# Modeling Prehistoric Health in the Middle Cumberland Region of Tennessee: Mississippian Populations on the Threshold of Collapse

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Christina Laiz Fojas
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# Abstract

This research explores differences in mortality and survivorship resulting from factors associated with the abandonment of the Middle Cumberland Region (MCR) of Tennessee during the Mississippian period (ca. 1000-1500 AD). My dissertation investigates whether individuals from the Late Mississippian period had a greater risk of death than individuals from the Early Mississippian period. Adult age-at-death estimates (n=545) were calculated using Transition Analysis, a Bayesian maximum likelihood method. Gompertz and Gompertz-Makeham hazard models were utilized to reconstruct the mortality profile of the MCR as they model human adult mortality and generate robust parametric mortality profiles. Rather than recount the prevalence of disease conditions, this project uses MCR skeletal data to understand the biological, social, and ecological processes that positioned some individuals in the community with a greater risk of death than others. To this end, biological markers of childhood physiological stress and poor dental health, skeletal evidence of warfare-related trauma, and paleoclimate data were analyzed as health co-variates in a series of Kaplan-Meier survival analyses and log-rank tests.

The paleodemographic results suggest that survivorship did not simply decrease with age. Marked differences between the sexes indicate that females had increased mortality compared to males. Survivorship of males decreased sharply from the Early Mississippian to Late Mississippian period, possibly due to elevated rates of conflict. On the whole, mortality was elevated in the Late Mississippian period compared to the Early Mississippian period. Paleoepidemiological results demonstrate that risk of death was not uniform across the MCR during the Mississippian period. While some findings support

traditional interpretations that the presence of certain conditions (porotic hyperostosis, carious lesions, skeletal trauma) had a negative impact on survivorship, results for linear enamel hypoplasias, dental abscesses, and antemortem tooth loss offer support for the osteological paradox.

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# Chapter 1: Introduction

The demographic collapse of populations in the New World remains one of the most enduring mysteries in the history of the Americas, with broad appeal to scholars interested in human cultural change and the rise and fall of complex societies (Tainter, 1988; Diamond, 2005). For protohistoric groups that came into contact with European expeditions, exposure to the smallpox, influenza, and measles viruses provide a fairly clear-cut and oft-cited explanation for their ultimate demise (Walker and Johnson, 1992; Roberts and Ahlstrom, 1997; Steckel, 2005). For prehistoric groups that abandoned settlements prior to European contact, the rationale is not as straightforward. In the latter context, it is necessary to move beyond the idea that abandonments were sudden, catastrophic failures, luring public interest solely because of their sensationalist nature. In the present context, "abandonment" is taken to denote the gradual vacancy of year-round habitation of settlements—in effect, the depopulation of sites (Williams, 1990). Though the word abandonment may conjure negative connotations, its use in this research by no means suggests that populations disappeared overnight. I use the terms "abandonment" and "depopulation" interchangeably herein to imply a slow population decline and movement away from major cultural centers.

Instead of being perceived as events, abandonment should be reconceptualized as a process with multicausal factors ranging from changes in subsistence strategy, warfare, and climatic conditions (Nelson and Schachner, 2002). It is essential to position

individuals into this context, underscoring social actors as active—and not passive—decision makers. Despite the importance of people as constituents of complex, adaptive societies, the demographic profiles of groups that experienced depopulation prior to European contact are unknown or in need of reanalysis, particularly with respect to health. A full appreciation of the health of communities on the threshold of collapse is lacking, especially with regard to how well-being may have contributed to or compromised community existence. This research aims to contribute to such a framework by using skeletal samples from the southeastern United States during the Mississippian period. Using the Middle Cumberland Region (MCR) of Tennessee promises to deliver a fuller representation of populations on the threshold of collapse.

The terms "stress" and "health" are frequently used in the paleodemographic and paleopathological literature, with many bioarchaeological interpretations of prehistoric health based on skeletal evidence of physiological stress. The World Health Organization (1948) defines health as a state of physical, mental, and social well-being, the maintenance of homeostasis, and normal physiological function. Health is a complex notion to quantify in living populations, and exponentially difficult to measure in the past populations that bioarchaeologists study. Applying perspectives from the field of epidemiology provides a means for anthropologists to assess risk of death, which is not equated to but is related to the concept of health.

Following Washburn's (1951) approach to a "New Physical Anthropology," bioarchaeology as we know it today is focused on the reconstruction of human histories, emphasizing anthropological problem-solving and the integration of archaeological contexts (Buikstra, 1977). By analyzing biological, social, and ecological variables, my

dissertation investigates age and sex-specific risks of death resulting from factors associated with abandonment of the MCR during the Mississippian period (ca. 1000-1500 AD). If and how these risks of death co-varied with interpersonal violence and drought episodes are examined throughout the region and across temporal scales. To explore whether a skeletal signature of abandonment exists, evidence of childhood stress and poor dental health are evaluated to address disproportionate risks of death, providing an innovative model by which health is shaped by the synergy of multifactorial processes.

## Research Hypotheses

This research utilizes adult skeletal remains to elucidate how the process of selective mortality acts upon the heterogeneous frailty of individuals. Two hypotheses are proposed: a paleodemography hypothesis that I test in Chapter 7 and a paleoepidemiology hypothesis tested in a series of ways in Chapter 8.

**Paleodemography hypothesis:**

*Given social and environmental changes during the Mississippian period, mortality will be elevated in the Late Mississippian MCR compared to the Early Mississippian MCR.*

The Early Mississippian period is marked by a favorable climate, which would have served as an optimal backdrop for Mississippian cultures to expand and thrive, given their reliance on maize agriculture. Climate fluctuations and low crop yields in the Late Mississippian period may have dismantled Mississippian groups, resulting in interpersonal violence and a societal chasm. I argue that these demographic changes are detectable in the skeletal record, and may present as a lower mean age-at-death of individuals from Late Mississippian sites compared to Early Mississippian sites.

**Paleoepidemiology hypothesis:**

*Given the concepts of heterogeneous frailty and selective mortality, individuals without markers of childhood stress and poor oral health will have a greater risk of death than similarly-aged individuals with these markers.*

Evidence supporting this hypothesis would lend credence to the interpretations put forth by the osteological paradox (Wood et al., 1992). The osteological paradox contends that individuals vary in their susceptibility to disease and death. The presence of skeletal lesions may not equate with poor health, but rather, may be interpreted as a sign of survival. Males, females, young adults, and old adults are expected to respond to physiological stress and disease in disparate ways. As such, an examination of age and sex-specific risks of death is essential.

## Dissertation Organization

This dissertation is organized into ten chapters. Chapter 2 summarizes the rich archaeological period known as the Mississippian cultural tradition as it relates to southeastern North American archaeology. This includes a discussion of agricultural intensification, the development of chiefdoms, and platform mound-building efforts which have come to characterize Mississippian cultures. A discussion of the Vacant Quarter hypothesis is contained in this chapter; this phenomenon describes the apparent depopulation of sites and cultural centers from Missouri to Tennessee in the Late Mississippian period. It contextualizes the population decline of the region, thereby propelling the questions framing my dissertation. Additionally, Chapter 2 presents the environmental and cultural landscape of the MCR, the geographic area in which this

dissertation is focused. The terrain, settlement practices, chronology, and mortuary practices are outlined in addition to an explanation of the Early, Middle, and Late Mississippian culture variations specific to the MCR. Descriptions of the MCR skeletal sample and study sites are summarized in Chapter 3. Information regarding archaeological excavations, site location, dates of site occupation, and previous research conducted on MCR skeletal remains is included.

Background on the principles of paleodemography is provided in Chapter 4. This chapter reviews bioarchaeological principles and the use of skeletal remains as a means to reconstruct prehistoric population dynamics. The reconstruction of population structure is an essential component of my research, as it dovetails with overarching research questions concerning risk of death related to age and sex specificity. Chapter 5 elucidates the paleoepidemiological framework that grounds my dissertation. It details methodological advances in the field of paleopathology ranging from seminal studies on the interpretation of skeletal health to burgeoning quantitative research incorporating frailty analysis.

Chapter 6 presents paleodemographic and paleoepidemiologic methods, which are divided into two sections. The section on paleodemographic techniques details the aging and sexing methods used in this research. The Transition Analysis age estimation method is described, as is a discussion of the hazard models used to create mortality profiles of the Mississippian MCR sample. The section on paleopathological methods identifies the scoring systems for data collected with regard to enamel hypoplasias, porotic hyperostosis, dental caries, dental abscesses, and antemortem tooth loss. Evidence of

warfare-related trauma and tree-ring derived paleoclimate data (Palmer Drought Severity Index values) are also clarified.

Chapter 7 summarizes the paleodemographic results, age and sex distributions, and mortality patterns of the Gompertz and Gompertz-Makeham hazard models. Paleoepidemiologic results are presented in Chapter 8. Kaplan-Meier survival plots are presented and log-rank tests calculate differences in survivorship given age, sex, the presence or absence of health variables described in Chapter 6, and time period. Death is selective and these results explore the suite of processes that put some individuals at a greater risk of death than others, possibly compromising community existence during the Late Mississippian period.

Chapter 9 offers a discussion of the results and presents implications to model health questions of the past and present. Chapter 10 summarizes key findings and includes ideas for future avenues of research.

# Chapter 2: The Mississippian Cultural Tradition in the Southeastern United States

The term *Mississippian* originated at the turn of the twentieth century to categorize a prehistoric ceramic style observed in the Mississippi Valley (Holmes, 1886; Holmes, 1903). In the last century, the definition has evolved to denote a time frame, regional complexity, and cultural tradition that distinguishes it from its predecessor, the Late Woodland Period. Late Woodland societies (ca. 600-1000 A.D.) began as small, scattered communities consisting of little more than a few households, with many settlements eventually increasing in size and complexity (Jefferies, 2004). Hunting and gathering practices from previous centuries endured, and Late Woodland groups began to implement small-scale horticulture for subsistence (Steponaitis, 1986; Emerson et al., 2000; Cobb, 2003). Between 800 and 1000 A.D., a new complex of material culture, in addition to the widespread adoption of maize agriculture, occurred in the Eastern Woodlands—the area that roughly spans the eastern United States from the Atlantic Ocean to the Mississippi River (Willey, 1966). The region's temperate forested environments and major river systems made the river valleys of the Eastern Woodlands attractive settlement sites throughout prehistory.

Anderson and Sassaman (2012:153) use the term "Mississippian" as a temporal construct to refer to 1000-1500 A.D., though they acknowledge that its precise end is difficult to establish. Mississippian cultures were highly varied and characterized by an intensification of maize agriculture, increased sedentism, and ranked sociopolitical

organization (Steponaitis, 1986; Muller and Stephens, 1991; Cobb, 2003; Anderson and Sassaman, 2012). This chapter explores the main traits of the Mississippian cultural tradition as it pertains to my dissertation research in the Southeastern United States. The Southeastern United States lies south of the Ohio and Potomac Rivers and includes Virginia, North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi, Louisiana, Arkansas, Kentucky, and Tennessee, as well as portions of adjacent states (Steponaitis, 1986; Anderson and Sassaman, 2012). The geography, chronology, and cultural history of my research area—the Middle Cumberland Region—will be described. Finally, I will discuss population decline and the Vacant Quarter hypothesis, and the reasons proposed for abandonment in the Eastern Woodlands during the Late Mississippian period.

## Agricultural Intensification

Although broad variations exist, Mississippian societies share a number of common traits. These features differed in scale, not kind, from previous Woodland cultures. While parts of the Southeast began to employ maize agriculture earlier than 1000 A.D., the most revolutionary change during the Mississippian period was the wholesale adoption of agriculture, as recognized in macrobotanical assemblages and stable isotope analysis of human bone (van der Merwe and Vogel, 1978; Chapman and Shea, 1981; Baden, 1987; Buikstra et al., 1987; Buikstra and Milner, 1991; Schoeninger, 1995; Schroeder, 1999; Reber and Evershed, 2004; Danforth et al., 2007). Archaeobotanical evidence in the Lower Mississippi Valley and Lower Little Tennessee River Valley confirms that domesticated *Zea mays* was the main dietary resource in the Mississippian period across much of the Southeast (Chapman and Shea, 1981; Fritz and

Kidder, 1993). By 1200 A.D., large quantities of maize were being cultivated and consumed, with the exception of coastal regions of Georgia and Florida where nonagricultural forms of subsistence continued into the 1500s ((Marquardt, 1986; Smith, 1986; Smith, 1989; Hutchinson et al., 1998; Schoeninger, 2009).

