions and shaping populations' health and well-being. While the demographic transition associated with the Neolithic Revolution has been a common focus in bioarchaeology, the present study analyzes human skeletal remains from a large 19th century cemetery in central Indiana to examine population dynamics during the second demographic transition, a period generally characterized by decreasing fertility rates and improvements in life expectancy. This study aims to identify the potential timing and interactions between the broad-scale socioeconomic changes and technological advancements characterizing the time period and documented changes in survivorship and fertility based on the age-at-death distributions.
Materials and Methods: This study uses three temporally distinct samples (AD 1827-1869; 1870-1889; 1890-1935) from the Bethel Cemetery (n = 503). Kaplan-Meier survival analyses with a log--rank tests are utilized to evaluate survivorship and mortality over time. Next, Cox proportional hazard analyses are employed to examine the interaction between sex and time as covariates. Finally, the D0-14/D ratio is applied to estimate fertility for each of the three temporally bounded cohorts.
Results: The Kaplan-Meier survival analyses and Cox proportional hazard modeling revealed statistically significant differences in survivorship between the three time periods. Age-specific mortality is shown to improve among adult females and males in this rural community over the course of the 19th and early 20th centuries, resulting in the increasing life expectancies associated with the second demographic transition. While mortality in early adulthood was common during the first time period and decreases thereafter, sex was not identified as a meaningful covariate. The proportion of juveniles in the three temporal samples indicate that fertility rates were higher than national averages for the better part of the 19th century and subsequently declined around the turn of 20th century for this community.
Conclusion: The results indicate temporal differences between the three periods, demonstrating increased survivorship and decreased mortality and fertility over time. These findings corroborate two key features of the second demographic transition characterized by the move from high rates of both fertility and mortality to reduced rates and a general easing of demographic pressures. The observed trends likely reflect improvements in health, coinciding the industrial advance and economic development within and around Indianapolis. While the socioeconomic factors characterizing the Industrial Revolution drove demographic shifts that parallel an equally important epidemiological transition, potential regional differences are discussed to highlight variability in the timing of demographic transitions. The paleodemographic methods utilized in this study demonstrate improved accuracy and efficacy, which ultimately advances researchers' potential to disentangle population-specific socioeconomic factors that may contribute to asymmetrical experiences of health and mortality.

1. Introduction

Utilizing a variety of datasets, human biologists, bioarchaeologists, and other researchers have routinely examined population dynamics derived from a variety of sources to explain shifts in human health and disease patterns, drawing upon demographic and epidemiological transition models as a framework for interpreting trends in past and contemporary societies (e.g., Gage, 1994; Wood, 1998; McCaa, 2002; Lee, 2003; Johnson-Hanks, 2008; Lesthaeghe, 2014; Schmidt and Sattenspiel, 2017). Among these researchers, Omran (1971) was the first to coin and utilize the epidemiological transition model to describe declining mortality from infectious diseases following the Industrial Revolution in the United States and Western Europe (Caldwell 2001; Gage, 2005). Placing Omran's classic model into a larger evolutionary framework, researchers now consider there to be a series of demographic and epidemiological transitions of varying intensity and length, from the first that coincided with the Neolithic Revolution, to the present and ongoing transition of emerging and reemerging infectious diseases (Barrett et al., 1998; Harper and Armelagos, 2010). In this expanded model, Omran's original transition is recognized as the second major one, involving a reduction in infectious disease-related deaths and increasing life expectancy (McKeown, 2009). In light of these demographic and epidemiological changes over the last two centuries in the United States and elsewhere, the present study focuses on the demographic dimensions of this second transition by conducting bioarchaeological analyses of survivorship, mortality, and fertility for a 19th century rural agrarian community from central Indiana (see Figure 1).

The contemporary relevance of both transition models and the documented demographic changes revolve around their potential for interpreting and understanding the dynamic and interdependent relationships among demographic, social, economic, and environmental factors, especially as they relate to public policy, migration, population forecasting, and the evolution and spread of disease (e.g., Caldwell, 2007; Harper and Armelagos, 2010; Fleischer et al., 2014; DeWitte, 2016). Today, as modern populations face circumstances similar to the first epidemiological transition, including zoonotic infections, considerable effort has been dedicated to interpreting the historic and contemporary patterns of subsistence, social organization, and migration that may signal the emergence and reemergence of infectious disease (Zuckerman, 2014; Zuckerman et al., 2014). The intensification of agriculture and increased sedentism, associated with the Neolithic Revolution are recognized as coinciding with the first major demographic and epidemiological transitions, which variably resulted in increased fertility and elevated mortality rates (Bocquet-Appel, 2002, 2011; Eshed et al., 2004; Wilson, 2014). While the intensity and speed of urbanization, social stratification, and globalization has increased since the Neolithic, the contemporary effects of these processes remain relatively similar (Moore, 2003). However, interpreting past demographic trends can be challenging given the absence of documentation in prehistory. As such, the analysis of human skeletal remains has been critical for examining trends in timing, elucidating the health trade-offs of urbanization, and identifying conditions that impacted the severity of past disease outbreaks and epidemics in various social and ecological contexts (e.g., Nagaoka and Hirata, 2007; DeWitte and Wood, 2008; DeWitte, 2010, 2014a; Zhang et al., 2016; Walter and DeWitte, 2017).

While archaeological sequences and skeletal samples have been critical to modeling the major demographic changes accompanying the shift from foraging to farming (e.g., Bocquet-Appel and Naji, 2006), in contrast, analyses of the second epidemiological transition have primarily relied on historical records given their general ubiquity for the 19th and early 20th centuries. The second demographic transition has been broadly characterized as involving increasing life expectancy at birth, decreasing age-specific mortality rates, and progressive declines in fertility rates throughout the latter half of the 19th and most of the 20th century in many western countries (Riley, 2001; Caldwell, 2007). Omran (1971) contended that the improvements in disease load and health during this transition particularly benefited the young, including infants and children, as well as reproductive-age women, resulting in improved survivorship. The general properties of this transition include declining mortality rates that were not immediately accompanied by reductions in the average number of children per woman, resulting in population growth rates between one and two percent during the time period in question (Livi-Bacci, 2007). Population growth was especially pronounced when, during this transition, the birth and death rates were imbalanced, a feature that is also believed to have characterized the Neolithic Demographic Transition (Bocquet-Appel, 2002, 2009, 2011; Gage and DeWitte, 2009). In addition, this second transition was characterized by stabilization of annual death rates in western countries by the mid-19th century. Given the interdependence of these demographic measures, life expectancy at birth (e_0) has profoundly improved from under 45 years in the early to mid-19th century to over 80 years today, especially among women in several western countries (Oeppen and Vaupel, 2002). Drawing on federal census records from 1850 onward, Haines (1994) provides crucial estimates of life expectancy and total fertility for Euro-Americans in the United States. In brief, life expectancy at birth hovered around 40 to 45 years during the mid-to-late 19th century, while fertility rates were steadily declining from 5.4 in 1850 to 3.6 in 1900. Unlike the demographic transition in Europe where reductions in mortality preceded those for fertility, Haines (1994) contends that fertility rates, posited as beginning between seven and eight live births per woman, were already in decline in the United States by the onset of the 19th century. Meanwhile, more precipitous gains in life expectancy beyond 50 years of age are characterized as a largely 20th century phenomenon. -

Collectively, these studies indicate that advances in industry and medicine instituted during the Industrial Revolution, led to improvements in sanitation and other public health measures that dramatically reduced mortality from infectious disease (Ellms, 1928; Meeker, 1972; Higgs, 1979; Okun, 1996; Cutter and Miller, 2005). Cutter and Miller (2005), for instance, used census data to demonstrate how the availability of clean water and sanitary facilities, such as city sewer systems, reduced total mortality by half and infant mortality rates by three-quarters in the United States. However, several studies that have developed models for smaller communities have questioned the assumed accuracy of historical records (Funari, 1999; Johnson, 1999), indicating they are limited and biased towards larger cities and national-level data sets for which more sources exist. While many of these studies generally corroborate assertions regarding the impact of public health initiatives on declining mortality during the 19th and 20th century (Preston, 1976; Preston and Haines, 1991; Gage, 1994, 2005), they contend that far less is understood about rural, low-income, and marginal regions for which documentation is piecemeal or entirely absent, thereby suggesting a different experience during the second demographic and epidemiological transition (Farmer, 1996; Higgs, 1973; Marinho et al., 2013). For example, Stattenspiel and Stoop's (2010) analysis of headstone data from the Columbia Cemetery in Columbia, Missouri demonstrated that the onset of major mortality shifts occurred in the late 1920s or early 30s, substantially later than similar changes in urban areas, including eastern cities and states. And yet, just knowing the numbers and ages of people who died may still not provide a clear picture of the health and disease experience of the once living population. Biased by a writer's discursive power, the contents of recorded histories often reflect privileged circumstances and potentially obscure or alter marginal experiences (Johnson, 1999), rendering interpretations of local-level changes incomplete (Higgs, 1973; Beemer, 2010; Koepke, 2014). In consolidating population-specific trends under an umbrella of aggregate data, the initial aim of these models to identify how and when shifts in mortality and fertility occurred is missed. The variety of socioecological conditions, especially those characterizing underrepresented populations and including the rural community in the present study, is critical for interpreting the forces that drive the speed and intensity of these transitions and provide a better understanding of the variation characterizing the second demographic transition.

Bioarchaeological and paleodemographic analyses can provide empirical data on health, mortality, and fertility patterns that expands the geographic and temporal scope of research on demographic and epidemiological transitions. Given that individuals cannot obscure their biological response to processes affecting individual health and the lived experience, such as disease, early childhood stress, and malnutrition, analyses of skeletal data can serve as an invaluable source for building a more balanced picture of the demographic change driven by biosocial and ecological variables (Krieger, 2005; DeWitte, 2014b). Deriving meaningful data from skeletal analyses, however, can be challenging given the inherent limitations of a mortuary context to accurately represent the once-living population, including the length of cemetery use, demographic non-stationarity, and the selective nature of mortality that results in the frailest in a given age cohort entering a death assemblage at higher rates than others (Wood et al, 1992; Waldron, 1994; Milner et al., 2008; DeWitte and Stojanowski, 2015; Milner and Boldsen, 2017). Additionally, considering the proximity of the second transition to the present, the availability of skeletal samples as data sources to assess demographic change is often limited. As such, the ability to consider bioarchaeological and textual data side-by-side render studies, such as the present one, invaluable.

Augmented by the wealth of regional- to national-level demographic data and vital statistics available for this time period, a primary objective of this study is to understand the potential of human skeletal remains and paleodemographic analyses to detect the aforementioned transition and inform our understanding of human biology and demography in the past. As part of the larger Bethel Cemetery Relocation Project (BCRP) undertaken in 2018 with input and feedback from descendants and community members (Peterson et al., 2019), the present study utilizes skeletal data from this 19th and early 20th century cemetery to analyze trends in survivorship, mortality, and fertility, while also assessing the divergence of our paleodemographic results from historical accounts and census records that capture the second demographic transition. Put simply, this study first examines how patterns of survivorship, mortality, and fertility changed, if at all, leading up to the height of Industrial Revolution. Second, we examine sex as a covariate with the goal of understanding to what degree a differential experience in mortality existed between females and males in this rural, agrarian community interring the deceased in their parish-associated cemetery. Third, we utilize a recently developed proportional measure of juveniles from skeletal samples (McFadden and Oxenham, 2018) to examine changes in total fertility rates (TFR) over time, comparing our results to national-level statistics on fertility for the time periods in question. Lastly, the present study aims to address several of the methodological issues and challenges raised by previous researchers regarding the analysis of cemetery samples (Bocquet-Appel and Masset, 1982; Buikstra and Konigsberg, 1985; Wood et al., 1992; DeWitte and Stojanowski, 2015), highlighting the benefits of newer age estimation and paleodemographic techniques, as well as a multidisciplinary approach.

2.Biocultural Context

2.1 Background

The skeletal sample analyzed in the present study is derived from the Bethel Cemetery, which was excavated in its entirety over 17 weeks during a 2018 mitigation project on the southwest side of Indianapolis, Indiana (Peterson et al., 2019). The excavation resulted in the assignment of 543 burial numbers. As depicted in the insets of Figure 1, 506 individuals were exhumed and underwent skeletal inventorying and analysis, while 24 were exhumed, but remained in concrete vaults. The remaining 13 burials were associated with graves lacking human skeletal remains, but including material culture, such as nails and small fragments of coffin wood. The Bethel Cemetery was in use between 1827 and 1935 and associated with the Bethel Methodist Episcopal Church, a congregation of Euro-American settlers to central Indiana. The cemetery is located some 11 km from the heart of Indianapolis, which was declared Indiana's capital in 1821, ultimately spurring economic growth in this region. The individuals and families interred at the Bethel Cemetery resided in Decatur Township with historical documentation for this area describing the community as agrarian and rural for most of the 19th century (Sulgrove, 1884). While parish and cemetery records are mostly lost or missing, it is reasonable to assume that members of the Bethel Methodist Episcopal Church community would have shared many of the experiences of other early central Indiana settlers.

During the early part of 19th century, Indiana's inexpensive land and fertile soils drew settlers to farm with the non-Native population of the state going from several thousand in 1800 to nearly a million by 1850. Social and economic opportunities were accompanied by several hardships, however, including harsh environments, a heavy disease burden, and physically demanding labor that challenged these early settlers to adapt (Sulgrove, 1884; Ferguson, 1893; Johnson, 1951; Daly, 2008). Daly (2008) notes that cholera outbreaks were a frequent occurrence in many smaller communities across Indiana between the 1830s and 1870s, attributing the elevated risk to shallow water wells and sewage contamination of drinking water. By the mid-to-late 19th century, Indiana like many Midwestern states, experienced significant economic growth and demographic change, at the heart of which was the railroad industry (Abbott, 1978; Simons and Parker, 1997). Industrialization and urbanization peaked between 1880 and 1929 and was characterized by new technologies in manufacturing and task-divided labor, which increased demand for a large labor force to maximize production (Phillips, 1968). Industrialization and urbanization reinforced one another, augmenting the growth of cities, including Indianapolis, as waves of immigrants concentrated in these urban centers for jobs and access to resources. Evidence of urbanization at the turn of the 20th century is demonstrated as the US Census recorded a mere 1,555 individuals residing in Decatur township, compared with the 117,328 people that occupied Indianapolis' urban Center township (US Census Bureau, 2010).

Even as cities became the new centers of American life, Indiana remained one of the nation's top agricultural producers (Butz, 1966; Baer, 2003; USDA Census of Agriculture, 2012). Connecting farm and factory maintained the bucolic aspects of rural communities with advances in agricultural technology allowing farmers to grow more using less labor (Baer, 2003; Peden, 2009). The isolation of agrarian communities, however, often meant differential access to resources (Phillips, 1968). Higgs (1973) has suggested that the mortality decline began in rural American around 1870, while in contrast a sustained decline in mortality did not take place in urban areas until after 1880 (Meeker, 1972). Urban centers characterized by crowding, social stressors, and poor air, food and water quality initially fostered high mortality compared to rural areas where land development and the mechanization of production lead to improved nutritional status and living standards (Haines,1977,1979b). But not all rural areas were similarly productive and over the next decade, urban mortality declined at a faster rate and health differences narrowed (Higgs, 1973). The late 19th century changes in social environments with regard to urbanization, industrialization, and improved living standards appear to have corresponded with the changing health status characterizing the second demographic and epidemiological transition (Meeker, 1972; Higgs, 1979; Preston and Haines, 1991). As mortality due to infectious disease transitioned to morbidity related chronic disease, rural areas were disproportionally affected, as the advantages of urban dwelling provided access to resources and opportunities that would signal improved health status (Elman and Myers, 1997).

2.2 Skeletal Sample

Skeletal preservation predictably varied from poor to very good and excellent among the 506 individuals from the Bethel Cemetery analyzed by bioarchaeologists from Indiana University-Purdue University Indianapolis (IUPUI) and the University of Indianapolis. The level of preservation was largely a function of several factors, including the location within the cemetery, a variable water table, type of coffin, the presence of a viewing pane, and the utilization of the coffins' shipping crates as a wooden vault. The collapse of the view panes, coffins, and wooden vault tended to result in very poor preservation of the scapulae, ribs, and vertebrae. With the records for the cemetery lost decades ago, erect and buried headstones (n = 151) were the only means of corroboration with the biological profiles described below. One-hundred and forty-four of the headstones were deemed to match the estimated biological profile, while seven headstones had been moved or fallen over and subsequently misplaced over another individual. In sum, over 70% of the individuals exhumed from the Bethel Cemetery originated from unmarked graves.

During the excavation, structure-from-motion (SfM) photogrammetry was used to document the state of preservation, coffin hardware, and location of associated material culture (Badillo et al., 2020). Given the large number of unmarked graves, the analysis of coffin hardware and personal effects buried with individuals was required to develop *terminus post quem* (TPQ) and *terminus ante quem* (TAQ) estimates for each burial. These temporal estimates enabled the division of the larger cemetery into three diachronic sub-samples of AD 1827-1869 (Period 1; n_1 = 261), AD 1870-1889 (Period 2; n_2 = 150), and AD 1890-1935 (Period 3; n_3 = 92). Three of the 506 burials with skeletal remains could not be attributed to a specific time period of cemetery use. Meanwhile, the variability in sub-sample size is a function of both the coffin hardware's temporal specificity and usage of the cemetery by parishioners. Assuming complete recovery during the 2018 excavations and the accuracy of temporal assignments for the three time periods, the rate of interment varied over time from 6.4 and 8.5 individuals per year for Period 1 and Period 2 to 2.5 individuals per year for Period 3. The reduced rate of interment during the final period of the cemetery's usage likely reflects the gradual decline of the parish and use of other local cemeteries by descendants in the late 19th and early 20th centuries.

To facilitate data collection in a timely manner prior to reburial in 2019 for the larger Bethel Cemetery Relocation Project, Osteoware 2.4 and the Sybase® Advantage Data Architect

SQL database were employed to record and score the skeletal inventory and analysis of each individual (Peterson et al., 2018). Osteoware is largely based on the methodologies described in *Standards for Data Collection from Human Skeletal Remains* (Buikstra and Ubelaker, 1994) with notable additions related to, for example, dental morphology. Each individual was evaluated for preservation, taphonomy, pathology, oral health, metric and non-metric cranial and post-cranial variation, and morphological characteristics and metrics related to age-at-death and sex as described below.

3. Materials and Methods

3.1 Age and Sex Estimation

Age-at-death estimation for juveniles from the Bethel Cemetery was contingent upon the relative stage of maturation of the individual (e.g., fetal vs. infant vs. child vs. adolescent), as well as skeletal and dental preservation. Age for fetal remains lacking a developing deciduous dentition was consistently estimated based on the dimensions of pars basilaris and pars lateralis of the occipital bone and pars petrosa of the temporal bone given their preservation at the Bethel Cemetery relative to other cranial and post-cranial skeletal elements. Given the durable nature of the dentition, crown and root development for the deciduous and permanent teeth was the primary means of estimating age at death following Moorrees and colleagues' (1963a, 1963b) stages that have been recently revised by AlQahtani and colleagues (2010). When the dentition was poorly preserved or absent, age was estimated based on long bone diaphyseal length and the pattern of epiphyseal fusion following the reference data presented by Scheuer and Black (2000) and Cunningham and colleagues (2016). As a performance evaluation for the juvenile age estimates from the Bethel Cemetery prior to paleodemographic analysis, a Pearson's correlation was conducted on the known and estimated ages for the 36 juveniles with headstones, revealing a strong association between the two ages ($r = 0.957$, $p = 0.000$). The high degree of accuracy and precision associated with juvenile age estimation is depicted in Figure 2, where the green circles reflect the known ages for the 36 juveniles and the whiskers depict the upper and lower bounds of the skeletal age estimate.

Transition analysis (Boldsen et al., 2002) was the primary means of estimating age at death for adults from the Bethel Cemetery. This technique, involving maximum likelihood estimation, orders individual components and sites within the pelvic girdle and cranium into senescent stages, requiring the analyst to estimate sex and ancestry, as well as a generalized mortality model, prior to the calculation of age. Transition analysis has been extensively used in paleodemographic and epidemiological research over the past 15 years given the technique's ability to more accurately estimate age in individuals older than 50 or 60 years at the time of death (e.g., Boldsen, 2007; DeWitte and Wood, 2008; DeWitte, 2010, 2014; Wilson, 2014; Walter and DeWitte, 2017). Validation studies of transition analysis have clearly demonstrated its effectiveness (Milner and Boldsen, 2012; Fojas et al., 2018). Likewise, given the aim of the present study to detect improvements in life expectancy associated with the second demographic transition, transition analysis represents a significant improvement over older age estimation techniques involving the pubic symphyses and auricular surfaces of the ilia. For the 108 individuals above 18 years of age at death with associated headstones, a second Pearson's correlation was performed to assess the degree of association between the known and estimated ages. A strong, but predictably weaker association (as compared with the juveniles) between known and estimated age was obtained ($r = 0.869$, $p = 0.000$), highlighting both the utility and limitations of transition analysis discussed by Milner and Boldsen (2012). In opposition to the pattern observed for the 36 juveniles of known age at the time of death, Figure 2 also highlights the imprecision associated with adult age estimation with the whiskers around the circles representing the 95% confidence intervals for age-at-death obtained while utilizing transition analysis.