While the transition to agriculture took place at different times in different regions, its intensification was fairly rapid. Maize is a $C_4$ plant with a distinct photosynthetic pathway compared to $C_3$ plants like beans, nuts, and tubers. $C_3$ and $C_4$ plants metabolize the two stable isotopes of carbon in disparate ways and these differences are passed down the food chain. Stable isotope analysis can distinguish the nature of the plant food base in human bone collagen, and a potential rise in $C_4$ plant intake can be detected (Schwarcz and Schoeninger, 1991). From the Late Woodland to Mississippian periods, an abrupt elevation in maize consumption is reflected in isotope analyses (van der Merwe and Vogel, 1978; Bender et al., 1981). When this spike occurred, $C_4$ levels rose from being barely discernable to levels that indicate maize may have comprised half of the total diet on average. Other indigenous cultigens supplemented the Mississippian diet, including goosefoot, sumpweed, beans, and squash (Steponaitis, 1986). Despite the increased dependency on crops, wild plants and animals continued to be procured seasonally (Larson, 1980; Chapman and Shea, 1981).

The optimal conditions for maize cultivation are warm rain and high temperatures both during the day and at night. The maturation of maize is assisted by a dry period or lowered temperatures. Recent paleoclimatic reconstructions reveal that the intensification of agriculture in the Eastern Woodlands corresponds with the Medieval Warm Period (ca. 800-1200 A.D.)—a global phenomenon of relatively warmer-than-average temperatures

and increased precipitation during the Holocene (Hughes and Diaz, 1994; Crowley, 2000; Broecker, 2001). An increase in rainfall would have produced compact, loamy soil which would be have been easy to cultivate. It is undeniable that these conditions contributed to the particularly favorable environment for the extensive spread of agriculture throughout the Southeastern United States.

Maize yields are a function of the climate and soil properties in which the crop grows. Evidence of technological innovations suggest advancements in the preparation, cultivation, and storage of maize that would have aided in its wholesale adoption during the Mississippian period. In the Late Woodland period, a shift to shell as a tempering agent was introduced, resulting in pastes that were easier to work, lighter, and less likely to shrink (Steponaitis, 1984; Feathers, 2006; O'Brien and Kuttruff, 2012). These advances in shell-tempered pottery permitted the creation of larger, long-lasting cooking vessels and were quickly embraced in locales where it was established. The appearance of pottery in the archaeological record indicates a level of sedentism, as such vessels were cumbersome and difficult to transport. Given the needs of growing settlements, agricultural intensification of the Mississippian period was not carried out on a small scale; digging tools and extensive field clearance were required. Chert hoes were used to move dirt and cultivate gardens, and polish on the working edge of blades suggests their heavy use for this intent (Winters, 1981; Cobb, 1989; Milner et al., 2010).

Prior to 1000 A.D., maize may have remained a minor cultigen because of its high start-up costs in land-clearance and field maintenance. The intensification of agriculture was likely predicated on demographic pressures placed on existing resources, and/or the development of more productive species of maize (Steponaitis 1986, Smith 1989).

Population density increased due to higher fertility levels, which was a result of increased sedentism; it simply became too restrictive to depend on foraging as a primary means of subsistence to support a growing population. As de Soto and his men traveled across the Southeast from 1539-1543, accounts depicted vast swaths of cultivated land and an abundance of surplus grain in storehouses (Clayton et al., 1993). The importance of maize as a storable food is implied by the increase in size of household storage pits from pre-Mississippian to Mississippian times. This increase in storage pit volume led researchers to estimate that they would accommodate double the seasonal requirement of an extended family unit in the Central Mississippi Valley (Morse and Morse, 1983) and the American Bottom (Kelly et al., 1984). The appearance of large communal storage pits located at the center of the community is suggestive of increased social complexity, illustrating a level of organization beyond the basic household unit (Wesson, 1999). Steponaitis (1986) argues that agricultural intensification and the production of food surpluses created the basis on which social complexity burgeoned during the Mississippian period.

## Ranked Sociopolitical Organization

The wholesale shift to maize-centered agriculture across the Eastern Woodlands ushered in an amplified scale of subsistence as well as sociopolitical organization. The intensification of agriculture allowed for a transformation of more egalitarian lifeways present in the Late Woodland sequence to one of ranked hierarchy that characterized Mississippian cultures. These socioeconomic and political transformations became entrenched within the Mississippian chiefdom system. Although complex organizational forms were undoubtedly observed prior to chiefdom emergence, Mississippian groups

built upon the foundation set in the Late Woodland, which made the development of chiefdoms possible. Cobb (2003) remarks that most archaeologists today use the term *Mississippian* to refer to the sociopolitical characteristics of chiefdoms, though stresses that there are many levels of complexity to consider. Despite its ubiquity in the literature, use of the term *chiefdom* has been criticized for being typological and ahistorical; in response to this outcry, the term has been repackaged and a better understanding of the range of Mississippian chiefdoms is urged (Pauketat, 2007). The term *chiefdom* will be used throughout my research with the understanding that there is wide variation across time and space, yet the classification does encompass unifying traits. As Pauketat (2007) argues, there is nothing wrong with using *chiefdom* as a descriptive device, but issues arise when employing the term as an explanatory device.

The complexity that characterizes Mississippians chiefdoms was hierarchical in organization, arose around 1000 A.D., and was widespread by 1200 A.D. (Steponaitis, 1986; Cobb, 2003). Knight (1986) identified a triad of institutional behavior that reflect a shared ideology that linked Mississippian chiefdoms. The three institutions are a warfare-cosmology complex, a communal agricultural fertility complex, and a priestly mortuary complex. The warfare-cosmology complex emphasizes the iconic representation of weaponry through ritual objects and motifs (Brown, 1976). Additionally, it focuses on the chiefs and elites in positions of power. The communal agricultural fertility complex served the ritual needs of the broader community and mediated community activities and rites. Its focus on the earth is represented by the building and rebuilding of public earthen works such as platform mounds that serve the entire community. The priestly complex maintained places of worship and administered mortuary rituals. Knight (1986: 681)

suggests that the priestly complex may have mediated between chiefly and communal ritual affairs entrenched with the other complexes. These three institutions were tied to the Southeastern Ceremonial Complex (SECC) defined by Waring and Holder (1945). Although Knight (1996) helped refine definitions of the SECC, he has since advised discarding the concept, as it promotes typological classifications and is neither completely southeastern, ceremonial, nor a complex (Knight, 2006). Instead, he proposes a careful evaluation of the variation existing in what is known as the SECC, much like Paukatat's (2007) call for new ways of understanding the chiefdoms that characterize Mississippian cultures. As a purely descriptive tool, the SECC is a recurring set of themes, motifs, and iconography that represents the primary component of religious ideology of Mississippian cultures (Cobb, 2003). Despite the lack of consensus of what the SECC embodied, it helps explain how elites may have yielded power over non-elites.

The connection between chiefs and a powerful ideology allowed for elites to maintain balance between the social and natural worlds (Cobb, 2003:74). Peebles and Kus (1977:434) contend that chiefly officials held privileged information over the community level and transferred their authority through ritual affairs. Mortuary patterns suggest that ranked status was not necessarily rigid or hereditary (Trocolli, 2002). High status could be either ascribed or achieved, and to some extent, was relegated by lineage, personal history, age-group, gender, and competence. In addition, women were capable of holding power in a convention similar to chiefs (Trocolli, 2002; Hally, 2008). Steponaitis (1986) asserts that one's status was an artifact of a continual process of social negotiation and may have been institutionalized by kinship or other means. Archaeological evidence supports the notion that Mississippian chiefs were entitled to

tribute payments from the lesser- and non-elite groups they controlled (Peebles and Kus, 1977; Steponaitis, 1978; Trocolli, 2002). Furthermore, ethnohistoric accounts describe maize and other subsistence goods being presented as tribute to highly ranked individuals (Smith, 1968; Clayton et al., 1993). Surplus and tribute goods were used by chiefly officials to organize feasting events as a means to reallocate food and gifts to followers. Such feasts served a significant purpose within the economic system of chiefdoms, as the security and redistribution of food and other goods incited a network of gratitude and obligation (Steponaitis, 1978; Wesson, 1999; Cobb, 2003). By organizing feasts for followers in the guise of hospitality, chiefs bolstered personal prestige and advanced their own social interests (Muller and Stephens, 1991; Blitz, 1993; Dye, 1995). Cobb (2003:72) asserts that "certain individuals and interest groups were particularly adept at acquiring the physical and symbolic capital that constituted the cornerstone of chiefly authority." As such, Mississippian chiefdoms relied on agricultural surplus not only as a means to offset poor harvests but also to sustain the political system through community projects, ceremonial rituals, and the exchange of goods. This economic redistribution system exemplifies the social inequality of Mississippian life that is representative of chiefdoms.

The existence of discrete forms of hierarchy and social inequality is arguably best illustrated through the examination of mortuary remains (Cobb, 2003). Case studies from Brown's edited volume (Brown, 1971a) demonstrate a processual link between burial treatment and social complexity that directs much of Mississippian mortuary research today. Commoners were interred in simple burials found in communal cemeteries or under house floors and in close proximity to villages (Peebles and Kus, 1977; Chapman,

2009; Sullivan and Mainfort, 2010). Non-elites were buried with utilitarian grave goods, simple beads, and ceramic vessels. On the other hand, high-ranked chiefly officials were buried with elaborate grave goods such as copper headdresses, ceremonial weapons, painted and effigy ceramics, and marine shell beads derived from imported sources (Brown, 1971b; Larson, 1971; Steponaitis, 1986). Non-local grave goods found in elite burials suggest they were imported, as part of a system of exchange (Peebles and Kus, 1977).

A hierarchical system is likewise apparent in the assessment of platform mounds. High status members of society were typically interred on or near preferential public spaces—typically placed on platform mounds—signifying the importance and wealth of these individuals (Brown, 1971b; Steponaitis, 1986). Buildings were placed on mounds and community activities such as music, dance, and rituals were carried out atop them (Lindauer and Blitz, 1997). Rituals helped establish social networks and stimulate social solidarity. Performing on mound summits—a vantage point above where the non-elite lived—created a stage that was not accessible to everyone in Mississippian society. The location, size, and configuration of mounds and other architectural monuments helped reestablish the existing social order demarcated by status and kin group (Steponaitis, 1986; Hally, 1993; Williams, 1995; Hally, 1996; Lindauer and Blitz, 1997; Knight, 1998; Blitz, 1999; Anderson and Sassaman, 2012). It is likely that the physical act of building, rebuilding, and adding to these structures served ceremonial purposes and may have been just as important as the end product (Sherwood and Kidder, 2011; Anderson, 2012; Anderson and Sassaman, 2012). Pauketat and Alt (2003) suggest that mound building was a social memory device, a part of the fabric of ongoing concessions between groups

that could affirm or deny the elites' legitimacy. Additionally, studies recognize the tremendous amount of labor that would have gone into making level ground in the construction of plazas (Pauketat, 2007; Alt et al., 2010). Plazas would have brought the community together for games, rituals, and communal feasting (Pauketat et al., 2002).

Chiefdoms had kin groups of disparate social rank and an elite, decision-making body led by a chief. In chiefdom systems, select sites were hubs where the chief established status and directed social, economic, and ceremonial activities (Steponaitis, 1978; Earle, 1991). Location theory provides a model for explaining certain patterns in the size and distribution of urban centers (Steponaitis, 1978; Hally, 1993). Different levels of chiefdoms are apparent in the archaeological record, each defined by the degree of control held by people in one community over those in other communities (Steponaitis, 1978; Wright, 1984; Anderson, 1994; Anderson, 1996). Chiefdom size and power was determined by the number of subordinate communities under the direct control of the primary chiefly center (Wright and Johnson, 1975; Wright, 1984; Anderson, 1996). A simple chiefdom is characterized by one decision-making level above the community, while complex chiefdoms have two administrative levels above the local community. Blitz (1999:578) discusses the primary center of a simple chiefdom in a civic-ceremonial center as being a platform mound, as does Hally (1993; 1996). Numerous secondary one-mound centers are tied to a multiple-mound regional or primary center in complex chiefdoms. Anderson (1990; 1994:9) proposes a level above the complex chiefdom—the paramount chiefdom—to refer to a complex chiefdom that exerts control over more than two chiefdoms. Hally (1996) takes issue with the idea of paramount chiefdoms, stating that they have no discernable settlement pattern or material culture in the archaeological

record, but Blitz (1999) suggests that they are best construed as an oscillating network of chiefdoms.