Biological sex was the final dimension of data collection during the Bethel Cemetery Relocation Project of importance to the current study. When preserved, macroscopic features of the pelvic girdle were heavily weighted during sex estimation following the methodologies outlined in *Standards for Data Collection from Human Skeletal Remains* (Buikstra and Ubelaker, 1994), as well as MorphoPASSE (Klales et al., 2012, 2020). Cranial and mandibular morphology were also assessed using the standard ordinal scoring system with the probability of male or female calculated using Walker's (2008) logistic regression formulae. Lastly, measurements of the appendicular skeleton, including humeral and femoral head size and humeral epicondylar breadth, were used to corroborate the sex estimates from the pelvic girdle and cranium following Milner and Boldsen (2012b; also Boldsen et al., 2015). In total, 268 individuals above 15 years of age at the time of death were given sex estimates, including 57 females and 55 males for AD 1827-1869, 38 females and 40 males for AD 1870-1889, and 42 females and 36 males for AD 1890-1935.

3.2 Kaplan-Meier Survival Analysis and Cox's Proportional Hazard Modeling

Kaplan-Meier survival analyses and the associated log-rank tests were conducted in SPSS 26.0 to examine survivorship across the three time periods of cemetery interment and within time periods to assess differences in mortality between adult females and females. This non-parametric approach to survival analysis has been utilized previously in bioarchaeological research to, for example, examine early childhood stress and later mortality among adult females and males in medieval Denmark (Boldsen, 2007), pre- and post-Black Death survivorship in medieval London (DeWitte, 2014), linear enamel hypoplasias and survivorship among pre-Columbian Native peoples in midcontinental North America (Wilson, 2014), urban and rural populations in Roman Britain (Redfern et al., 2015), and high and low socioeconomic status children and adults from industrial-era London (DeWitte et al., 2016). While Kaplan-Meier survival analyses cannot simultaneously analyze multiple covariates, such as sex, skeletal lesion presence, and time period, the approach is widely used for censored data and smaller samples where parametric hazard modeling is statistically inappropriate. For the Kaplan-Meier survival analysis factoring time and examining the entirety of the human lifespan, 227 individuals for Period 1 (AD 1827-1869), 141 individuals for Period 2 (AD 1870-1889), and 105 individuals for Period 3 (AD 1890-1935) were analyzed from the Bethel Cemetery. Meanwhile, the second series of Kaplan-Meier survival analyses examining survivorship between females and males above 15 years of age at death within each time period included 57 females and 55 males for Period 1, 38 females and 40 males for Period 2, and 42 females and 36 males for Period 3.

To assess the interaction between time period and sex, Cox's proportional hazard modeling was utilized. In recent years, bioarchaeologists have deployed this semiparametric approach of regression analysis to examine mortality and survivorship for linear enamel hypoplasias among Jomon people in Japan (Temple, 2014), vertebral neural canal size and linear enamel hypoplasias in late medieval and post-medieval London (Watts, 2015), long bone length, sex, and status in industrial London (Hughes-Morey, 2016), rural versus urban contexts among adult males and females in medieval London (Walter and DeWitte, 2017), and urbanization in medieval Poland (Betsinger and DeWitte, 2017). In the current study, age-at-death served as the predicted variable in a backwards conditional method where the three time periods and biological sex were identified as potential explanatory variables. In this form of stepwise regression, variables lacking explanatory power are iteratively removed, resulting in the most parsimonious model for, in this instance, survivorship. A total of 268 individuals that were 15 years of age or above at the time of death and reliably estimated to be adult females ($n_F = 137$) and males ($n_M = 131$) across the three time periods ($n_1 = 112$, $n_2 = 78$, $n_3 = 78$) of cemetery interments were included in the Cox's proportional hazard modeling.

3.3 Fertility Proxy

Previous studies have demonstrated a strong correlation between the proportion of juveniles in cemetery samples and the once-living population's birth and growth rates (Bocquet-Appel, 2002; Bocquet-Appel and Naji, 2006; Kohler et al., 2008). Given that age-at-death distributions in cemetery samples have been discussed as more sensitive to changes in fertility than to mortality fluctuations of the same scale, it is important to consider the role that crude birth and death rates had on population growth (Sattenspiel and Harpending, 1983). Previous research has demonstrated the relationship between fertility and mortality, such that as mortality increases the result will be an increase in fertility. However, estimating fertility using cemetery samples requires cautious interpretation, as the potential for bias may arise from multiple sources including inaccurate age estimation (Buikstra et al., 1986), infant underenumeration (Gordon and Buikstra, 1981), and inappropriately assuming demographic stationarity and population stability (Wood et al., 1992). Several fertility proxies have been developed to address these issues, thereby necessitating careful analysis of a skeletal sample's structure and history to select the appropriate proxy to generate the best fitting model. Though it is out of the scope of this study to discuss the variety of techniques and the specific analytical concerns each addresses (Bocquet-Appel and Masset, 1977; Buikstra et al., 1986; Bocquet-Appel, 2002; Robbins, 2011), several ratios were considered for their applicability to the Bethel Cemetery sample prior to selection.

McFadden and Oxenham (2018) used real, non-stationary populations to develop a linear regression that demonstrated the predictive capability of their ratio (D0-14/D) and known fertility rates for 52 countries with varying growth rates ($r = 0.848$). The D0-14/D ratio is a proportional measures of those between birth and 14 years of age over all individuals recovered from a cemetery sample, excluding fetal remains. While other methods for measuring fertility have focused on alleviating the problem of infant underenumeration in skeletal samples, the D0-

14/D ratio differs in requiring a well-represented infant and young child categories. The D0-14/D ratio argues for improved correlation resulting from the inclusion of the 0-4 age category due to this cohort's high sensitivity to changes in fertility. As the Bethel Cemetery sample assumes good juvenile preservation and representation based on its large infant and child sub-samples shown in Table 1, the D0-14/D ratio was employed to estimate fertility. To test for significance, the present study computes 95% comparison intervals following the statistical procedure outlined by Buikstra and colleagues (1986) and derived from Sokal and Rohlf (1981). Comparison intervals are utilized as a method for multiple comparisons of proportions (i.e., D0-14/D), while controlling for the overall level of significance. This is opposed to confidence intervals, which constitute interval estimates for the location of true means.

4. Results

As shown in Table 2, the Kaplan-Meier survival analysis and associated log-rank test examining those from birth to old age across the three periods of Bethel Cemetery's usage revealed significant differences in survivorship and the age-at-death distributions. During the first four decades of use, a considerable number of infants, children, adolescents, and young adults were interred in Bethel Cemetery with the mean and median age-at-death estimates reflecting this pattern. A similar pattern exists over the next two decades (i.e., Period 2), wherein infants and children represent some 40% of the mortality distribution. However, as depicted in the survival curves for the three time periods in Figure 3, distinct differences exist in the cumulative survivorship between Period 1 and the latter two during late adolescence and early adulthood, reflecting improved survivorship among these cohorts and older ones by the late 19th century. Meanwhile, the skewness of the distributions is reflected in the discrepancy between the mean and median age-at-death estimates for all three time periods at Bethel Cemetery shown in Table 2. During Periods 1 and 2, the lower median age-at-death estimates are strongly influenced by the fertility rates that are discussed below. In opposition, the higher median age-at-death estimate during Period 3 is likely a function of reduced age-specific mortality rates, decreasing fertility, and a reduced interment rate during the late 19th and early 20th centuries.

In the second series of Kaplan-Meier survival analyses, sex-based survivorship among adults older than 15 years of age at the time of death was examined for each time period at the Bethel Cemetery. As seen in Table 3, no significant differences in survivorship were detected with Figure 4 depicting the similarity between female and male mortality patterns over time. While comparable within the time periods of cemetery usage, Figure 4 illustrates the steady relaxation of age-specific mortality over time. Early adult mortality was high among both sexes during the cemetery's early use, but relatively negligible in Periods 2 and 3, suggesting the hazards associated with mortality in this community changed for both sexes during the demographic transition. This pattern is also reflected in mean and median age-at-death estimates in Table 3 with e_{15} for females and males moving from the lows 40s in the early-to-mid 19th century to the 50s by the late 19th century and 60s thereafter.

The Cox's proportional hazard modeling of adult females and males above 15 years of age at the time of death across the three time periods of cemetery usage was statistically significant (-2 Log Likelihood = 2431.349, X^2 = 46.771, df = 3, p = 0.000). Paralleling the results of the survival analyses, the backward stepwise regression removed sex from the model between Step 1 and 2 of the analysis as shown in Table X. The second model that included time as the only explanatory variable was statistically as parsimonious as the former one (-2 Log Likelihood = 2431.448, $X^2 = 46.682$, $df = 2$, $p = 0.000$), thereby indicating that sex does not significantly contribute to the variation in mortality observed within the Bethel Cemetery. Figure X depicts the survivorship between the three time periods for adults. From late adolescence onward, the age-specific risk of mortality is attenuated across the three time periods. While the velocities (*aka* slope) of the survival curves resemble each other, fewer individuals, irrespective of sex, are dying in late adolescence, as well as young and middle adulthood, during the second and third time periods, resulting in increased life expectancy and thereby corroborating one aspect of the second demographic transition documented via census data and other sources.

The D0-14/D ratios for the three periods of cemetery use and the calculated total fertility rates are presented in Table 5 alongside national averages for the same time intervals derived from Haines (2008). While overlap is reflected in the 95% comparison intervals, the D0-14/D ratios decline with each consecutive time period of use for the Bethel Cemetery. The decline between the first and second time periods is slight (9% decrease) with a more significant decline by Period 3 (31% decrease). These results are consistent with previous findings, indicating a drop in birthrates and probable improvements in survivorship. When compared to the estimates from Haines (2008), the total fertility rates derived from the D0-14/D ratios across all three time periods at the Bethel Cemetery remained higher with their decline being slower than national averages, ultimately suggesting variance in the second demographic transition.

5. Discussion

Despite the utility and accessibility of historical records for modeling the second demographic transition, the results of these investigations have been relatively broad with regards to demography, health, and well-being, while inadequately addressing fine-scale differences within and between populations. The present paleodemographic analysis of a rural, 19th century community from central Indiana provides better estimates of mortality, fertility, sex-specific survivorship, and life expectancy, ultimately informing our understanding of this second major transition in human population dynamics. Utilizing a multidisciplinary approach that integrates bioarchaeological research with parallel archaeological work and information from historical accounts, the present study illuminates regional and temporal differences that would otherwise remain obscured. The paleodemographic models utilized in the present study to examine survivorship and fertility demonstrate a strong correlation between the study's skeletal sample and known data derived from the once-living population. These results have proven useful in capturing demographic trends, as well as identifying divergent patterns of survivorship, mortality, and fertility. However, as a part of our more recent past, the accessibility of archaeological samples for analysis dating to this second demographic transition has been limited. As such, the few bioarchaeological studies that do exist (DeWitte, 2014b; Perry, 2014; Nystrom, 2014; Western and Bekvalac, 2017), including the present one, are critical for enhancing our understanding of the social and ecological conditions that characterized the second demographic and epidemiological transition and variably shaped populations' experiences related to health and disease.

The present study compared the age-at-death distributions between three temporally distinct periods of the Bethel Cemetery, demonstrating patterns of survivorship and mortality consistent with historically documented trends. As anticipated with second demographic transition models, improvements in survival, as indicated by each consecutive age-at-death distribution, demonstrated significant increases in the proportion of older adults (i.e., Table 1), which was corroborated by each Kaplan-Meier survivorship analysis presented in Tables 2 and 3. While appreciating the steadily declining mortality rates, specifically adult mortality, it is important to consider factors, such as migration, which may off-set these distributions. As existing historical documents indicate (Sulgrove, 1884), the social and economic circumstances characterizing the community during the earlier parts of the cemetery's use would have likely drawn younger adults and their children to migrate to and settle the township. As such, we would expect an increased proportion young adults relative to older adults in the earlier part of the cemetery's history. The increasing proportion of old adults, when accompanied by decreasing proportions of young and middle adults within and between consecutive time periods, suggests that the larger conclusions made here about improvements in adult survivorship are parsimonious with models for the second demographic transition where the force of mortality eased across the human lifespan.

While an important contribution of the present study was the ability to generate a paleodemographic model that accurately captured the demographic processes characteristic of the second demographic transition, of equal importance are the subtle divergences from prior census-derived analyses. Previous second transition models suggest that, as survivorship increased and mortality from infectious disease declined, there were simultaneous declines in fertility (Haines, 1979a, 1980 1998, Hirschman, 1994). Though the present study's hazard analysis demonstrates steadily declining mortality and improved survivorship, the Bethel Cemetery sample's D0-14/D ratios demonstrate minor changes in fertility and higher rates relative to recorded state-wide and national averages (U.S. Bureau of the Census, 1975;Yasuba, 1962; Modell, 1971; Vinovskis, 1976, Haines et al., 2000). At present, the relationship between changes in mortality versus changes in fertility for explaining the demographic transition are not well understood (Sattenspiel and Stoops, 2010). Several demographic studies have examined the role of socioeconomic and ecological factors that may benefit limiting fertility (Gillespie et al., 2007; Lawson and Mace, 2010; Lawson and Mulder, 2016), but the empirical data to explore these trends among small, rural communities is difficult to locate. Researchers have suggested that there were differences in the timing and degree of change across and within urban and rural areas (Condran and Crimmins 1980; Haines 1977,1979b; Higgs, 1973; Hacker, 2003), population subgroups (Condran, 1984), age (Meeker, 1972), and ethnicity (Haines 1977; Condran 1984), often finding that fertility in the 19th century tended to be higher among farming communities as compared with others (Easterlin, 1971; Atack and Bateman, 1987; Steckel, 1994). The results of the current study support these findings, further evidencing the need to reexamine interpretations of the second demographic transition for their uniformity.

Much like the inherent bias related to historical accounts and records, addressing bioarchaological studies' samples, methods, and the extent to which these data can be considered to reflect once-living populations has been a persistent concern in the field (Wood et al., 1992; Goodman and Martin, 2002; Walker et al., 2009). For example, are we able determine whether improvements in health and declining mortality were directly associated with changes brought on by the Industrial Revolution, or might they be artifacts of migration or changes in the cemetery's use? As discussed, the variation in this study's age-at-death distributions would be considered to reflect manipulation from migration alone in, for instance, the unlikely scenario that migrants had primarily consisted of older adults. Similarly, as fertility in this study appears to have neither influenced nor been affected by changes in survivorship and mortality, the inconsistency with rates indicated by historical records may illuminate a different experience for rural families. The challenges that accompany fertility measurements based on archaeological samples, however, have driven researchers to develop and apply new estimation methods that take into account sample-specific potentials for biases. Buikstra and colleagues (1986), for example, demonstrated a proxy (D30+/D5+) for estimating fertility among eight Woodland and Mississippian skeletal samples from west-central Illinois that contradicted previous models for the Neolithic Demographic Transition. The results suggest that demonstrated increases in fertility were the product of a dietary shift to high carbohydrate resources rather than the result of increased mortality (Buikstra et al., 1986). Recognizing the region-specific complexity of intervening variables, the aforementioned study, congruent with the present findings, is that while previous transition models have captured a broad picture of fertility patterns, interpreting regional variability in fertility is critical to generate and enhance models that explain said change. Similarly, selecting and statistically supporting the most appropriate fertility proxy was a priority of the present study, further supporting the suggestion that the divergence in results likely reflects urban-rural difference, rather than a source of methodological bias or error.

An additional consideration of this study, like that of other paleodemographic research, is the extent to which changes in mortality or fertility are an accurate indicator of health and can reflect the variety of forces driving these shifts. There are several factors related to population health status that researchers have explored as shaping demographic transitions, such as changing social conditions and health practices. Numerous studies, for instance, have suggested that changes in health that came subsequent to the implementation of specific public health and sanitation measures during the Industrial Revolution (Preston 1976; Higgs, 1979; Gage, 1994). As has become increasingly evident, a single agent for causation is unlikely given the variability both within and between populations (Farmer, 1996; Krieger et al., 2005; Sattenspiel, 2011). An aim of the present research was to contribute to the development of a framework for methodologically identifying and examining covariates that may contribute to this differential experience. Similar to the present study's results exhibiting variable shifts in fertility patterns between rural and urban communities, paleodemographic models of age-at death distributions can address for whom and in what geographic contexts changes in health and mortality arose differently. For example, the second demographic transition has been generally characterized by increased sex differentials in mortality, interpreted to likely reflect changing socioeconomic and environmental conditions as both men and women's health saw early improvement, subsequently marked by asymmetrically timed gains (Vaupel et al., 1979; Mooney, 2002). Prior to the second transition, demographic models have interpreted health and census data to demonstrate higher rates of mortality initially for women, with subsequent improvements in social status and reproductive technologies generating more forceful decline in mortality rates (Retherford, 1975). Inversely, these models suggest males to be increasingly disadvantaged with respect to mortality and longevity owing to a higher susceptibility to the chronic conditions that characterize the latter part of the second transition (Preston, 1976). The results of the present study, however, did not find any significant differences in adult mortality based on sex within or between time periods. These findings, which contradict expected sex differentials, advance our understanding of the diversity surrounding demographic transitions, significantly contributing to the field by demonstrating methods through which studies can tease apart numerous covariates.

The extent to which differentials in health status change and reflect biological, environmental, and social structures over time may help elucidate the conditions under which demographic transitions occur. This study contributes to the theoretical framework for examining the second transition, considering jointly primary source information and skeletal data to interpret geographic and demographic differences that may have shaped population dynamics. Despite the aforementioned limits and inherent biases associated with mortuary contexts, archaeological recovery, and skeletal analyses, this study's application and statistical evaluation of newer methods offers promising implications for improved accuracy and more visible efficacy of paleodemographic studies for modeling the second transition.

6. Conclusion

Previous research using large data sets from major US cities has illustrated the significant impact of the second demographic and epidemiological transition in the United States, but the resulting homogeneous picture obscures complexity and variance made evident by the regionally diverse experiences of how and when these changes occurred. The present study analyzed skeletal data to interpret trends is mortality, fertility, and longevity among a primarily agrarian community in rural Indiana, but contemporary to the Industrial Revolution in neighboring Indianapolis. The study's empirical data, measured against known historical accounts, is generally analogous, but underscores some more nuanced, rural-urban differences. Though the results do not generate assertions regarding the specific social and ecological forces shaping differential experience, they contribute to a foundation for future, complementary research. In growing the field's body of evidence, this study suggests that a multidisciplinary approach may provide opportunities for inferring causation and measuring the impact of forces governing the variable trajectories of demographic transitions. Moreover, this study carries contemporary relevance as modern populations are on the brink of a third transition characterized by decreasing fertility, increasing life expectancy, continued social stratification, increased globalization, and indiscriminate use of antibiotics. These conditions have paved the way for increased transmission and pathogen virulence, giving rise to what these models have long predicted to be largely devastating global pandemics. This study suggests that solidifying a methodological approach for modeling these transitions and disentangling social determinates of population dynamics and health can allow future research to more comprehensively address the consequences of inequality, irresponsibility. and the return of infectious disease crises, potentially offering suggestions for health crisis mitigation.

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AUTHOR CONTRIBUTIONS

GEZ and JJW designed and executed the paleodemographic components of the study. BLD conducted the analyses of the coffin hardware and associated artifacts to determine temporal affiliations. RP, JJW, and CWS oversaw the field investigations, exhumations, and reburial process, while JJW and CWS oversaw the skeletal analyses. GEZ and JJW analyzed the skeletal data and drafted all parts of the manuscript.

ORCID

Jeremy J. Wilson https://orcid.org/0000-0002-9968-438X

Christopher W. Schmidt https://orcid.org/0000-0002-4911-0660

REFERENCES

Abbott, C. (1978) Indianapolis in the 1850s: Popular Economic Thought and Urban Growth. *Indiana Magazine of History* 74:4, p.293–315.

AlQahtani, S., Hector, M., & Liversidge, H. (2010). Brief communication: the London atlas of human tooth development and eruption. *American Journal of physical anthropology*, *142*(3), 481-490.

Atack, J and Batman, F. (1987) *To Their Own Soil: Agriculture in the Antebellum North*. Ames, Iowa. Iowa State University Press

Baer, M. (2003) From tribal and Family Farmers to Part-time and Corporate Farmers: two hundred Years of Indiana Agriculture. *Centennial Farms of Indiana*. Edited by Baer, M; Breen, K. and Judith Q. McMullen. Indianapolis: Indiana Historical Society Press.

Barrett, R., Kuzawa, C., McDade, T., & Armelagos, G. (1998). Emerging and re-emerging infectious diseases: the third epidemiologic transition. *Annual review of anthropology*, *27*(1), 247-271.

Betsinger, T. K., & DeWitte, S. (2017). Trends in mortality and biological stress in a medieval polish urban population. *International journal of paleopathology*, *19*, 24-36.

Bocquet-Appel, J. P. (2002). Paleoanthropological traces of a Neolithic demographic transition. *Current Anthropology*, *43*(4), 637-650.

Bocquet-Appel, J. P. (2009). The demographic impact of the agricultural system in human history. *Current Anthropology*, *50*(5), 657-660.

Bocquet-Appel, J. P. (2011). The agricultural demographic transition during and after the agriculture inventions. *Current Anthropology*, *52*(S4), S497-S510.

Bocquet-Appel, J. P., and C. Masset. 1977. Estimateurs en pale´ode´mographie. L'Homme 17(4):65–90.

Bocquet-Appel JP and Masset C. (1982) Farewell to paleodemography. *Journal of Human Evolution* 11:321–333.

Bocquet-Appel, J.-P., and S. Naji. 2006. Testing the hypothesis of a worldwide Neolithic demographic transition. Current Anthropology 47:341–65.

Boldsen JL, Milner GR, Konigsberg LW, Wood JW. (2002) Transition analysis: A new method for estimating age from skeletons. In: Hoppa RD and Vaupel JW, editors. Paleodemography: Age distributions from skeletal samples. Cambridge: Cambridge University Press. p 73–106

Boldsen, J. L. (2007). Early childhood stress and adult age mortality—a study of dental enamel hypoplasia in the medieval Danish village of Tirup. *American Journal of Physical Anthropology*, *132*(1): 59-66.

Boldsen, J. L., Milner, G. R., & Boldsen, S. K. (2015). Sex estimation from modern American humeri and femora, accounting for sample variance structure. *American journal of physical anthropology*, *158*(4), 745-750.