The distribution of Mississippian chiefdoms spanned the southeastern United States from the Eastern margin of the Great Plains to the lower middle Atlantic seaboard (Griffin, 1967). Prominent centers include the sites of Cahokia outside of St. Louis, Moundville in Alabama, Etowah in northwest Georgia, and Serpent Mound in southwest Ohio. Cahokia in particular is thought to have played a significant role in the emergence of Mississippian cultures based on events occurring in the Central Political-Administrative Complex of the American Bottom, namely at the St. Louis, East St. Louis, and Cahokia mound groups (Pauketat, 1997). Cahokia and its affiliated sites were located at the confluence of the Mississippi, Missouri, and Illinois Rivers, with most populations settled in scattered, small-scale villages (Milner, 1998). Cahokia presents a series of monumental structures and was the most politically centralized settlement in the Eastern Woodlands with regards to size, population, and complexity (Muller and Stephens, 1991; Anderson, 1997; Pauketat and Emerson, 1997). Cahokia consists of over 120 mounds, with the largest—Monk's Mound—erected at over 100 feet high. It is the largest Mississippian site discovered, and with some positing that Mississippian culture started in Cahokia and spread to nearby regions by population movement (Conrad, 1991; Muller and Stephens, 1991) Anderson and Sassaman (2012: 163) remark that while Cahokia provided the spark, other groups built and sustained their own fires. The proximity of many prehistoric settlements to waterways undoubtedly facilitated the interaction of local groups, which gave chiefly officials the opportunity to display their high status to nearby groups.

With many Mississippian settlements located in river valleys, trade networks could be maintained with neighboring communities, as seen by the widespread distribution of nonlocal artifacts (Cobb 2003; Smith 1986; Steponaitis, 1986). Notably, copper and shell were traded across long distances and converted to markers of high status, such as gorgets, engraved bowls, and embossed plates found in elite burials (Johnson, 1994). The broad distribution of iconographic representations of the Southeastern Ceremonial Complex, such as the eagle warrior and trophy heads, demonstrate that interregional alliances may have played an important role in interregional exchange (Brown, 1976). The ubiquity of chipped stone hoes at Mississippian sites suggests river transport of these raw materials, as they were derived from Mill Creek chert or Dover chert from southern Illinois or middle Tennessee, respectively (Winters, 1981; Cobb, 1989; Cobb, 2000). Additionally, salt is a utilitarian item that appears to have been traded widely across the Midwest and Southeast. Brown (1980, 1999) found evidence of tools used to process salt, such as salt pans and pottery funnels; saline springs where salt was likely derived are located in southern Illinois and central Tennessee.

## Warfare

Peaceful trade relations among groups did not preclude conflict between neighboring communities. Ethnographic accounts provide widespread evidence that warfare played a major role in Mississippian ways of life (Smith, 1968). Warfare is defined as any context wherein spatially disparate groups of people partake in armed, intentional confrontation (Webster, 1993; Milner, 1999; Lambert, 2002). Lambert's (2002) definition includes small-scale forms of warfare such as raids, ambushes, and

surprise attacks characteristic of smaller organizational units like bands, tribes, and chiefdoms. She cautions that subtle manifestations of small-scale warfare can be difficult to interpret in the archaeological record, in contrast to more obvious forms, such as massacres.

Lambert (2002) identifies four lines of material evidence in support of the presence and scale of warfare among prehistoric North American groups, with direct application to the Mississippian context: 1) settlement data, 2) war weaponry, 3) iconography, and 4) osteological data. Settlement data provide possible evidence for the presence and scale of warfare. Archaeologically, this is displayed by the presence of post hole rows from palisade walls, forts, towers, and moats suggests a perceived threat and need for defense. Gaps between the posts were filled with sheets of bark or branches, which were reinforced with clay to create a continuous wall. Milner's (1998, 1999) survey of Late Woodland and Mississippian sites identifies a rapid increase in palisade construction around 1000 A.D. when Mississippian chiefdoms were a fixture of the Eastern Woodland landscape. The roughly contemporaneous appearance of fortified structures and Mississippian chiefdoms highlight the competitive nature of these groups, with palisade walls protecting people from outside attackers and intimidating potential enemies (Milner, 1999). The conscious decision to allocate labor and resources to erect defensive structures suggests a need for security; evidence of defensive structures in Mississippian settlement data is not inconsequential and implies that conflict was a common part of life (Milner, 1999; Lambert, 2002; Milner et al., 2013). Additionally, some sites demonstrate proof that sections of walls were repeatedly repaired or expanded upon, signifying its use. The burning of structures is a common aftermath of war and may

be indicative of past conflict events, though other causes of burning such as an accidental fire cannot be excluded.

War weaponry provides circumstantial evidence for warfare in the Eastern Woodlands. These weapons allowed for a range of interpersonal violence to play out. These varied from projectile weapons (bow and arrow, atlatl) wherein one could fight from a distance, to shock weapons and cutting weapons (warclubs, axes, maces, swords, knives) that necessitated hand-to-hand combat. However, it is difficult to say with certainty whether all of the aforementioned tools were used exclusively for human combat or if they functioned in the performance of utilitarian activities. For instance, knives and arrows were used for scalping and likewise held the function as tools for woodworking and hunting. As such, archaeological findings of weaponry must be considered alongside other lines of evidence to substantiate a broader pattern of interpersonal violence (Lambert, 2002; Dye, 2006; Dye, 2009; Milner et al., 2013). For example, arrows embedded in human bone provide convincing evidence of interpersonal violence, as does circumferential cut marks on the calvarium indicative of scalping (Owsley and Berryman, 1975; Smith, 2003; Steadman, 2008).

Iconography provides symbolic evidence for the significance of warfare in Mississippian society. Battle scenes, warriors, and trophy taking have been depicted in various forms such as pictographs, petroglyphs, and ceramic vessels. Dancing figures holding beheaded victims and pictures of human sacrifice have been found on sheet-copper plates and engraved marine-shell gorgets from Mississippian sites (King, 2001; Knight et al., 2001; Brown and Dye, 2007; Cobb and Giles, 2009). Military iconography appears to have been an integral part for the elite to establish their sociopolitical authority

through the materialization of a warrior ideology (Dye, 2006). However, the authenticity of warrior imagery is often called into question as such depictions may represent imagined characters and not actual scenes. It is obvious that some imagery is invented and represents mythical beings and supernatural creatures. As with war weaponry, multiple lines of evidence must be utilized to corroborate or discount iconography that supports the presence of warfare in the archaeological record.

Lastly, osteological evidence of violent trauma provides direct evidence of warfare in prehistory. Cranial blunt force trauma—either healed or perimortem—may be indicative of interpersonal violence. Evidence of antemortem cranial defects such as a depression fracture with signs of healing suggests a non-lethal injury. Blunt force perimortem trauma to the cranium would present a series of radiating and concentric fractures radiating from the impact site with no evidence of healing. Cut marks due to perimortem injuries, scalping, decapitation, or dismemberment likewise leave signature marks on bone. Parallel cut marks on the frontal or circumferentially around other bones of the calvarium suggest scalping, a form of trophy taking (Owsley and Berryman, 1975; Smith, 1995; Bridges, 1996). While the act of scalping is not definitively fatal, survivors may present a depressed surface relative to the unaffected cortex and healing may be complicated by secondary osteomyelitis (Hamperl and Laughlin, 1959; Aufderheide and Rodríguez-Martin, 1998; Ortner, 2003). Cut marks on the base of the cranium, cervical vertebrae, and mandible provide clear evidence of decapitation. Embedded projectile points in bone suggest violent injury, and the location of arrow points may discern trajectory. When postcranial fractures are observed in the archaeological record, they

should be interpreted cautiously, as they could be accidental in nature (Milner, 1998; Steadman, 2008).

It should be noted that isolated findings of trauma do not definitively indicate warfare. The entire pattern in the skeletal sample must be analyzed, as single incidences of trauma cannot rule out accidents (Lambert, 2002). On the other hand, numerous osteological markers of trauma on multiple skeletons buried in a single location may indicate a massacre. Therefore, burial context must be considered. Trauma interpretations that take into account the demographic profile are informative, and may reveal population-level impacts of warfare. A high proportion of male victims may represent a social convention of males commonly participating in conflict, while an equal representation of the sexes may suggest regional differences in the social sanctioning of violence (Bridges et al., 2000). It is important to note that the absence of warfare-related trauma cannot conclusively indicate true absence of conflict. It is possible that material evidence for warfare was not recorded archaeologically. In addition, not all bodily harm is manifested skeletally (Lambert, 2002). This has been documented in prehistoric and forensic contexts, and Walker (2001) has demonstrated that stab wounds and gun shots in modern day medicolegal contexts can be “through-and-through” the soft tissue and not leave their marks on bone.

While there does not appear to be a single causal factor for conflict, it has been suggested that as agricultural intensification rose, so too did the potential for political destabilization and the need to fortify settlements. Intersocietal conflict and subsistence stress shaped Mississippian warfare, transcending earlier forms of conflict present in the Late Woodland Period (Dye, 2006; 2009). Conflict between Mississippian chiefdoms

likely caused both subtle and dramatic shifts in settlement patterns and demographic distributions (Morse and Morse, 1983; Anderson, 1991a; Anderson, 1994; Anderson, 1996; Hally, 1996; Milner et al., 2001; Pauketat, 2007).

Larson (1972) was among the first to evaluate functional considerations of warfare in the Mississippian Southeast. Through his examination of the Etowah site in Georgia, he determined that the site was surrounded on three sides by palisade walls with the fourth side being the Etowah river—a natural barrier to protect from attacks. Larson suggests that the main function of warfare was to gain control of a town, and thus the territory it controlled. In this way, warfare was likely an adaptive mechanism as the demographic pressures of a growing population were tempered by either predatory expansion or a considerable number of deaths causing a decline in the population (Harris, 1971). Arable land would have been of critical economic importance given the reliance on agriculture for subsistence in the Mississippian period.

Gibson (1974) questioned Larson's claim that land control was a causal factor for conflict. Instead, Gibson (1974) attests that the social factors associated with chiefdoms—prestige and revenge—were impetuses of warfare in Mississippian society, serving to regulate social statuses. In an attempt to merge Larson and Gibson's explanations, Dickson (1981) supports both Larson's materialist and Gibson's social rationales. Sociopolitical factors drove warfare on a "tactical level," but competition for land justified warfare on an immediate "strategic level" (Dickson, 1981: 914). Steinen (1992) affirms that warfare had a political goal and was fueled by a continuous struggle for prestige between neighboring polities. As prehistoric groups became increasingly dependent on agriculture, favorable climatic conditions were necessary, though

unpredictable. Extreme climatic conditions may have destabilized crop yields for subsistence, creating both resource stress and disrupting the economic system of chiefdom redistribution (Anderson et al., 1995; Benson et al., 2009; Meeks and Anderson, 2013). Regardless of the causes of conflict in Mississippian chiefdom systems, they were likely interrelated and the importance of agriculture is readily apparent. Much of the research conducted on warfare focuses on its sociopolitical causes and consequences, and seldom considers the physiological costs of conflict. In order to have a holistic appreciation of health and population dynamics, it is necessary to perceive violence as a possible covariate of health, and its impact an individual's well-being.

## Middle Cumberland Region: Geography and Environment

The current study focuses on Mississippian groups from the Central Basin of the Cumberland Basin of middle Tennessee. More specifically, this region spans a 775 square mile area of the Cumberland River Valley in Central Tennessee in close proximity to modern day Nashville. The study area is referred to as the Middle Cumberland Region (MCR). The greatest concentration of MCR sites lies between the intersection of the Caney Fork and Cumberland Rivers to the east and the convergence of the Cumberland and Red Rivers to the west (Moore et al., 2006a). The MCR is situated within two major physiographic locations, the Central, or Nashville, Basin and the surrounding Highland Rim (Figure 2.1). The Central Basin is an elevated depression that spans 125 miles north-south and 60 miles east-west. It is subdivided into Outer and Inner Basins. The Outer Basin is more deeply dissected with a higher elevation than the Inner Basin, which is situated in a lower elevation with a gently rolling, smooth terrain (Miller, 1974; Moore et al., 2006b). The adjacent Highland Rim is several hundred feet higher than the Central

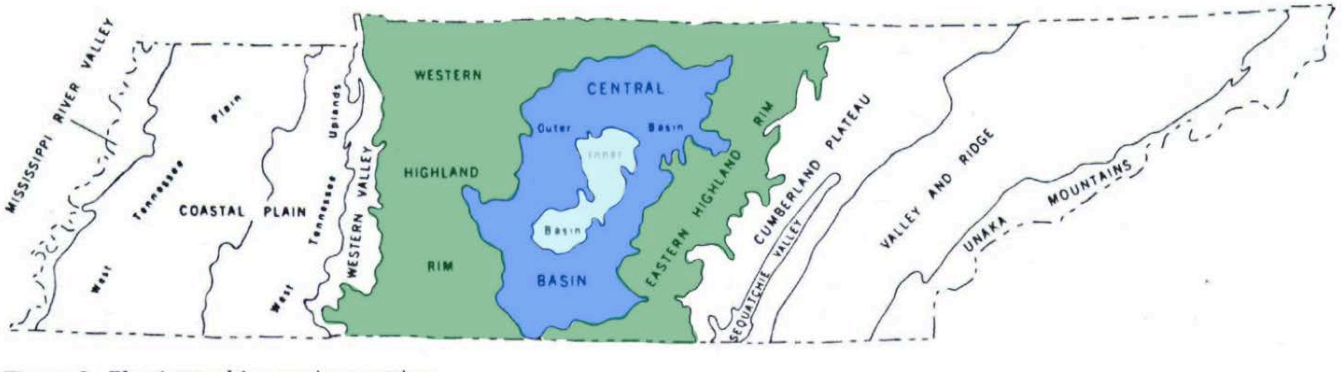


Figure 2.1 Map of the Middle Cumberland Region (adapted from Moore et al., 2006:90).

Blue shading represents the Central Basin, with light blue demarcating the Inner Basin and dark blue signifying the Outer Basin. The Highland Rim is in green.

Basin, with a more dissected and rolling terrain (Moore et al., 2006b).

The riverine networks that cross-cut the Middle Cumberland Region are supported by high annual precipitation averaging 55 inches in the present day. High rainfall in Mississippian times is expected to have given way to diverse flora and fauna, including domesticated maize. Smith (1992) notes that the Cumberland River and its tributaries have wide, well-developed floodplains and experience cycles of flooding every 10-15 years. The threat of flooding, crop loss, and settlement damage may explain why few MCR sites or midden deposits are discovered within the floodplains of Middle Tennessee. MCR sites are unlike most Mississippian settlements, with sites situated "marginally" in higher elevations between secondary or tertiary streams (Ferguson, 1972b; Eisenberg, 1986). Despite the rugged, upland terrain, soil fertility in the MCR is maintained by high levels of naturally-occurring phosphate, allowing for effective agricultural yields to support a growing population in the Mississippian Period (Moore et al., 2006b). In turn, this has prompted researchers to rethink the notion of where successful Mississippian sites are located, and that a deterministic site-soil association may be overly simplistic.

## Middle Cumberland Region: Settlement Chronology

Over 400 Mississippian sites have been identified in the Middle Cumberland Region, variously classified into an array of categories. More than thirty mound centers are present in the MCR, though none rival the size of those found at Cahokia or Moundville. In increasing order of size, these include resource acquisition camps, seasonal agricultural stations, farmsteads, hamlets, village, and towns/mound centers (Autry, 1983; Broster, 1988; Smith, 1992; Moore et al., 2006b). Placement of sites was

likely based on the high phosphate soils of the Outer Basin and, more generally, the geographic arrangement of waterways in the Central Basin. Site types have been incorporated into a regional cultural chronology and two broad regional periods were defined by researchers: the Dowd period (1050-1250 A.D.) and Thruston period (1250-1450 A.D.) (Smith, 1992; Moore et al., 2006). The Dowd regional period is an emergent phase consisting of small farmsteads and hamlets that encircled a centralized town containing platform mounds. The spatial relationship of mounds and settlements suggests the existence of several growing chiefdoms within the MCR. During the subsequent Thruston regional phase, groups began to move away from dispersed sites and congregated in larger nucleated towns. Construction of platform mounds ceased and palisade walls were built around town perimeters, with the region eventually abandoned by around 1500 A.D.

More recently, Moore and Smith (2009:202-210) revised the Mississippian MCR chronology, subdividing it into five regional periods, better illustrating the fluctuation of settlement patterns. Regional Phase I (1000-1100 A.D.) comprised small scattered settlements like farmsteads, hamlets, and villages. Concurrently, mound centers were established on the western edge of the Central Basin, with a chiefdom established at the Mound Bottom site that persisted for at least three centuries. Regional Period II (1100-1200 A.D.) is characterized by an eastward expansion of chiefdoms, including the growth of Mound Bottom. Smaller mound centers at the sites of Moss-Wright and Bowling Farm were also established. The MCR experienced further growth during Regional Period III (1200-1325 A.D.), with more mound centers forming north and south of the Cumberland River. A hierarchy of mound centers and the proliferation of chiefdoms was apparent at

this time, as was the use of stone-box graves and the construction of small burial mounds associated with residential sites.

Regional Period IV (1325-1425 A.D.) signaled a marked shift in cultural and settlement patterning in the Middle Cumberland Region. Mound construction and chiefdom expansion came to a halt, and the possible decentralization of chiefly polities manifested in a move to more village-centered organization. These villages were progressively more fortified, and the number and size of them began to decline. Moore and Smith assert that Regional Period V (1425-1475 A.D.) represents "a concept rather than [an] archaeologically visible reality (2009: 210). The dispersal of nucleated villages and inability of detect archaeological sites in the mid-fifteenth century—with the exception of the Averbuch site (Cobb et al., 2015)—indicates significant population decline.

As I will discuss in later sections, regional depopulation was not a unique phenomenon in the MCR and was experienced by groups across the Southeast and Eastern Woodlands during this time. By Regional Period IV, it is clear that some groups experienced significant social upheaval (Smith, 1992). At sites that date late in the MCR chronology such as Averbuch, skeletal remains indicate that individuals experienced poor dental health (Berryman, 1981; Eisenberg, 1986). Additionally, skeletal evidence of warfare-related trauma have been documented in all but three MCR sites (Worne, 2011). However, limited research has been carried out to quantify whether Late Mississippian MCR populations had reduced survivorship compared to earlier groups that inhabited the region. My research assesses skeletal signatures of a number of biological, social, and

environmental processes that may have contributed to population decline in the Middle Cumberland Region.

## Middle Cumberland Region: Culture History

Isotopic studies of human bone provide evidence that the adoption of maize took place by at least 1000 A.D. in the MCR. Data from Buikstra (Buikstra et al., 1988; Buikstra, 1992) demonstrate that maize intensification was quicker and more extreme in the Middle Cumberland Region compared to temporally similar groups in Illinois and Missouri. In the MCR, as much as 75% of the carbon recovered from bone collagen originated from $C_4$ plants (Buikstra,1992:95). The intensification of maize agriculture allowed local populations to adopt a new lifestyle. Despite the heavy reliance on maize, Mississippian MCR populations diversified their diet and exploited wild plant and animal species. Nuts, berries, and fruit comprised an important portion of the MCR diet, and faunal remains corroborate that hunting, fishing, and trapping continued to be an important part of their subsistence economy (Breitburg, 1982; Smith, 1992). Deer were frequently exploited and supplied meat, hides, and bone to work into tools. Smaller mammals like squirrel, rabbit, and raccoon were commonly found in the zooarchaeological record, with birds making up the second highest proportion of the faunal assemblage, particularly wild turkey (Smith, 1992). These findings maintain that MCR populations relied on mixed hunting and gathering and maize agriculture subsistence strategies.

Mortuary practices in the MCR include burials in stone-box graves, coffins of stone slabs constructed to the dimensions of the interred individual (Figure 2.2). Ferguson (1972) coined the term “Cumberland Stone-Box” to characterize the graves found in the

MCR. Cumberland Stone-Boxes were form fit to the body, typically wider at the head and narrower at the feet. This style is distributed in the Central Basin and Western Highland Rim of the MCR, with the style shifting to a larger and more symmetric rectangle shape outside of the region. The distinctive construction of these graves, coupled with their distribution, suggests that the Central Basin was at the center of the stone-box phenomenon, with the practice thought to be one of the most diagnostic traits of MCR culture (Brehm and Evans, 1977; Smith, 1992).

Limestone was the most common material used to construct the sidestones, endstones, and topstones of stone-box graves in the Middle Cumberland Region. Pervasiveness of the material is most likely due to the availability of limestone outcrops along stream banks in Central Tennessee (Brown, 1981; Dowd, 2008). After limestone, shale was used, but was only found in 5% of MCR stone-box graves, likely attributed to its scarcity rather than preference. Based on experimental burials, Brehm and Evans (1977) estimate that it would take eight hours to construct a single grave; given the time investment, assembling the grave may have been a principal mortuary rite in MCR culture. MCR stone-box graves usually contained a single individual but were frequently reused by pushing the original occupant to the side and adding another individual next to the body (Dowd, 2008). Variations of the Cumberland Stone-Box existed and include large and small square boxes with flexed or semi-flexed individuals, though these styles comprise only a small fraction of the burials found in the MCR (Dowd, 2008). Unlike the accumulation of exotic grave goods that mark elite burials elsewhere in the Southeast, the spatial distribution of burials appears to have been the primary defining marker of ranked status in MCR mortuary remains (Smith, 1992). Cemeteries in small towns and villages




Figure 2.2 Example of a Cumberland Stone-Box grave from Gordontown (40Dv6)

(Dowd, 2008: 178)

.were possibly of specific familial lineages. With only a quarter of excavated MCR burials containing grave artifacts, wealth appears to have been egalitarian but perhaps distributed to a small extent at the village level. Smith (1992) suggests that these burials represent kinship lineages within villages that were able to achieve a particular status during their lifetime. The type and quantity of grave goods of MCR mortuary data appear to reflect achieved wealth rather than ascribed, inherited status. Furthermore, Smith (1992) theorizes that individuals buried in or near mounds were of higher status and from wealthier lineages, perhaps living in the mound center or in larger villages.

Evidence of an exchange network between MCR groups and neighboring regions is evident given the presence of non-local goods such as marine shell, mica, and copper (Moore and Smith, 2009). Symbolic iconography representing deities, ceremonies, and religion has also materialized in MCR sites. These include depictions observed on stone, ceramic, shell, and textile artifacts (Ferguson, 1972; Smith, 1992). Decorative representations of the human form are presented on effigy bowls and bottles, pipes, and figurines. Small stone and ceramic figures in seated positions have been found across MCR sites (Figure 2.3); these figurines are thought to symbolize ancestor worship and agricultural fertility (Dowd, 1972; Smith, 1992). The Thruston Tablet represents one of the most intriguing artifacts of the Southeast (Holmes, 1891; Steponaitis et al., 2011). It was found near Castalian Springs in Sumner County where Rocky Creek enters the Cumberland River, and dates to roughly 1200-1300 A.D. (Myer, 1928). This engraved limestone tablet features human figures carrying weapons and arranged in a variety of scenes (Figure 2.4). While Smith (1992) argues that it depicts a historic account of individuals engaged in acts of warfare, Steponaitis and colleagues (2011) contend that it




Figure 2.3 Human effigy bottle from Brentwood Library (40Wm210)

(Moore and Smith, 2009:192)



Figure 2.4 Holmes' (1891) drawing of the Thruston Tablet

(Steponaitis et al., 2011:140)

represents the ideological warfare-cosmology institution of the Southeastern Ceremonial Complex.

## Middle Cumberland Region: Warfare

Evidence of warfare in the MCR has been analyzed by Worne and colleagues. Worne (2011; Worne et al. 2012) examined warfare-related trauma in the MCR by site location and found that many sites were located away from river valleys and in the marginal uplands. Through viewshed analysis, it is apparent that many of the sites located in the hinterlands and bluffs were strategically chosen, affording maximum visibility of the land below. From this vantage point, one could keep watch of a rival group's location. These findings speak to the role of conflict in the Mississippian Southeast. MCR sites such as Averbuch and Gordontown were fortified with palisade walls which, minimally, suggests that a threat of violence was present.

There is no evidence for large scale massacres in the MCR, though skeletal evidence supports conflict-related trauma. Worne (2011) estimated a 5% overall frequency of skeletal trauma, with nine of the thirteen sites studied presenting evidence. Both Berryman (1981) and Worne (2011) report cut marks associated with scalping in a number of crania, signifying enemy trophy taking. Worne et al. (2012) document healed cranial blunt force trauma; the fact that these wounds require time to heal indicates that victims survived the attack and died of other causes later in life. A similar finding of high frequencies of healed cranial blunt force trauma by Smith (2003) in the eastern Tennessee sites of Dallas and Mouse Creek further provide further credence of endemic warfare in the Southeast. Both Worne (2011) and Smith's (2003) findings of healed blunt force trauma from sites in Tennessee indicate that conflict may have functioned as a form of

ritualized conflict, representative of interpersonal violence more than intergroup violence. Heightened competition resulted in increased warfare, which caused chiefdoms to wax and wane in sociopolitical complexity and dominance. By incorporating the skeletal trauma markers analyzed by Worne (2011), I consider violence to be a co-variate of health in order to discern the epidemiological impact of warfare on risk of death in the MCR.