Buikstra, J. E., & Konigsberg, L. W. (1985). Paleodemography: critiques and controversies. *American anthropologist*, *87*(2), 316-333.

Buikstra, J. E., Konigsberg, L. W., & Bullington, J. (1986). Fertility and the development of agriculture in the prehistoric Midwest. *American Antiquity*, *51*(3), 528-546.

Buikstra J., & Ubelaker D, editors. (1994) Standards for data collection from human skeletal remains: Proceedings of a seminar at the field museum of natural history (Arkansas archaeology research series 44). Fayetteville: Arkansas Archeological Survey Press.

Butz, E. (1966). Agriculture—An industry in Evolution. In: Carmony, D, editor. Indiana: A Self-Appraisal. Bloomington: Indiana University Press

Caldwell, J. C. (1991). Major new evidence on health transition and its interpretation. *Health transition review*, pp. 221-229.

Caldwell, J. C. (2001). Population health in transition. *Bulletin of the World health Organization*, *79*, pp.159-160.

Caldwell, J. C. (2006). The Analytical Approach. In *Demographic Transition Theory.* pp. 3-19. Springer, Dordrecht.

Caldwell, J. C. (2007). *Demographic transition theory*. Springer Science & Business Media.

Caselli, G. (1996). National differences in the health transition in Europe. *Historical Methods: A Journal of Quantitative and Interdisciplinary History*, *29*(3), 107-125.

Condran, G. and Crimmins, E. (1980) Mortality differentials between rural and urban areas of states in the Northeastern United States, 1890-1900. *Journal of Historical Geography.* 6: 27-54

Condran, G. (1984) An evaluation of estimates of under-enumeration in the census and the age pattern of mortality in Philadelphia, 1880. *Demography* 21: 53-69.

Cunningham, C., Scheuer, L., & Black, S. (2016). *Developmental juvenile osteology*. Academic press.

Cutter, D. and Miller, G. (2005) The role of public health improvements in health advances: the twentieth century United States. *Demography* 42:1–22.

Daly, W.J. (2008). The Black Cholera comes to the Central Valley of America in the 19th century- 1832, 1849, and beyond. *Transactions of the American Clinical and Climatological Association,* 119: 143-153.

DeWitte, S. N. (2010). Sex differentials in frailty in medieval England. *American Journal of Physical Anthropology*, *143*(2), 285-297.

DeWitte, S. N. (2014a). Mortality risk and survival in the aftermath of the medieval Black Death. *PloS one*, *9*(5).

Dewitte, S. N.(2014b). Modeling the second epidemiologic transition in London: patterns of mortality and frailty during industrialization. *Modern Environments and Human Health: Revisiting the Second Epidemiologic Transition*, 35-53.

DeWitte, S. N. (2016). Archaeological evidence of epidemics can inform future epidemics. *Annual Review of Anthropology*, *45*, 63-77.

DeWitte, S. N., & Stojanowski, C. (2015). The osteological paradox 20 years later: past perspectives, future directions. *Journal of Archaeological Research*, *23*(4), 397-450.

DeWitte, S. N., & Wood, J. W. (2008). Selectivity of Black Death mortality with respect to preexisting health. *Proceedings of the National Academy of Sciences*, *105*(5), 1436-1441.

DeWitte, S. N., Hughes-Morey, G., Bekvalac, J., & Karsten, J. (2016). Wealth, health and frailty in industrial-era London. *Annals of human biology*, *43*(3), 241-254.

Easterlin, R. A. (1971). Does human fertility adjust to the environment?. *The American Economic Review*, *61*(2), 399-407.

Ellms, J. (1928) Water purification. 2nd ed. New York: McGraw-Hill.

Elman, C. and Myers, G. (1997) Age and sex differentials in morbidity at the start of an epidemiological transition. *Social Science and Medicine*. 45: 943-56.

Eshed, V., Gopher, A., Gage,T., and Hershkovitz, I. Has the transition to agriculture reshaped the demographic structure of prehistoric populations? New evidence from the Levant. *American Journal of Physical Anthropology*: The Official Publication of the American Association of Physical Anthropologists 124, no. 4 (2004): 315-329

Farmer, P. (1996). On suffering and structural violence: A view from below. *Daedalus*, *125*(1), 261-283.

Farmer, P. (1996). Social inequalities and emerging infectious diseases. *Emerging infectious diseases*, *2*(4), 259.

Ferguson, C. (1893); Reminiscences of a journey to indianapolis in the year 1836. Indiana Historical Society Publications. 2:9, p.2-25

Fleischer, N., McKeown, R., & Zuckerman, M. K. (2014). The second epidemiologic transition from an epidemiologist's perspective. *Modern environments and human heath: revisiting the second epidemiologic transition. Hoboken, NJ: Wiley-Blackwell*, 353Á69.

Fojas, C. L., Kim, J., Minsky-Rowland, J. D., & Algee-Hewitt, B. F. (2018). Testing inter-observer reliability of the Transition Analysis aging method on the William M. Bass forensic skeletal collection. *American journal of physical anthropology*, *165*(1), 183-193.

Funari, P. (1999). Historical Archaeology from a world perspective. *Historical Archaeology: Back From the Edge.* Eds. Funari, P., Hall, M., Jones, S. pp1-20. London: Routledge.

Gage TB. 1988. Mathematical hazard models of mortality: an alternative to model life tables. Am J Phys Anthropol 76:429–441.

Gage TB. 1991. Causes of death and the components of mortality: testing the biological interpretations of a competing hazards model. Hum Biol 3:289–300.

Gage, T. (1994) Population variation in cause of death: level, gender and period effects. *Demography*. 31, 263-288.

Gage TB. 2005. Are modern environments really bad for us? Revisiting the demographic and epidemiologic transitions. Yearb Phys Anthropol 48:96–117

Gage, T. B., & DeWitte, S. (2009). What do we know about the agricultural demographic transition?. *Current anthropology*, *50*(5), 649-655.

Gillespie, D., Ahmed, S., Tsui, A., & Radloff, S. (2007). Unwanted fertility among the poor: an inequity?. *Bulletin of the World Health Organization*, *85*, 100-107.

Goodman, A. H., & Martin, D. L. (2002). Reconstructing health profiles from skeletal remains. *The backbone of history: Health and nutrition in the Western Hemisphere*, *2*, 11.

Gordon, C. C., & Buikstra, J. E. (1981). Soil pH, bone preservation, and sampling bias at mortuary sites. *American Antiquity*, *46*(3), 566-571.

Hacker, J. D. (2003). Rethinking the “early” decline of marital fertility in the United States. *Demography*, *40*(4), 605-620.

Haines, M.R. (1977) Mortality in nineteenth century America: Estimates from New York and Pennsylvania census data, 1865 and 1900. *Demography* 14:311-31.

Haines, M. R. (1979a). *Fertility and occupation: population patterns in industrialization*. Academic Pr.

Haines, M.R. (1979b) The use of model life tables to estimate mortality for the United States in the late 19th Century. *Demography* 16:289-312.

Haines, M. R. (1980). Fertility and marriage in a nineteenth-century industrial city: Philadelphia, 1850–1880. *The journal of economic history*, *40*(1), 151-158.

Haines, M. R. (1994). *The population of the United States, 1790-1920* (No. h0056). National Bureau of Economic Research.

Haines, M. R. (1996). Long-term marriage patterns in the United States from colonial times to the present. *The History of the Family*, *1*(1), 15-39.

Haines, M. R. (1998). The relationship between infant and child mortality and fertility: Some historical and contemporary evidence for the United States. *From death to birth: Mortality decline and reproductive change*, 227-253.

Haines, M. R., Haines, M. R., & Steckel, R. H. (Eds.). (2000). *A population history of North America*. Cambridge University Press.

Harper, K., & Armelagos, G. (2010). The changing disease-scape in the third epidemiological transition. *International journal of environmental research and public health*, *7*(2), 675-697.

Higgs, R. (1973) Mortality in rural America 1870-1920: estimates and conjectures. *Explorations in Economic History* 10:177- 96.

Higgs, R. (1979) Cycles and trends of mortality in 18 large American cities, 1871-1900. *Explorations in Economic History* 16:381-408.

Hirschman, C. (1994). Why fertility changes. *Annual review of sociology*, *20*(1), 203-233.

Hughes-Morey, G. (2016). Interpreting adult stature in industrial London. *American Journal of Physical Anthropology*, *159*(1), 126-134.

Johnson, H. (1991). *A Home in the Woods* (Vol. 16, No. 2). Indiana University Press.

Johnson, O. (1951). A home in the woods; Oliver Johnson's reminiscences of early Marion County, as related by Howard Johnson. *Indianapolis, Indiana Historical Society*, 143-234.

Johnson, F. L. (1999). *Speaking culturally: Language diversity in the United States*. Sage.

Johnson-Hanks, Jennifer. (2008). Demographic transitions and modernity. Annual review of anthropology, 37, 301-315.

Klales, A. R., Ousley, S. D., & Vollner, J. M. (2012). A revised method of sexing the human innominate using Phenice's nonmetric traits and statistical methods. *American journal of physical anthropology*, *149*(1), 104-114.

Klales, A. R. (2020). MorphoPASSE: Morphological pelvis and skull sex estimation program. In *Sex Estimation of the Human Skeleton* (pp. 271-278). Academic Press.

Koepke, N. (2014). The wider background of the second transition in Europe. Information from skeletal material. *Modern Environments andHuman Health. Revisitingthe SecondEpidemiological Transition*, 55-80.

Kohler, T. A., Glaude, M. P., Bocquet-Appel, J. P., & Kemp, B. M. (2008). The Neolithic demographic transition in the US Southwest. *American Antiquity*, *73*(4), 645-669.

Krieger, N. (2005). Embodiment: a conceptual glossary for epidemiology. *Journal of Epidemiology & Community Health*, *59*(5), 350-355.

Krieger, N., Smith, K., Naishadham, D., Hartman, C., & Barbeau, E. M. (2005). Experiences of discrimination: validity and reliability of a self-report measure for population health research on racism and health. *Social science & medicine*, *61*(7), 1576-1596.

Lawson, D. W., & Mace, R. (2010). Optimizing modern family size. *Human Nature*, *21*(1), 39-61.

Lawson, D. W., & Borgerhoff Mulder, M. (2016). The offspring quantity–quality trade-off and human fertility variation. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *371*(1692), 20150145.

Lee, Ronald. 2003. "The Demographic Transition: Three Centuries of Fundamental Change." Journal of Economic Perspectives, 17 (4): 167-190.

Lesthaeghe, Ron. (2014). The second demographic transition: A concise overview of its development. Proceedings of the National Academy of Sciences, 111(51), 18112-18115.

Livi-Bacci, M. (2007). *A Concise History of World Population* (4th Edition). Malden, MA: Blackwell Publishing.

Marinho, F. M., Soliz, P., Gawryszewski, V., & Gerger, A. (2013). Epidemiological transition in the Americas: changes and inequalities. *The Lancet*, *381*, S89.