## Population Decline of Prehistoric Populations

Cycles of warfare persisted regionally and challenged weaker neighboring chiefdoms across the Eastern Woodlands during the Mississippian Period. Individual Mississippian societies are said to have undergone phases of chiefdom "cycling": materialization, development, collapse, and reemergence, with the process playing out at a regional scale (Anderson, 1996). Anderson (1990, 1994, 1996) uses findings from the Savannah River Basin to demonstrate that Mississippian societies did not hold on to prominence for more than one or two centuries. One society expanded and gained power at the expense of weaker neighboring groups; this created the hierarchical pattern of primary-secondary administration centers characteristic of complex chiefdoms. (Hally, 1996) Anderson (1994:9-10; see also Hally, 1993) describes this behavior as "the recurrent process of the emergence, expansion, and fragmentation of complex chiefdoms amid a regional backdrop of simple chiefdoms." This model proposes the emergence of large mound centers from an antecedent series of smaller centers, with these complex chiefdoms fractioning once more into a number of smaller, autonomous centers down the line. Therefore, the regional settlement pattern oscillates between simple and complex chiefdom configurations. Many reasons have been advanced to generate cycling

behavior, including climate variation, factional competition for chiefly office, and rivalries between large chiefdoms in river valleys (Anderson, 1994, 1996).

Blitz (1999) evaluates South Appalachian mound centers and posits a "fission-fusion" process as an alternative explanation of Mississippian political development; Blitz believes that the simple-complex chiefdom cycle cannot explain the full extent of spatial arrangements and political dynamics. He agrees that large chiefdoms emerge from small ones, which in turn morph into less centralized polities. However, Blitz (1999:589) asserts that configurations fluctuated between dispersed and concentrated regional centers without ever establishing hierarchical administration centers. In this way, settlement patterns and polity formation were driven by a desire for autonomy and a need for security. Both cycling and fission-fusion processes recognize that Mississippian chiefdoms did not follow a straightforward path of increasing complexity. Instead, individual chiefdoms continually rose and fell as a result of their inherent political instability mediated by warfare, environment, and subsistence stress. When regional sites are considered spatially, some scholars have referred to the appearance and decline of chiefdom systems alternating in a pattern akin to lights on a Christmas tree (Anderson, 1991; Hally, 2006; Anderson and Sassaman, 2012:166).

A pressing issue, not only among Southeastern archaeologists but Eastern Woodland archaeologists, concerns the fate of many of the Mississippian populations that fail to resurface following collapse, as numerous large scale "abandonments" have been documented in the archaeological record. A myriad of evidence exists in portions of the Late Mississippian Southeast for large scale territorial abandonments and sharp population declines. These derive from a lack of cemeteries, a cessation of major mound

building efforts, and the lack of cultural horizon markers (Williams, 1990; Anderson, 1991b; Anderson, 1996; Cobb and Butler, 2002; Anderson and Sassaman, 2012). While the depopulation of the Southeast resultant of novel measles, flu, and smallpox viruses carried with European expeditions is often cited for the decimation of Native American populations in the 16th and 17th centuries, the cause of regional abandonments observed archaeologically prior to European contact remains elusive. Two examples of regional abandonments in the Eastern Woodlands are given for the Savannah River Basin (Anderson 1994, 1996) and Vacant Quarter (Williams, 1990).

Anderson's (1994, 1996) examination of the Savannah River Basin in South Carolina and Georgia provides evidence for abandonment in the prehistoric Southeast due to regional chiefly cycling processes: oscillating fluctuations of power between simple and complex chiefdoms. Chiefdoms in this region began to appear around A.D. 1100 but disappeared from the landscape by around 1450 A.D., even before European expeditions entered the area. Mound centers dotted the landscape, particularly between 1150 and 1200 A.D. though only the mound centers of Rembert and Mason's Plantation remained by 1300 A.D.; other mound centers could have migrated elsewhere with the hope of finding better land for agriculture or perhaps due to the rival political power held by these centers and a consolidation of power. Rembert's authority in the region faded in strength, and sites at the river mouth and headwaters, at Irene and Tugalo, respectively, reemerged after 1400 A.D. By 1450 A.D., the majority of sites in the Savannah River Basin were depopulated and not inhabited again for another two-hundred years. While Hally (1996) and Blitz (1999) challenge Anderson's cycling model of polity

transformation, there is no question that a widespread abandonment took place in the Savannah River Basin in the 15th century.

### *The Vacant Quarter*

In the Midwest and Southeastern United States, parts of the Central Mississippi Alluvial Valley were virtually abandoned between 1450 and 1550 A.D., leaving a "vacant" or "empty" quarter (Smith, 1986; Williams, 1990; Godfree, 2012). First posited by Stephen Williams in the 1980s, the Vacant Quarter hypothesis describes the considerable depopulation of sites and centers in the Central Mississippi Valley, in the north from the American Bottom to New Madrid, Missouri, in the south up the Ohio River to Evansville, Indiana, and up the Cumberland River to the Nashville Basin (Williams, 1990:173). Through the use of horizon markers and radiocarbon dates, this depopulation refers to an abrupt cessation in major mound building efforts and the demise of ceremonial centers in the region. Williams (1990:173) emphasizes that, rather than complete decimation of the population, reorganization, resettlement, or relocation occurred instead. Although the word "vacant" is invoked, the area was not completely devoid of prehistoric peoples but rather that year-round occupation of settlements no longer occurred.

A growing body of data support the Vacant Quarter hypothesis with sites in the Lower Ohio River Valley (Cobb and Butler, 2002), the central Mississippi River Valley (Morse and Morse, 1983; Benson et al., 2009), the Yazoo Delta (Williams, 2001), the Tennessee River Valley (Meeks, 2009; Meeks and Anderson, 2013), and the Middle Cumberland Region (Smith, 1992; Moore et al., 2006b) documenting the decline of Mississippian cultures. Williams (1990) hypothesizes that river valleys were abandoned

but upland sites would have still been populated, though admits his theory needed testing. The timing of depopulation episodes has been continually revisited, though most concur that the Vacant Quarter was abandoned prior to European contact, and was one of a number of episodes in the late prehistoric period. This pan-regional documentation of abandonment delivers mounting evidence of the phenomenon's existence and less evidence of its nonexistence (Lewis, 1990; Cobb and Butler, 2002; Meeks and Anderson, 2013).

Cobb and Butler's (2002) decade-long research in southern Illinois afforded an opportunity to test Williams' hypothesis that depopulations only took place in the river valleys. Using three upland sites—Hayes Creek, Dillow's Ridge, and Millstone Bluff—the authors observe a sharp decrease in the summed probability distributions of radiocarbon data from these sites, consistent with the timing of the Vacant Quarter between 1400 and 1450 A.D. Cobb and Butler's (2002) research in the lower Ohio valley disproves Williams' hypothesis that abandonment only occurred in river valleys, and provides evidence that abandonment of upland, marginal sites also took place. Their findings lend credence to a notion that regional abandonment cross-cut environmental zones.

Several scholars highlight the southern extent of the Vacant Quarter in the western-middle Tennessee River Valley (Meeks, 2009; Meeks and Anderson, 2013). Using radiocarbon dates and spatiotemporal distribution of sites, Welch (2006) and Anderson et al. (2013) found that abandonment of sites such as Shiloh occurred around 1400 A.D., which corresponds with Williams' (1990) proposed timing of abandonment. The timing of abandonment episodes has been continually revisited, though nearly all

scholars concur that the Vacant Quarter was abandoned prior to the arrival of European expeditions, precluding the effect of novel European disease epidemics as grounds for abandonment.

### *Explaining Regional Depopulation*

Reasons as to why the Vacant Quarter underwent population decline have attracted the research attention of archaeologists and continue to be a heavily researched topic. One credible explanation for abandonment is climate change. In contrast to the Medieval Warm Period (ca. 800-1200 A.D.) when groups may have enjoyed opportune growing seasons, the succeeding Little Ice Age (ca. 1300-1850 A.D.) ushered in an approximately 1-2º C decrease in mean annual temperature (Delcourt and Delcourt, 2004). In addition to cooler temperatures, evidence of sustained droughts may have contributed to decreased maize yields and crop failures.

Several studies in the Eastern Woodlands have used tree-ring derived reconstructions of water availability as a proxy for maize crop yields (Anderson et al., 1995; Stahle et al., 2007; Benson et al., 2009; Nolan and Cook, 2010; Meeks and Anderson, 2013). Benson et al.'s (2009) research in the American Bottom uses values published by Cook et al. (2004) to conclude that favorable climate conditions correspond with an increase in agricultural productivity in the American Bottom where the large Mississippian center of Cahokia was located. These conditions allowed for the population expansion in downtown Cahokia and adjacent administrative centers. Subsequent multidecadal droughts contributed to arid soils and drought, which may have compromised agricultural productivity and led to the demise of Cahokia.

Similarly, Meeks and Anderson (2013) examined the possibility that prolonged drought events led to decreased maize yields for five regions in the Vacant Quarter. Tree-ring derived reconstructions of spring rainfall water availability and radiocarbon dates were used as a proxy to infer population histories. Bald cypress trees are typically used for paleoclimatic reconstructions as they are very sensitive to spring rainfall fluctuations (Anderson et al., 1995). The estimated crop yields derive from the Palmer Drought Severity Index (PDSI), a most commonly used drought index from the National Climate Data Center (Cook and Krusic, 2004). PDSI values measure soil moisture and temperature to determine any deviations from "normal" soil properties. Maize is reported to be highly sensitive to moisture conditions (Meeks and Anderson, 2013). Extreme fluctuations in climate may have caused excessive rainfall or prolonged drought, either of which would have drastically altered the subsistence strategies of populations at hand. Meeks and Anderson (2013) calculated the food reserves necessary to sustain a population if suffering from extreme climate conditions. They determined that a two-year storage capacity was essential to maintain a chiefdom's status and control of other polities. Their reconstructions documented four periods of drought-induced stress during the Mississippian period. Two of these events correspond to the time frame of abandonment in the Vacant Quarter and would have directly affected the MCR. These findings present a convincing explanation for depopulation, as drought-induced crop failures offered little incentive to remain in their current settlements. Limited availability of resources may be placed stress on groups, resulting in competition and heightened intergroup conflict. For prehistoric groups relying on precipitation-dependent resources such as maize, the impact of the Little Ice Age is assumed to have been profound,

prompting demographic shifts and movement across the landscape (Benson et al., 2007; Benson et al., 2009; Meeks and Anderson, 2013).

Sociopolitical transformations provide additional grounds for regional abandonment in that they may have been shaped by responses to ecological stressors. For agrarian societies dependent on a narrow range of climate conditions, a period of cooler temperatures, however slight, may have been detrimental to their crop yield. Maize harvests are susceptible to minor changes in rainfall, and an adjustment in climate would affect not only caloric potential but also the redistribution system of a chiefdom's structure (Anderson, 1994; Anderson et al., 1995; Schroeder, 1999). A dramatic decrease in crop yields may have led to political instability, as chiefly elites were increasingly incapable of delivering feasts and ceremonies to the groups they controlled. When elites were unable to establish legitimacy, conflict and population decline may have ensued (Peebles, 1986). Williams (1990) finds sociopolitical transformations the most credible explanation for the regional abandonment. Williams (1990) cites Peebles (1986) who describes the abrupt "Social Devolution" of Moundville in the late 15$^{th}$ century, later than the American Bottom site of Cahokia and the other sites in the Central Mississippi Valley. Williams also references the work of Cordell (1984) in the Southwest, who found that abandonment of villages in the Mesa Verde region may have been the result of the social system's inability to sustain large population sizes. Large-scale abandonments in the American Southwest and elsewhere support the claim that these demographic shifts were not unique to Late Mississippian Eastern Woodland groups.

Furthermore, the nearly contemporaneous emergence of fortification structures in the region's chiefdoms illustrates the importance of conflict in regulating Mississippian

society. Palisaded walls and skeletal trauma observed osteologically suggest that warfare and social unrest were recurrent events (Milner, 1999; Worne et al., 2012). Though chronic interpersonal violence is evident, further dating is needed to determine whether heightened conflict and construction of palisades took place close to the timing of abandonment, hinting at increased political and social strife that may have accelerated population decline. As Hsiang et al. (2013) illustrate, the link between climate change and violence is strong and must be considered as profound stimuli of demographic change in both past and present societies, including phenomena such as regional abandonment.

Anthony (1990) discusses the importance of contemplating the circumstances that precipitate groups of people to migrate elsewhere. He proposes that migration causality has not only negative "push" stresses in the home region but positive "pull" factors as well. While conditions in one's current location may be hostile and uninhabitable, there concurrent factors may attract individuals to move elsewhere. Whether migration was gradual or abrupt, individuals must be considered active agents and not simply passive to the conditions surrounding them. The processes contributing to the collapse of Mississippian populations likely did not act in isolation and can be attributed to a host of interrelated factors.

## Chapter Summary

The Mississippian Period encompassed a diverse series of traits that differed across time and space. The intensive cultivation of maize afforded a reliable food source and permitted groups to grow in size and complexity. Successful harvests served more than just a practical purpose of having a surplus of food during times of shortfalls. It also

served as a means to finance the social structure and support the advancement of the elite through tribute mobilization and redistribution. Many Mississippian settlements rivaled those that we may be more familiar with in Mesoamerica. Conflict played a significant role in the emergence and development of Mississippian societies, as warfare was crucial in chiefdom political consolidation and maintenance. As warfare escalated among Mississippian groups, chiefly officials may not have been able to control their chiefdoms, which would have led to political instability. Despite the wealth of archaeological explanatory models for depopulation, it is unknown how the interface of biological, social, and environmental factors may have taken a toll on the health of many Mississippian groups under investigation. How these processes may have contributed to the survivorship of Late Mississippian period populations and the extent to which individuals were physiologically burdened will be addressed using skeletal collections from the Middle Cumberland Region of Tennessee.

# Chapter 3: Middle Cumberland Region Sites

The Middle Cumberland Region (MCR) of Tennessee has held great interest to both professional and avocational archaeologists for nearly two centuries. Haywood (1823) was among the first to describe the geography and archaeological remains of the MCR, and also reported now-outdated interpretations of so-called pygmies in the skeletal record. Endeavors to "collect" archaeological evidence from MCR sites in the late 1800s were undertaken by archaeologists from the Peabody Museum at Harvard University. Many early archaeological explorations did not have a research agenda so much as a desire to acquire unique artifacts. This is evidenced by poor written records or the keeping of prehistoric artifacts for one's own personal collection.

Today, over 1.5 million people call the greater Nashville area home. Development in and around Nashville has disturbed or destroyed MCR sites in the interest of phosphate mining, construction, urbanization, and farming practices (Moore et al., 2006a). Much of modern-day Nashville is thought to lie atop innumerable sites that were never excavated. From the 1970s to 2000s, cultural resource management and salvage archaeology projects, in conjunction with the Tennessee Division of Archaeology (TDOA) and University of Tennessee, sought to protect and rescue MCR sites (Klippel and Bass, 1984; Moore et al., 2006a). From these endeavors, hundreds of burials have been reinterred following state law or comprise portions of osteological collections. These include skeletal collections at the Peabody Museum of Archaeology and Ethnology at Harvard University, Vanderbilt University, the University of Tennessee, Knoxville, and

the Tennessee Division of Archaeology. These existing collections were the focus of skeletal analyses in this dissertation and total 12 Mississippian sites and 545 adult individuals (Figure 3.1).

The Middle Cumberland Region sites examined here are separated into Early, Middle, and Late Mississippian period groups and presented alphabetically (Table 3.1). These coincide with Moore and Smith's (2009) revised Regional Period chronology of the MCR. Sites that date to Regional Periods I, II, and III were grouped into an "Early Mississippian" category. In the MCR culture history, these sites are indicative of times of emergence, expansion, and proliferation. Sites that date to Regional Periods IV and V were grouped into a "Late Mississippian" category. This time period signals a shift in the cultural patterning of the region, i.e., decentralization and depopulation. Therefore, in this research, MCR sites dating prior to approximately 1325 A.D. are considered Early Mississippian, and post 1325 A.D. sites are Late Mississippian. Three sites (Arnold, Gray's Farm, and Ganier) date to Regional Period III but also had substantial overlap into Regional Periods IV and V. A "Middle Mississippian" category comprises those sites. Given the overlap, this category can be considered a "Middle-Late" chronology. For each site, the site number and current and previous site names are found in parentheses. The location, size, ecology, and culture history is discussed, as is the history of excavations from the nineteenth-century to the most recent archaeological investigations.

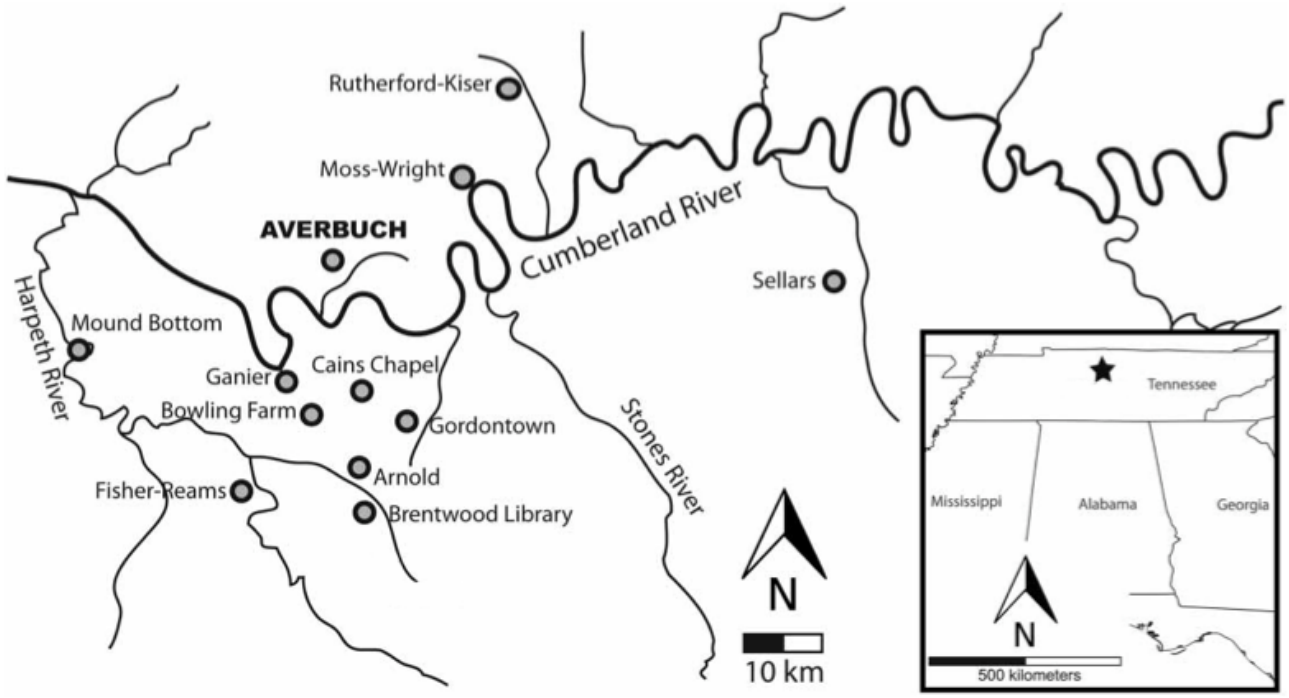


Figure 3.1 Map of the twelve Middle Cumberland Region sites examined

The star on the inset map marks the approximate location of these sites in Middle Tennessee. Figure modified from Cobb et al. 2015, p. 47, Fig. 1

Table 3.1 Middle Cumberland Region Sites and Dates

| Site | Occupation Dates (A.D.) | Regional Period | Time Period |
|---|---|---|---|
| **Bowling Farm** (n=29) | 1100-1250 | II-III | **Early Mississippian MCR** |
| **Moss-Wright** (n=13) | 1000-1200 | I-II | |
| **Mound Bottom** (n=4) | 900-1325 | I-III | |
| **Noel Cemetery** (n=25) | 1175-1265 | II | |
| **Sellars** (n=4) | 1000-1240 | II-III | |
| **Arnold** (n=61) | 1200-1425 | III-IV | **Middle Mississippian MCR** |
| **Ganier** (n=4) | 1200-1475 | III-V | |
| **Gray's Farm** (n=21) | 1200-1475 | III-V | |
| **Averbuch** (n=306) | 1275-1475 | IV-V | **Late Mississippian MCR** |
| **Brentwood Library** (n=26) | 1298-1455 | IV-V | |
| **Gordontown** (n=31) | 1294-1443 | IV-V | |
| **Rutherford-Kizer** (n=11) | 1281-1493 | IV-V | |

## Early Mississippian MCR Sites

### *Bowling Farm (40Dv426; Bosley Farm)*

The Bowling Farm site is located on a low ridge overlooking the east bank of Richland Creek in Davidson County, 4.5 miles southwest from Nashville. With permission from the property owner, Frederic Ward Putnam and Edwin Curtiss (both from the Peabody Museum), and John Wesley Powell from the Smithsonian Institution excavated five mounds in 1877. Putnam (1878) reported that the five mounds contained an estimated total of 600 to 800 burials, with all but one placed in stone-box graves. However, the precise number of burials Putnam excavated is unknown. In his report, he notes that one mound contained 250 skeletons and briefly describes 54 individuals of varying completeness. Burial assemblages included ceramic, stone, shell, bone and mineral artifacts such as cylindrical neck bottles (Moore and Smith, 2009). No habitation structures or palisade walls were discovered, and no additional excavations were carried out after 1877. Eighty-nine burials were available for analysis at the Peabody Museum.

While no radiocarbon dates exist for the Bowling Farm site, Moore and Smith (2009) have used artifact assemblages to place the site into Regional Periods II-III (1100-1325 A.D.).

***Moss-Wright (40Su20)***

Moss-Wright is located on the edge of a terrace formation above Mansker Creek in the northeast corner of the Goodlettsville City Park in Sumner County. The soil of the Moss-Wright site consists of the Armour silt loam series, typical of level or slightly sloping stream terraces. The site was first excavated by the TDOA during the summer of 1977 prior to construction of a softball complex. Benthall (1987) archaeological report reveals the presence of a low burial mound containing stone-box graves. Ninety-six stone-box graves were excavated from the burial mound; these comprised 106 individuals, though only 19 were reasonably preserved for adequate analysis, with the rest being too fragmentary and incomplete to study (Benthall, 1987:11). Some lithics were found, but there was an overall scarcity of ceramic vessels or grave goods recovered. At the time of the 1977 excavations, no habitation area was found, possibly attributed to the project's boundaries limited to the mound.

A 1996 TDOA survey of an adjacent plot of land extended the size of the Moss-Wright site. These later excavations unearthed multiple palisade lines, another platform mound, several structures, and a number of human remains (Moore and Smith, 2001:233). Combining the 1977 and 1996 excavations allowed for the analysis of 116 burials at the Tennessee Division of Archaeology. Although no carbon samples for dating were available for Moss-Wright, archaeological evidence suggests that it was an early

mound site occupied during the Early Mississippian Period, placing the site into Regional Periods I-II (1000-1200 A.D.).

### *Mound Bottom (40Ch8)*

Mound Bottom is located 20 miles west of Nashville in Cheatham County. The site is practically surrounded on all sides by water, as it is situated within a horseshoe-shaped bend of the Harpeth River (Figure 3.1). Mound Bottom consists of 14 mounds around a sizeable plaza area, residential areas, and a palisade with bastions (O'Brien, 1977). The Pack site (40Ch1) is located 1.8 miles south of Mound Bottom. Pack and Mound Bottom are thought to be part of a larger complex, referred to by some as the Mound Bottom-Pack locality (Autry, 1983; Smith, 1992; Dye and Smith, 2008). However, precisely how the two sites were related socially, politically, and chronologically is poorly understood (O'Brien and Kuttruff, 2012).