McCaa, R. (2002). Paleodemography of the Americas. *The backbone of history: health and nutrition in the Western Hemisphere*, 94-124.

McFadden, C., & Oxenham, M. F. (2018). The D0-14/D ratio: A new paleodemographic index and equation for estimating total fertility rates. *American journal of physical anthropology*, *165*(3), 471-479.

McKeown, R. E. (2009). The epidemiologic transition: changing patterns of mortality and population dynamics. *American journal of lifestyle medicine*, *3*(1_suppl), 19S-26S.

Meeker, E. (1972) The Improving Health of the United States, 1850-1915. *Explorations in Economic History* 9:353-74

Meyer, D. (1990) The Rise of the Industrial Metropolis. *Social Forces* 68:731-52

Milner, G. R., Wood, J. W., & Boldsen, J. L. (2008). Advances in paleodemography. *Biological anthropology of the human skeleton*, 561-600.

Milner, G. R., & Boldsen, J. L. (2012a). Transition analysis: A validation study with known-age modern American skeletons. *American Journal of Physical Anthropology*, *148*(1), 98-110.

Milner, G. R., & Boldsen, J. L. (2012b). Humeral and femoral head diameters in recent white American skeletons. *Journal of forensic sciences*, *57*(1), 35-40.

Milner, G. R., & Boldsen, J. L. (2017). Life not death: Epidemiology from skeletons. *International journal of paleopathology*, *17*, 26-39.

Modell, J. (1971). Family and fertility on the Indiana frontier, 1820. *American Quarterly*, *23*(5), 615-634.

Mooney, G. (2002). Shifting sex differentials in mortality during urban epidemiological transition: the case of Victorian London. *International Journal of Population Geography*, *8*(1), 17-47.

Moore, J. W. (2003). The Modern World-Systemas environmental history? Ecology and the rise of capitalism. *Theory and Society*, *32*(3), 307-377.

Moorrees CFA, Fanning EA, Hunt EE Jr. 1963a. Formation and resorption of three deciduous teeth in children. Am J Phys Anthropol 21:99-108.

Moorrees CFA, Fanning EA, Hunt EE Jr. 1963b. Age variation of formation stages for ten permanent teeth. J Dent Res 42:1490-1502.

Nagaoka, Tomohito, and Kazuaki Hirata. "Reconstruction of paleodemographic characteristics from skeletal age at death distributions: perspectives from Hitotsubashi, Japan." American journal of physical anthropology 134, no. 3 (2007): 301-311.

Nystrom, K. C. (2014). The Bioarchaeology of Structural Violence and Dissection in the 19th-Century United States. *American Anthropologist*, *116*(4), 765-779.

Omran, A.R. (1971) The epidemiological transition: a theory of the epidemiology of population change *Milbank Memorial Fund Quarterly* 49, 509-538.

Oeppen, J., & Vaupel, J. W. (2002). Broken limits to life expectancy.

Okun DA. 1996. From cholera to cancer to cryptosporidiosis. J Environ Eng 6:453–458.

Peden, R. (2009) *Rural Free: A Farmwife's Almanac of Country Living*. New York: Alfred A. Knopf, 1961. Reprint, Bloomington: Indiana University Press

Perry, M. A. (2014). Tracking the second epidemiological transition using bioarchaeological data on infant morbidity and mortality. *Modern Environments and Human Health: Revisiting the Second Epidemiological Transition, Wiley Blackwell, Hoboken, NJ*, 225-241.

Peterson, R.; B. Drew; K. Settle; J. Okray; J.J. Wilson; C.W. Schmidt; M. Hoffman; G.E. Zoeller; A.M. Powell; G. Bocko. 2019. *Preliminary Report on the Bethel Cemetery Relocation Project (CR49-12, Site: 12Ma1025), Marion County, Indiana*. Prepared for the Indianapolis Airport Authority and Indiana Department of Natural Resources' Division of Historic Preservation & Archaeology. 1,872 pages.

Phillips, C. (1968) Indiana in Transition: The Emergence of an Industrial Commonwealth, 1880–1920. The history of Indiana 4. Indianapolis: Indiana Historical Bureau and Indiana Historical Society, 1968

Preston, S., Keyfitz, N. and Schoen, R. (1972) *Causes of Death*. Seminar Press. New York

Preston, S. (1976) *Mortality Patterns in National Populations with Special References to Recorded Causes of Death*. Academic Press. New York.

Preston, S. and Haines, M. (1991) *Fatal Years: Child Mortality in Late Nineteenth Century America.* Princeton, NJ: Princeton University Press.

Redfern, R. C., DeWitte, S. N., Pearce, J., Hamlin, C., & Dinwiddy, K. E. (2015). Urban–rural differences in Roman Dorset, England: A bioarchaeological perspective on Roman settlements. *American Journal of Physical Anthropology*, *157*(1), 107-120.

Retherford, R. D. (1975). The changing sex differential in mortality: Studies in population and urban demography# 1.

Riley, J. C. (2001). *Rising life expectancy: a global history*. Cambridge University Press.

Robbins, G. (2011). Don't throw out the baby with the bathwater: Estimating fertility from subadult skeletons. International Journal of Osteoarchaeology, 21(6), 717-722.

Sattenspiel, L., & Harpending, H. (1983). Stable populations and skeletal age. *American Antiquity*, *48*(3), 489-498.

Sattenspiel L. and Stoops, M. 2010. Gleaning signals about the past from cemetery data. Am J Phys Anthropol 42:7–21.

Sattenspiel L. 2011 Regional patterns of mortality during the 1918 influenza pandemic in Newfoundland. Vaccine 29S:B33–B37.

Scheuer, L., and Black S. (2000). Developmental Juvenile Osteology. *San Diego: Elsevier Academic*.

Schmidt, D. M., & Sattenspiel, L. (2017). The second epidemiologic transition on the brink: What we can learn from the island of Newfoundland during the early 20th century. *American Journal of Human Biology*, *29*(5), e22997.

Simons, R. and Parker, F. (1997) Railroads of Indiana. Bloomington: Indiana University Press

Sokal, R.R., and F.J. Rohlf. (1981). *Biometry* (2nd edition). San Francisco: W.H. Freeman.

Steckel, R. H. (1992). The fertility transition in the United States: Tests of alternative hypotheses. In *Strategic factors in nineteenth century American economic history: A volume to honor Robert W. Fogel* (pp. 351-374). University of Chicago Press.

Steckel, R. (1994) Health and Nutrition in the American Midwest: Evidence from the Height of Ohio National Guardsman 1850-1910. In: Komlos, J. (Ed.) *Stature, Living Standards and Economic Development*. University Press of Chicago, Illinois. P117-128.

Sulgrove, B. R. (1884). *History of Indianapolis and Marion County, Indiana*. LH Everts & Company.

Strassmann, Beverly I., and Wendy M. Garrard. 2011. "Alternatives to the Grandmother Hypothesis." Human Nature 22: 201–22

Temple, D. H. (2014). Plasticity and constraint in response to early-life stressors among late/final jomon period foragers from Japan: Evidence for life history trade-offs from incremental microstructures of enamel. *American Journal of Physical Anthropology*, *155*(4), 537-545.

U.S. Bureau of the Census, (1975), Series 67-68 for 1800-1970.- national averages

US Cesus Beaureau,2010, https://www.census.gov/population/www/censusdata/PopulationofStatesandCountiesoftheUnitedStates1790-1990

USDA. Census of Agriculture, 2012, http://www.agcensus.usda .gov/index.php.

Vaupel JW, Manton KG, Stallard E. 1979. The impact of heterogeneity in individual frailty on the dynamics of mortality. Demography 16:439–454.

Vinovskis, M. A. (1976). Socioeconomic determinants of interstate fertility differentials in the United States in 1850 and 1860. *The Journal of Interdisciplinary History*, *6*(3), 375-396.

Waldron I. (1984) The role of genetic and biological factors in sex differences in mortality. In: Lopez AD and Ruzicka LT, editors. Sex differentials in mortality: Trends, determinants, and consequences. Canberra: Department of Demography, Australian National University. p 141–164.

Waldron, I. (1993) Recent trends in sex mortality ratios for adults in developed countries. *Social Science and Medicine* 17, 1107-1123.

Waldron, T. (1994). *Counting the dead: the epidemiology of skeletal populations*. John Wiley & Sons.

Walker, P. L. (2008). Sexing skulls using discriminant function analysis of visually assessed traits. *American Journal of Physical Anthropology*, *136*(1): 39-50.

Walker, P. L., Bathurst, R. R., Richman, R., Gjerdrum, T., & Andrushko, V. A. (2009). The causes of porotic hyperostosis and cribra orbitalia: A reappraisal of the iron-deficiency-anemia hypothesis. *American Journal of Physical Anthropology: The Official Publication of the American Association of Physical Anthropologists*, *139*(2), 109-125.

Walter, B., and DeWitte, S. (2017) Urban and rural mortality and survival in Medieval England." Annals of Human Biology 44, 4 : 338-348.

Watts, R. (2015). The long-term impact of developmental stress. Evidence from later medieval and post-medieval London (AD1117–1853). *American journal of physical anthropology*, *158*(4), 569-580.

Western, A. G., & Bekvalac, J. J. (2017). Hyperostosis frontalis interna in female historic skeletal populations: Age, sex hormones and the impact of industrialization. *American journal of physical anthropology*, *162*(3), 501-515.

Wilson, J. J. (2014). Paradox and promise: Research on the role of recent advances in paleodemography and paleoepidemiology to the study of “health” in Precolumbian societies. *American Journal of Physical Anthropology*, *155*(2), 268-280.

Wood, J. W., Milner, G. R., Harpending, H. C., Weiss, K. M., Cohen, M. N., Eisenberg, L. E., ... & Katzenberg, M. A. (1992). The osteological paradox: problems of inferring prehistoric health from skeletal samples [and comments and reply]. *Current anthropology*, *33*(4), 343-370.

Wood, JW (1998) A theory of preindustrial population dynamics: Demography, economy and well-being in Malthusian systems. *Current Anthropology.* 39: 99-135.

Wood JW, Holman DJ, O’Connor KA, Ferrell RJ. 2002. Mortality models for paleodemography. In: Hoppa RD and Vaupel JW, editors. Paleodemography: Age distributions from skeletal samples. Cambridge: Cambridge University Press. p 129–168

Yasuba, Y. (1962). *Birth rates of the white population in the United States, 1800-1860: An economic study* (No. 2). Baltimore, Md.: Johns Hopkins Press.

Zhang, Hua, Deborah C. Merrett, Zhichun Jing, Jigen Tang, Yuling He, Hongbin Yue, Zhanwei Yue, and Dongya Y. Yang. "Osteoarchaeological studies of human systemic stress of early urbanization in late Shang at Anyang, China." PloS one 11, no. 4 (2016): e0151854.

Zuckerman, M. (2014). Introduction: Interdisciplinary approaches to the second epidemiologic transition. *Modern Environments and Human Health: Revisiting the Second Epidemiologic Transition*, 1-17.

Zuckerman, M., Harper, K., Barrett, R., & Armelagos, G. (2014). The evolution of disease: anthropological perspectives on epidemiologic transitions. *Global health action*, *7*(1), 23303.

Table 1. Age class distribution and percentages for the 503 individuals from the Bethel Cemetery attributed to the three periods of cemetery use.

Age Class	AD 1827-1869	AD 1870-1889	AD 1890-1935
Fetal (16-36 weeks in utero)	23 (8.8%)	12 (8.0%)	2 (2.2%)
Infant (0-2 yrs.)	55 (21.1%)	45 (30%)	12 (13%)
Young child (2-5 yrs.)	19 (7.3%)	8 (5.3%)	6 (6.5%)
Older child (5-12 yrs.)	33 (12.6%)	7 (4.7%)	2 (2.2%)
Adolescent (12-18 yrs.)	16 (6.1%)	4 (2.7%)	4 (4.3%)
Young adult (18-35 yrs.)	44 (16.9%)	15 (10%)	8 (8.7%)
Middle adult (35-60 yrs.)	24 (9.2%)	16 (10.7%)	7 (7.6%)
Older Adult (60+ yrs.)	35 (13.4%)	43 (28.7%)	50 (54.3%)
Adult (20+ yrs.)	4 (1.5%)	0	1 (1.1%)
Unknown	8 (3.1%)	0	0
Total	261	150	92

Table 2. Kaplan-Meier survival analysis and log-rank test for all individuals infant and older across the three time periods in the Bethel Cemetery.

Measure	Time Period	Estimate	SE
Mean age at death	AD 1827-1869	23.846	1.693
Median age at death	AD 1827-1869	15.000	2.371
n		227	
Mean age at death	AD 1870-1889	32.998	2.692
Median age at death	AD 1870-1889	23.070	3.752
n		141	
Mean age at death	AD 1890-1935	52.632	3.059
Median age at death	AD 1890-1935	68.770	3.577
n		105	
Log-rank test- Time effect		62.706	
p		0.000	

Table 3. Kaplan-Meier survival analyses and log-rank tests for sex-specific adult mortality in relationship to the three time periods at the Bethel Cemetery.

		Males		Females	
Measure	Time Period	Estimate	SE	Estimate	SE
Mean age at death	AD 1827-1869	43.532	3.104	44.612	2.849
Median age at death	AD 1827-1869	41.000	4.588	40.000	8.196
n		55		57	
Log-rank test- Sex effect		0.002			
p		0.965			
Mean age at death	AD 1870-1889	56.190	3.696	55.811	3.669
Median age at death	AD 1870-1889	61.630	5.257	61.000	6.126
n		40		38	

Log-rank test- Sex effect		0.019			
p		0.891			
Mean age at death	AD 1890-1935	66.357	3.427	65.900	3.080
Median age at death	AD 1890-1935	72.500	1.212	72.500	1.231
n		36		42	
Log-rank test- Sex effect		0.069			
p		0.793			

Table 4. Results of Cox's proportional hazard modeling: relative mortality risk by time period and sex at the Bethel Cemetery.

Step 1	**Variable**	**n**	**Wald**	**Exp(B)**	**Sig.**	**95% C.I.**
	Sex	268	0.099	1.040	0.753	0.816-1.324
	Time period	268	44.188		0.000	
	Period 1	112	42.736	2.806	0.000	2.059-3.823
	Period 2	78	6.608	1.518	0.010	1.104-2.088
Step 2	**Variable**	**n**	**Wald**	**Exp(B)**	**Sig.**	**95% C.I.**
	Time period	268	44.129		0.000	
	Period 1	112	42.663	2.801	0.000	2.057-3.816
	Period 2	78	6.540	1.514	0.011	1.102-2.081

Table 5. The D0-14/D ratios, 95% comparison intervals, and estimates for total fertility rates (TFR) by time period at the Bethel Cemetery compared to national averages for TFR.

Period	**D0-14/D**	**95% Comparison Intervals**	**Calculated TFR**	**National Average TFR (Haines, 2008)**
1827-1869	0.58	0.48-0.68	6.71	5.08
1870-1889	0.49	0.38-0.62	6.07	3.71
1890-1935	0.25	0.12-0.38	4.16	3.01

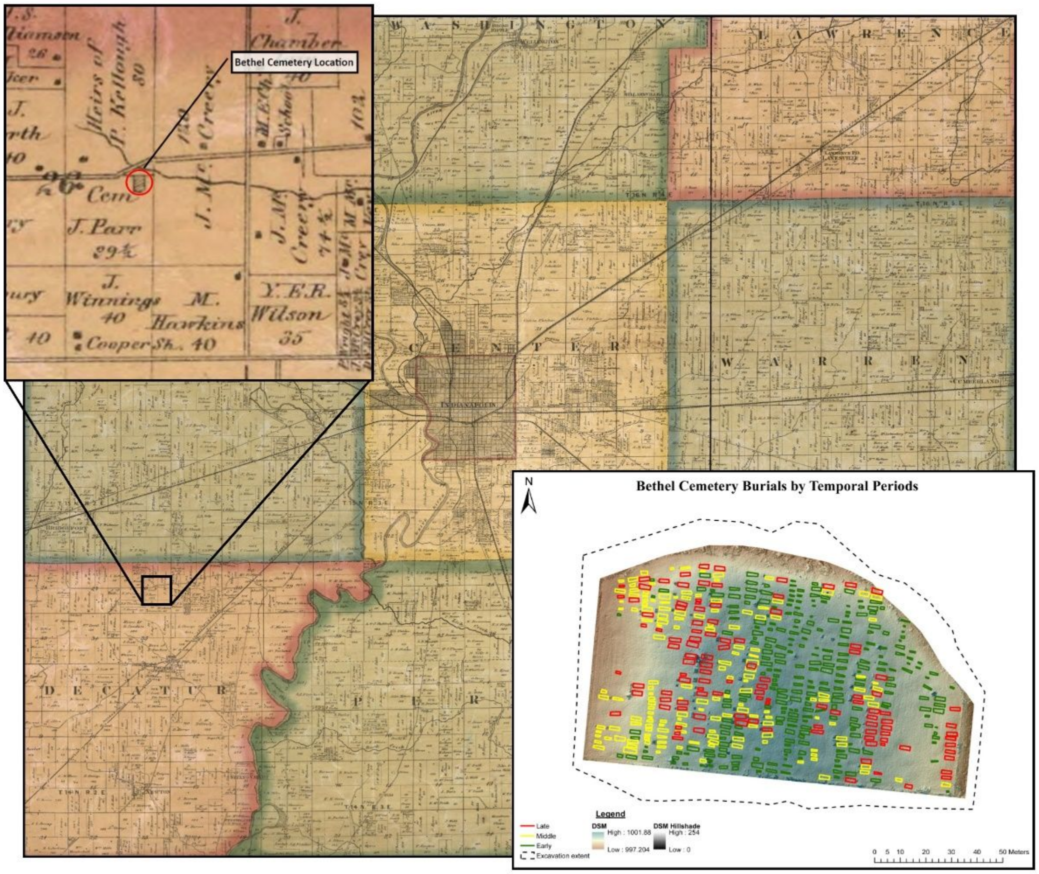

Figure 1. An 1866 map of Indianapolis and surrounding communities with insets detailing the location of the Bethel Cemetery in Decatur Township and a digital elevation map (DEM) with the early (AD 1827-1869), middle (AD 1870-1889), and late (AD 1890-1935) interments (Source: Warner, A., Worley & Bracher & Bourquin, F. [1866]. Map of Marion County, Indiana. Philadelphia: C.O. Titus, Publisher. Retrieved from the Library of Congress, https://www.loc.gov/item/2013593173/).

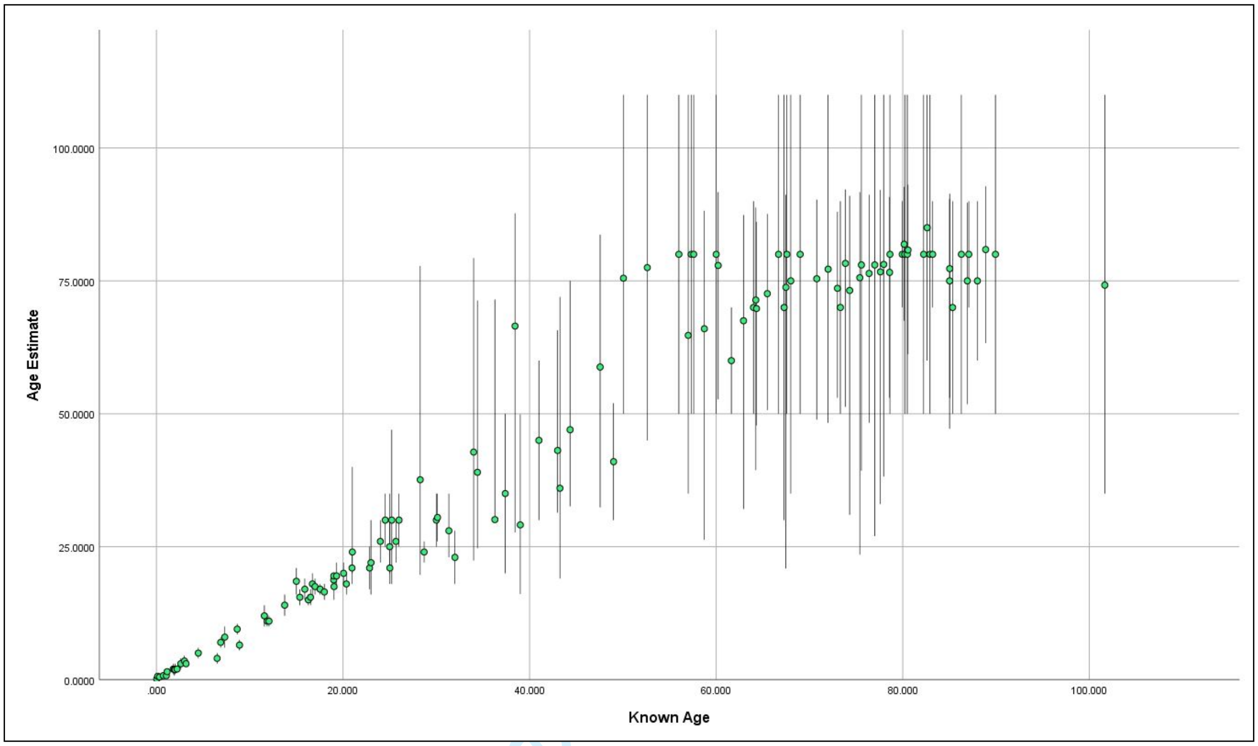

Figure 2. A scatterplot comparing known age (x-axis) with the age estimate (y-axis) for individuals from the Bethel Cemetery exhumed from graves with headstones and presumptively identified as matching based on the biological profile. The green circles represent the known age from the headstone, while the whiskers reflect the estimated skeletal age.