Mound Bottom has been subject to extensive excavations by at least five separate agencies. Curtiss spent three days in 1878 excavating the site for the Peabody Museum. During this undertaking, he surveyed the site, took measurements of the largest platform mound (40 feet), and opened approximately 40 stone-box graves (Moore and Smith, 2009). In the 1920s, on behalf of the Smithsonian Institution, William E. Myer conducted excavations at the Pack site. While in the area in 1923, Myer arranged to have professional engineering maps made for Mound Bottom (Moore and Smith, 2009; Figure 3.2). In 1926, Tennessee State Archaeologist Parmenio Cox and his crew spent one month excavating Mound Bottom. While Cox never published his findings, his field

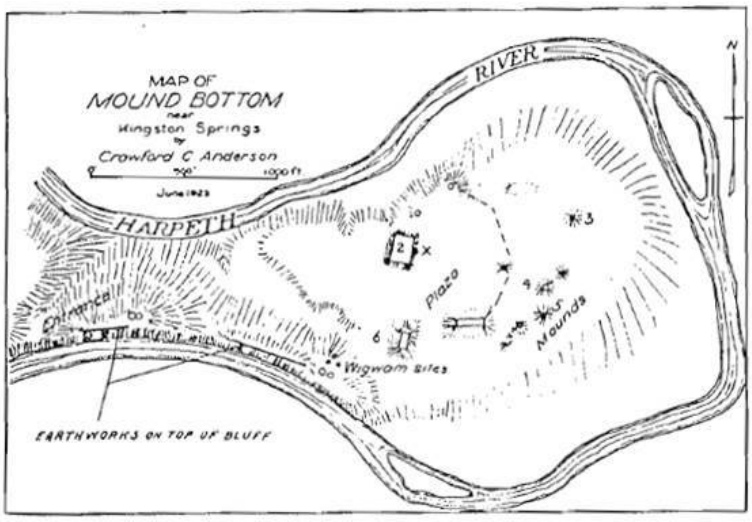


Figure 3.2 Map of Mound Bottom commissioned by William E. Myer

Figure from Moore and Smith, 2009 p. 93, Fig. 100

notes detail the 70 stone-box graves he exposed and their associated grave goods (Autry, 1983). In December 1936 and January 1937, Stu Neitzel directed the University of Tennessee Works Progress Administration (WPA) exploration of Mound Bottom, wherein 34 stone-box graves were excavated. Charles Nash continued the WPA excavations in 1940 and excavated 33 stone-box graves and pit burials. These WPA excavations generated the 26 Mound Bottom burials available for analysis in this dissertation. These skeletal remains are housed at the McClung Museum at the University of Tennessee and were in poor and fragmentary condition. Lastly, the TDOA and a Vanderbilt University field school excavated Mound Bottom in 1974 and 1975. These two field seasons formed the basis of O'Brien's (1977) dissertation. Burials excavated by the TDOA and Vanderbilt University did not yield skeletal remains available for analysis.

The results of decades of excavations at Mound Bottom suggest that the site was occupied for a long period of time, beginning very early in the Mississippian MCR chronology. Ten carbon samples yielded a date range of approximately 900-1325 A.D (O'Brien, 1977). However, O'Brien and Kuttruff (2012) note that these samples were produced by the now-defunct Dicarb Radioisotope Company. This company was found to produce dates consistently younger than assays generated from other labs (Reuther and Gerlach, 2005). Despite this caution, the absence of wide strap handles characteristic of Late Mississippian MCR ceramic vessels also support the early occupation of Mound Bottom (Smith, 1969). Given these lines of evidence, it is likely that Mound Bottom was occupied during Regional Periods I-III (1000-1325 A.D.), placing its occupation in the Early Mississippian period.

***Noel Cemetery (40Dv3; Cain's Chapel; Kain's Chapel)***

Noel Cemetery is located two miles southwest of the Cumberland River along Brown's Creek in Davidson County. During the Mississippian occupation, it is estimated to have spanned one-half square mile. Curtiss surveyed the Noel Cemetery site in 1878 and identified three mounds and hundreds of stone-box graves. He and other archaeologists from the Peabody Museum retrieved over 60 ceramic vessels from these burials, including notched rim bowls and effigy jars. Thruston (1890:2) described Noel Cemetery as "a large town or city surrounded by fortified towns to protect the central thickly settled district." According to Thurston (1890), 3,000 stone-box graves were opened on the site. Unfortunately, none of these burials or other structures were scientifically studied (Benthall, 1983). Many of the burials were later destroyed by looters who turned their attention to site following Thruston's explorations. Over 600

ceramic vessels were recovered from the site. Thruston kept several of these artifacts for his personal collection but later donated some items to Vanderbilt University, with many currently on exhibit at the Tennessee State Museum in Nashville, TN.

Although there has been tremendous archaeological interest in the Noel Cemetery site since Curtiss' time, little is known about the site organization, settlement patterns, and mortuary context (Moore and Smith, 2009). Formal excavations of an undisturbed part of Noel Cemetery were carried out during a three-week period in the summer of 1973 by the Tennessee Division of Archaeology. This salvage project was prompted by the construction of a highway and its exit ramp (Benthall, 1983). The TDOA's 1973 excavations centered on a terrace near the northwest corner of Granny White Pike and Clifton Lane. Its location along Brown's Creek likely provided the main water supply during prehistoric times (Benthall, 1983). The water source would have also attracted animal species, thereby increasing the potential for nearby groups to hunt and fish. The soil of the Noel Cemetery site consists of the Maury silt loam series, with a high phosphate content typical of the broad uplands of the Outer Basin (North, 1977). TDOA excavations revealed a portion of a palisade wall, five structures, eight refuse-filled pits, and 19 stone-box graves (Moore and Smith, 2009:86). Fifty-seven burials were available for analysis at the Peabody Museum. Structure 5, a possible corncrib, yielded an uncalibrated radiocarbon date of 1175-1265 A.D., placing the Noel Cemetery into Regional Period III (Moore and Smith, 2009).

***Sellars (40Wi1; Lindsley Estate, Greenwood Earthworks, Greenwood Seminary)***

The Sellars site is located in a bend on Spring Creek, a tributary of the Cumberland River, in Wilson County. The site is unique as it is the only one in the MCR

located within the Inner Basin. Additionally, it is situated in a “cedar glade,” a biotic region with dense red cedar and low phosphate content. The Inner Basin’s poor soil quality may have resulted in low agricultural potential, deterring prehistoric groups from settling there.

The site was first excavated by Putnam in 1877, and holds an earthwork enclosing between 10 to 11 acres. Inside the earthwork is a large platform mound 15 feet in height, a circular burial mound measuring 3 feet tall, and one-hundred circular ridges of earth ranging from a few inches to 3 feet in height (Putnam, 1878). Outside the earthwork were seven additional low mounds. Putnam’s excavations revealed a variety of artifacts such as animal effigy bowls, steatite pipes, and mica fragments. The best known items from the Sellars site are four well-preserved, seated stone statues (Figure 3.3), acquired by the University of Tennessee in 1940. Excavations of the burial mound exposed 60 stone-box graves arranged “in the form of a hollow square about the outer portion of the mound, in two or three irregular rows and in three tiers” (Putnam, 1878:342). Of the 60 graves, 33 burials were available for skeletal analysis at the Peabody Museum.

The TDOA conducted archaeological investigations at the Sellars site in 1974, 1977, and 1981. These excavations exposed a palisade wall with bastions, a wall trench structure, and a small mound. Radiocarbon dates from the site yield a date range of 1100-1240 A.D. (Butler, 1981), placing Sellars in the Early Mississippian Regional Periods II-III.



Figure 3.3 Four statues from the Sellars site

(photo from the Tennessee Daughters of the American Revolution website, http://www.tndar.org/)

## Middle Mississippian MCR Sites

### *Arnold (40Wm5; Emily Hayes Farm)*

The Arnold site is located on a low, gently sloping ridge along the north bank of the Little Harpeth River in the Outer Basin (Ferguson, 1972a). It is located 9 miles south of Nashville in Williamson County. In 1879, Curtiss explored the site, noted palisade walls and a burial mound with four tiers of graves, and excavated 137 stone-box graves (Moore and Smith, 2009). Artifacts retrieved from the burial mound include human and animal effigy bowls, a Dover chert chisel, and a marine shell gorget (Moore and Smith, 2009:149). Skeletal remains, mostly crania, were shipped to the Peabody Museum.

In 1965 and 1966, amateur archaeologists from the Southeastern Indian Antiquities Survey (SIAS) conducted salvage excavations at the Arnold site in advance of subdivision development (Ferguson, 1972a). These investigations exposed 151 stone-box graves and 17 house structures. Due to time constraints, the domestic structures were not

fully excavated but no evidence exists that the dwellings were rebuilt, suggesting a short occupation. Ceramic artifacts from SIAS investigations include a negative painted owl effigy bottle, human and animal effigy vessels, and notched-rim bowls. Skeletons from the Arnold site are housed at three institutions; 178 burials are curated at Vanderbilt University, 15 burials at the Peabody Museum, and 21 burials were studied at the TDOA. Radiocarbon dates from two femora yield a date range from 1200-1425 A.D. (Ferguson, 1972a). This dates the Arnold Site to the Late Mississippian period, Regional Periods III-V.

***Ganier (40Dv15)***

The Ganier site is situated on 25 acres of gently sloping land on the left bank of the Cumberland River in Davidson County (Broster, 1972). The soil is a rich medium to dark brown loam, satisfactory for agricultural productivity. In 1966 and 1967, archaeologists with SIAS excavated the site prior to destruction by real estate developers. Shell middens, refuse pits, and four features thought to be house structures were found. The site does not present any evidence for platform mounds or palisade lines. The relatively small size of the site and dearth of artifacts recovered implies that Ganier was a small farming village, with no more than 15 to 20 houses present at one time (Broster, 1972:77).

SIAS excavations of Ganier revealed 102 stone-box graves in two different locations (Broster, 1972). The first burial area was located in the south central part of the site and contained the most burials. The other burial area was located to the west near the bank of the creek. 82 burials were available for skeletal analysis at Vanderbilt University.

Radiocarbon dating from Burial 55 yields a date range of 1200-1450 A.D. This dates the Ganier site to Middle-Late Mississippian occupation, Regional Periods III-V.

***Gray's Farm (40Wm11; Fisher-Reams)***

The Gray's Farm site is located inside a bend on the Harpeth River, 13 miles south of Nashville in Williamson County. The site represents one of the most extensive excavations done by Curtiss and the Peabody Museum, yet no map or size estimate of the site exist. Curtiss' excavations in 1878 unearthed several burial mounds, with one mound exhibiting three or four tiers of stone-box graves. These burials contained associated artifacts, in particular, a remarkable number of hooded effigy bottles (n=8) and marine shell gorgets (n=15), among the highest found from a single Mississippian MCR site (Moore and Smith, 2009: 104). Curtiss does not mention the presence of palisade walls at the Gray's Farm site, but it is unknown whether this represents a true absence of fortification structures or simply a mistaken omission in his notes. A habitation structure existed along the ridge of the site with a higher proportion of juvenile burials than adult burials reported. This was a common finding, as juvenile burials are typically located under and around house floors in Mississippian sites.

One-hundred ninety-seven stone-box graves were excavated, with skulls sent to the Peabody Museum. Subdivision development in the 1970s destroyed part of the habitation area, and construction of a road disturbed one of the burial mounds (Moore and Smith, 2001). The land that the site is located on is privately owned, and no excavations have been carried out since Curtiss' endeavors in the 19$^{th}$ century. Forty-two burials were available for analysis at the Peabody Museum, consisting mostly of cranial remains. While no radiocarbon dates exist for Gray's Farm, Moore and Smith (2009)

have used artifact assemblages to place the site into Regional Periods III-IV (1200-1425 A.D.).

## Late Mississippian MCR Sites

### *Averbuch (40Dv60)*

The Averbuch site is located on broad hill near a lesser stream in Davidson County. Unlike most Mississippian MCR sites found along major river systems, Averbuch is located on an upland slope nearly 2.5 miles north of the Cumberland River; this leads some to consider its location "marginal" relative to other sites closer to waterways and on more agriculturally productive soils (Eisenberg, 1986). Despite its location in the uplands, the site shows strong evidence of maize agriculture subsistence typical in the MCR (Buikstra et al., 1988). The site was identified during the expansion of the Royal Hills residential subdivision in 1975. The TDOA began surveying the site in 1975, revealing a cemetery, palisaded village, stone-box graves, house structures, and refuse pits (Berryman, 1981). The Department of Anthropology at the University of Tennessee continued full-scale excavations in 1977 and 1978.

Averbuch excavations centered mainly on mortuary recovery. The site consists of three distinct cemeteries with a smaller number of accompanying structures (Klippel and Bass, 1984; Figure 3.4).Through these investigations, researchers posited that the site structure underwent significant changes during its occupation. For example, the palisade wall infringes upon Cemetery 3, indicating that the cemetery was in use before the town's fortification (Berryman, 1981; Klippel and Bass, 1984; Eisenberg, 1986). It is speculated that the settlement began as a loose cluster of houses, followed by the construction of a

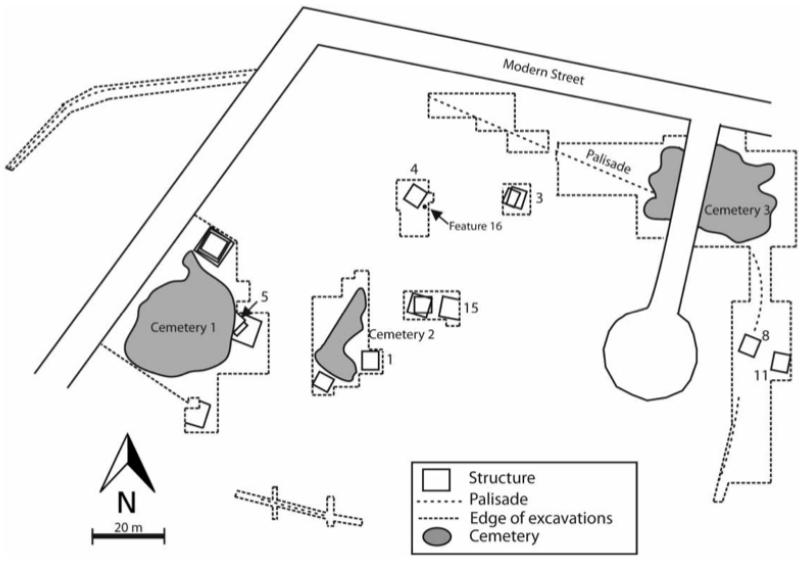


Figure 3.4 Map of the Averbuch site

Figure from Cobb et al., 2015 p. 48.

palisade one or two centuries later, and the subsequent nucleation of the town (Berryman, 1981; Klippel and Bass, 1984; Cobb et al., 2015).