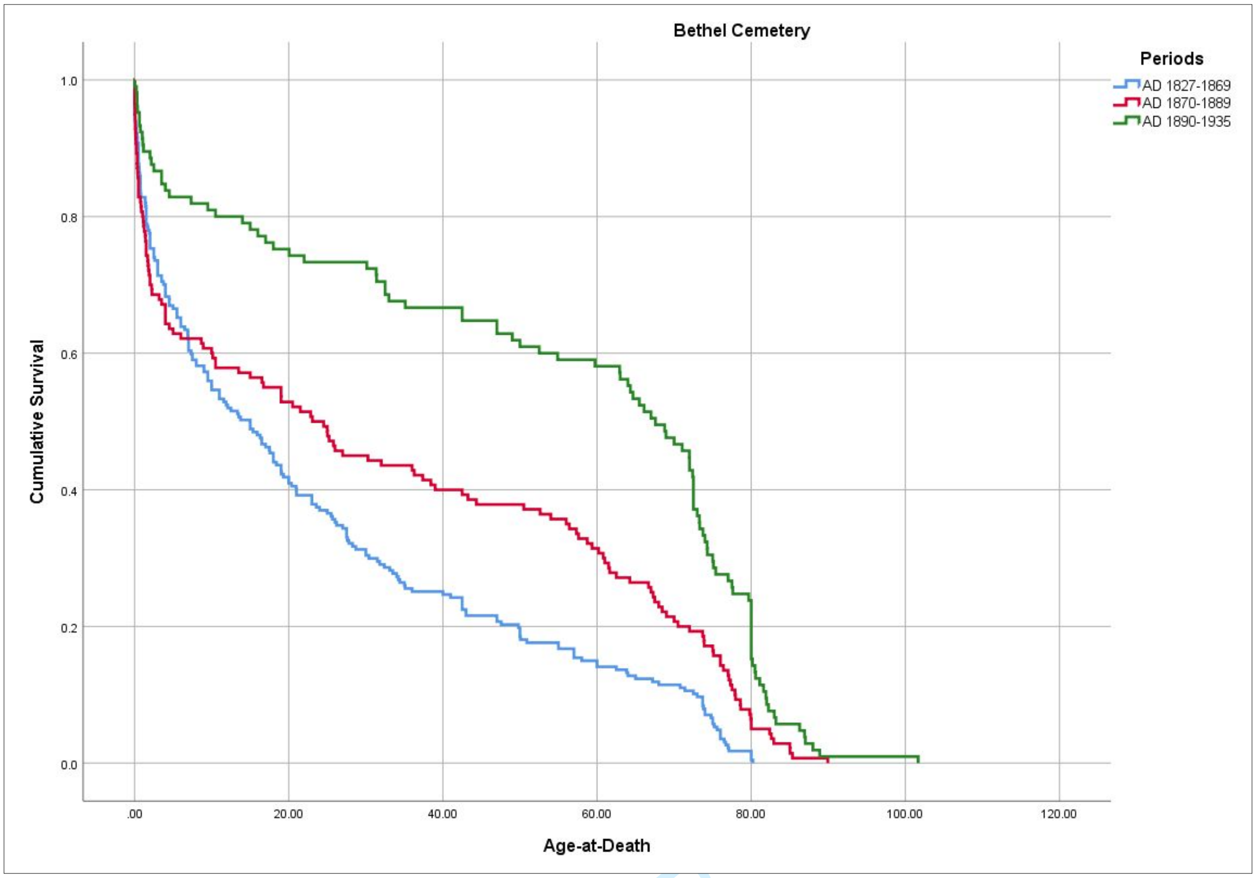

Figure 3. Kaplan-Meier survival curves depicting the cumulative rate of survivorship from birth to old age across the three time periods of interment at Bethel Cemetery.

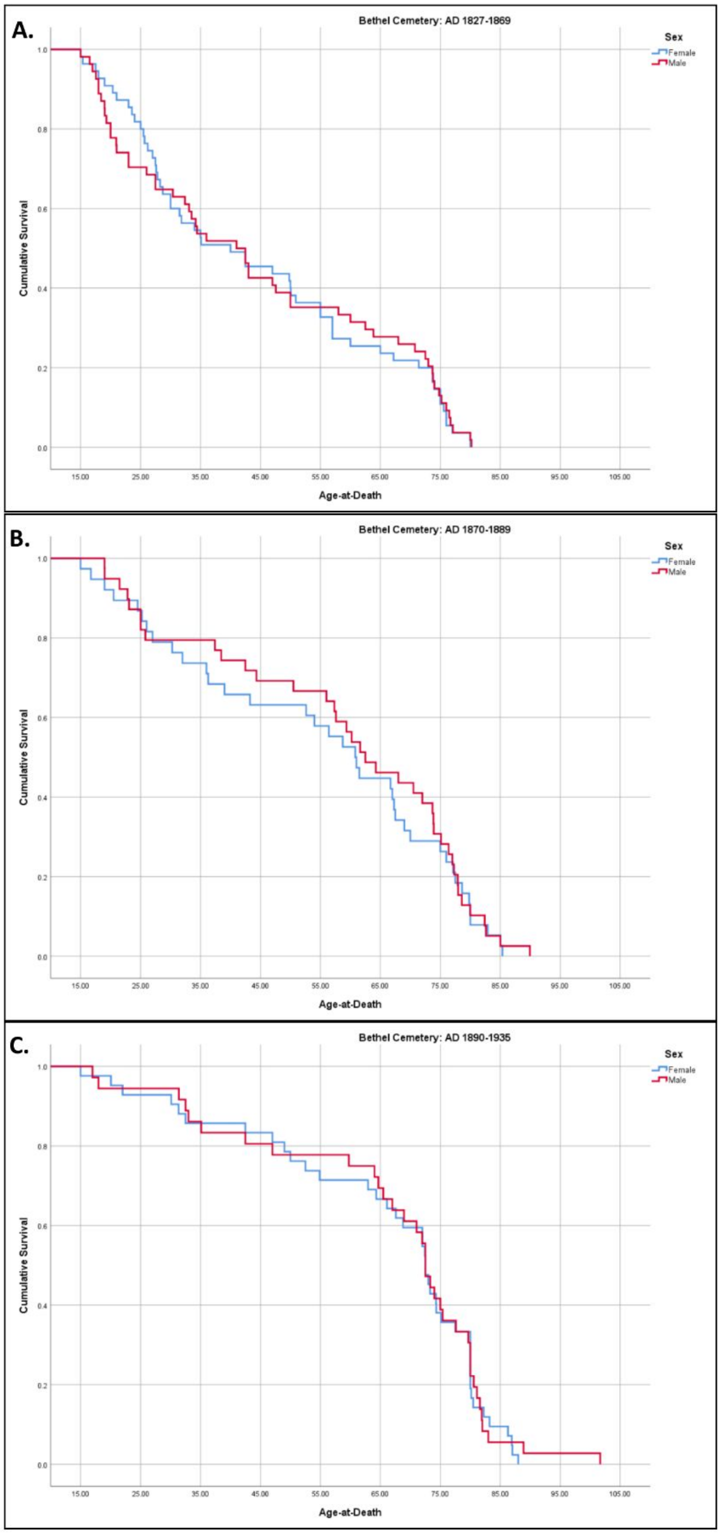

Figure 4. Kaplan-Meier survival curves depicting female and male survivorship by time period of interment at Bethel Cemetery. A: Period 1 (AD 1827-1869); B: Period 2 (AD 1870-1189), C: Period 3 (AD 1890-1935).

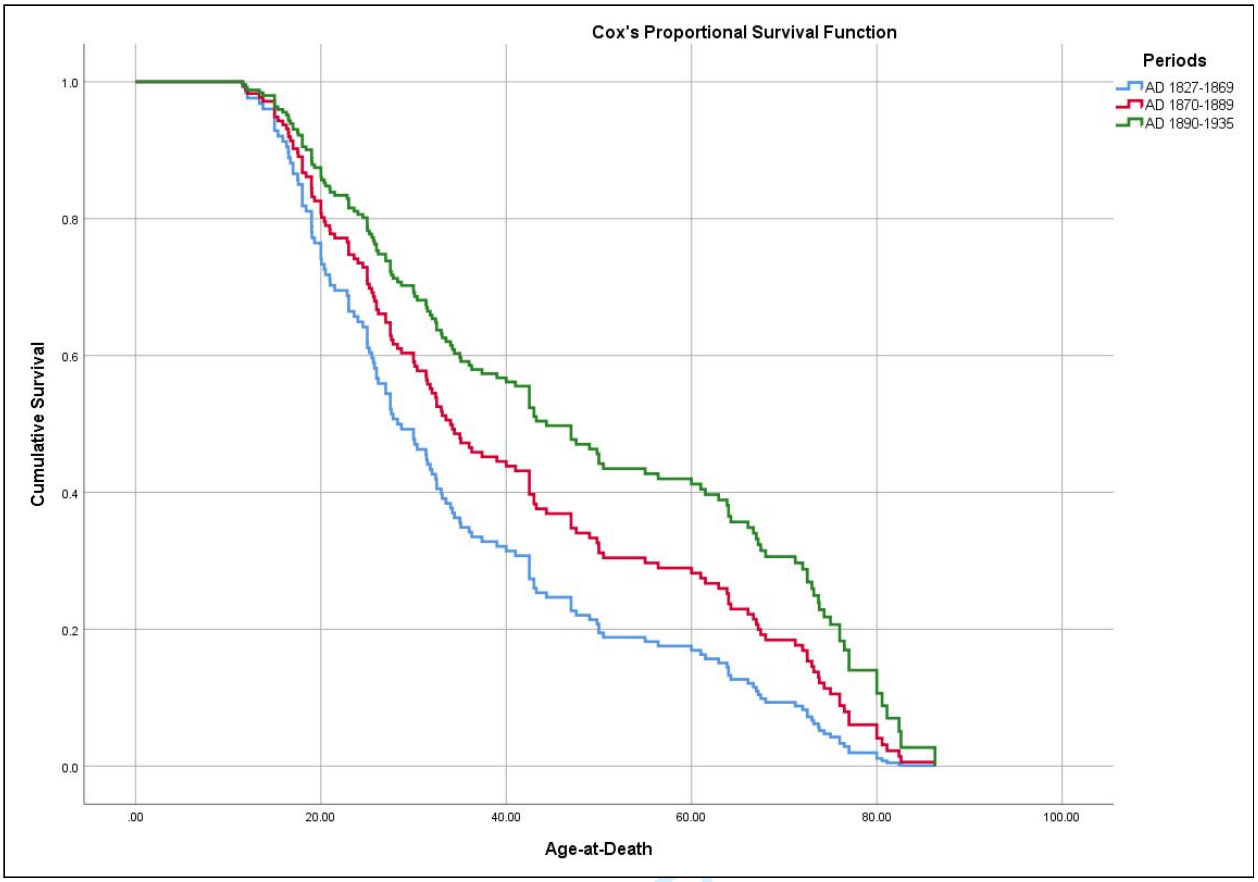

Figure 5. A Cox's proportional survival curve depicting improved survivorship among adults interred at the Bethel Cemetery across the three time periods of internment.