A total of 645 graves were available for skeletal analysis, amounting to 887 individuals. Most of these burials were adults excavated from the three cemeteries, though 35 juvenile burials were recovered from under house floors (Berryman, 1981). These skeletons are housed at the Archaeological Research Laboratory at the University of Tennessee. It is estimated that more graves were present but that 30% of the site was destroyed by recent housing projects and road construction (Berryman, 1981). New AMS radiocarbon dates generated by Bayesian chronological modeling offer support that the Averbuch cemeteries were used at different times (Cobb et al., 2015:52). The site was first established in the late 1200s to early 1300s, with the final portion of the site

occupied into the mid 1400s. Archaeological evidence that house structures were rebuilt only once or twice, coupled with these new radiocarbon dates confirm that Averbuch was occupied for a relatively short span of time (70-205 years). These findings date the Averbuch site to the Late Mississippian period, Regional Periods IV-V.

***Brentwood Library (40Wm210; Jarman)***

The Brentwood Library site is located in Williamson County, 15 miles from Nashville in the Outer Basin. It is situated on a low ridge bounded by the Little Harpeth River to the east and a large tributary to the west (Moore and Smith, 2009). The site was first excavated by Putnam in 1882 and 174 stone-box graves were found. Many of these burials yielded grave goods, namely shell-tempered ceramic vessels, effigy bottles, notched-rim bowls, a beaker, and non-local chert (Moore and Smith, 2009:177). Some of Putnam's findings were published in journals, but he never completed a comprehensive report on the site, which he referred to as Jarman Farm or the Brentwood site (Putnam, 1883b; Putnam, 1883a).

In the summer of 1997, the TDOA responded to a call to examine possible human graves disturbed by construction taking place at the site of the new Brentwood Library. Upon assessment, it was clear that the proposed library was being erected on top of a Mississippian town and construction was immediately halted. After a thorough review of notes from the Peabody Museum and Harvard University Archives, it became apparent that the Brentwood Library site was the same Jarman Farm site described by Putnam in the 19$^{th}$ century.

TDOA excavations of the Brentwood Library site took place between August and November 1997. These endeavors revealed complete or partial post patterns for 67 structures, 24 hearths, 14 limestone clusters, 143 pit features, and 10 ceramic vessels within the library construction zone (Moore, 2005:35). A number of artifacts were recovered from these structures and include shell-tempered vessels, stone tools, shell beads, and faunal remains. Additionally, two separate palisade lines were documented along the southeastern border of the library site, implying a need to fortify the settlement during prehistoric times.

Eighty-five stone-box graves were uncovered, with 66 of the 85 removed that could not be avoided during construction. These graves comprised 75 individuals and were analyzed by Emanuel Breitburg before being reburied by the Chickasaw Nation in 2004. The skeletal remains available for study at the Peabody Museum comprise the sample excavated by Putnam in 1882 and total 141 burials. Six radiocarbon dates obtained from three structures, two pit features, and a palisade post yielded a calibrated date range of 1298-1455 A.D. (Moore, 2005:119). Given that there is some overlap of these dates with Regional Periods yet a majority of them fall in the Late Mississippian period, I have placed the Brentwood Library site into Regional Periods IV-V (1325-1475 A.D.).

***Gordontown (40Dv6; T.F. Wilkinson's Farm, Scales Mounds)***

Gordontown is located on a 15-acre upland ridge between two large springs that feed a tributary of the Cumberland River. The site is located in Davidson County and was first excavated by Dr. Joseph Jones, the Health Officer for the city of Nashville. Through these investigations in 1868 and 1869, Jones excavated one burial mound said to contain

100 skeletons in stone-box graves (Jones, 1876). Curtiss explored the Gordontown site in 1877. His field notes describe a palisade line, habitation and cemetery locations, and three mounds (Moore and Smith, 2009:54). The first mound was a platform mound measuring four feet in height and 24 feet by 28 feet at its summit. Neither burials nor artifacts were encountered in this mound. The second mound was a burial mound measuring five feet in height; this was the same mound excavated by Jones a decade earlier. Multiple tiers of stone-box graves were excavated, and 35 burials were removed. Artifacts recovered from these burials include shell-tempered ceramic vessels, mussel shell spoons, and a notched rim bowl. The third mound was conical in shape and nearly 12 feet tall. Curtiss did not devote much attention to this mound in his notes, probably because of the very few artifacts salvaged. In 1920, William E. Myer of the Bureau of American Ethnology prepared a detailed map and described a platform mound, house structures, and a palisade with bastions (Moore and Smith, 2009). In the mid-1960s, SIAS and Vanderbilt University excavated some of the house structures defined by Myer, but no written documentations of these explorations has been recovered (Moore and Breitburg, 1998).

In 1985 and 1986, the TDOA excavated the Gordontown site prior to construction of a residential subdivision (Moore and Breitburg, 1998). House structures with single post patterns, refuse pits, and a section of a previously unidentified palisade wall were apparent. Many of the mounds described by Jones, Curtiss, and Myer were no longer evident, perhaps due in part to modern farming and construction projects. However, the mound excavated by both Jones and Myer yielded 43 stacked and tightly clustered stone-box graves (Moore and Breitberg, 1998). An additional 100 individuals from 85

undisturbed graves were also removed. One-hundred and one burials were available for skeletal analysis at the Tennessee Division of Archaeology. Two wood charcoal samples were submitted for radiocarbon analysis and produced a date range of approximately 1294-1443 A.D. (Moore et al., 2006b). Though there is some overlap of these dates with Regional Periods, the bulk of them fall in the Late Mississippian period, placing Gordontown into Regional Periods IV-V.

***Rutherford-Kizer (40Su15; Rutherford's Farm, Rutherford-Kiser)***

The Rutherford-Kizer site is situated on a sloping upland ridge overlooking Drakes Creek, a tributary of the Cumberland Region. The site is 20 miles northeast of Nashville in Sumner County. It is located in the Outer Basin, characterized by higher elevations and more deeply dissected terrain compared to the Inner Basin (Moore and Smith, 2001). Site soil is classified as the Maury-Braxton-Harpeth series, with some of the best upland agricultural areas in Tennessee occurring within this soil type. The first excavations were carried out by Curtiss in December 1878. His sketch map included an important reference point: an east-west fence that divides the site into north and south halves; this fence persists to the present day and is of immense use for modern archaeologists. The site spans 15 acres and contains a platform mound twenty-six feet in height, several smaller mounds, house circles, and palisade lines with bastions (Moore and Smith, 2001). Attention was focused on the area south of the east-west fence due to property lines and permissions. Curtiss exposed 108 stone-box graves, the majority of which came from inside palisade walls. The site produced several artifacts including marine shell gorgets, painted effigy bottles, human effigy figurines, and shell-tempered bowls. Perhaps the most unique item recovered from the Rutherford-Kizer site was a

cedar wood disk with a circular piece of buffalo horn on one side and a thin sheet of copper affixed to the other. Moore and Smith (2001) believe this item to be an ear spool, while Putnam postulated that it was a suspended adornment.

The TDOA excavated the Rutherford-Kizer site in response to subdevelopment construction on the property. Moore and Smith (2001) detail the archaeological excavations that took place between 1993 and 1995, again concentrating on the area south of the east-west fence due to restrictions by the land owners. Site investigations in 1993 produced stone-box graves, pit burials, an intact midden zone, large refuse-filled pits, a palisade trench, and a possible elite residential structure. TDOA excavations in 1994 recorded non-mortuary features, defined features exposed from the previous season, and removed the stone-box graves. In 1995, more stone-box graves were found within a proposed house lot, in addition to the documentation of a palisade trench, domestic structure, and three refuse-filled pits. These excavations produced a sparse assortment of ceramic, lithic, and bone artifacts. Very few burials contained grave goods, which may be credited to Curtiss' excavations or looting of the site by locals aware of the site.

The result of TDOA investigations generated a total of 81 stone-box graves. However, due to Tennessee Cemetery Law, prehistoric remains discovered after 1986 are subject to reinterrment following consultation with Native American groups. As such, the TDOA burials were no longer on hand for analysis. The graves excavated by Curtiss yielded 22 burials available for skeletal examination at the Peabody Museum. Carbon samples of Rutherford-Kizer suggest that the site was primarily occupied between 1281 and 1493 A.D (Moore and Smith, 2001). Though there is some overlap of these dates

with Regional Periods, the bulk of them fall in the Late Mississippian period, so I have placed Rutherford-Kizer into Regional Periods IV-V.

## Chapter Summary

Extensive archaeological excavations of Mississippian sites have been conducted throughout the Middle Cumberland Region of Tennessee. Many of these projects were instigated by the development and urbanization of the greater Nashville area. Most of the research in the MCR has focused on site-level analysis, with the Averbuch site of particular bioarchaeological interest due to its large skeletal sample size. The groups occupying these Mississippian sites had disparate experiences, with some living in more optimal locations and under more favorable conditions than others, both socially and environmentally. Did Early Mississippian groups experience better ways of life than Late Mississippian groups, and if so, is this possible to detect in the skeletal record? The focus of the current study is to discern temporal differences in mortality and survivorship across multiple lines of evidence: biological, social, and ecological. In this way, risk of death can be studied as another means to interpret regional depopulation and the Vacant Quarter hypothesis. Before inferences about community health can be made, it is necessary to understand principles of paleodemography and reconstruct the demographic profile of the MCR.

# Chapter 4: Paleodemography: "Devilishly Difficult"

## Demography Basics

Demography offers a porthole into the interactions between people and their natural, economic, and cultural landscapes (Hershkovitz and Gopher, 2008). Literally a "description of people," demography describes people of specific ages and sexes (Bogue, 1969). The field of demography seeks to understand population dynamics through the examination of three processes: fertility, mortality, and migration.

Demographers construct life tables to explore the effects of mortality and survivorship on age-specific probabilities of death. A life table is a mathematical device that summarizes the frequency and probability of events (in this case, deaths) occurring within age intervals (usually 5- or 10-year intervals) throughout the entire range of life of a population (Chamberlain, 2006). The number of deaths taking place within these intervals is used to calculate different parameters of life tables such as life expectancy, the probability that someone entering a specified age interval will die within that interval, and the living age distribution implied by the distribution of deaths across all age intervals (Konigsberg and Frankenberg 2013). Counts of individuals in each age category are used to create life tables. The seven columns that comprise an abridged life table are defined in Table 4.1 (Chamberlain, 2006; Frankenberg and Konigsberg, 2006). Demographers use life tables to reconstruct mortality in living groups, with

Table 4.1 Descriptions of life table columns

| **Symbol** | **x** | **d(x)** | **l(x)** | **q(x)** | **L(x)** | **e(x)** | **c(x)** |
|---|---|---|---|---|---|---|---|
| **Description** | Age | Proportion of deaths | Survivorship | Age-specific probability of death | People-years lived in age class | Life expectancy | Proportion of the living population in age class |

paleodemographers using the approach to examine populations in prehistoric samples, though better approaches (hazard models) have since been adopted.

## Paleodemography Defined

Paleodemography uses archaeological skeletal assemblages to reconstruct the demographic characteristics of past populations. Human skeletal remains are used to estimate the age-at-death of individuals and the sex of adults to identify the mortality profile of a population. The reconstruction of past population dynamics is a key objective because survival patterns are fundamental to our understanding of conditions people experienced in the past. More than merely identifying the mortality profiles of past populations, however, paleodemographers are concerned with health and life-history (Meindl and Russell, 1998). As such, paleodemography is a central focus among bioarchaeologists interested in the impact of changing cultural practices on human biology. It is necessary that paleodemographic interpretations be situated within a solid theoretical framework that considers population processes inferred from archaeological data, such as evidence of fluctuations in settlement and household numbers (Milner et al., 2008).

Demographers of contemporary populations utilize a range of written data including census and parish records, and vital statistics registries that document births, deaths, marriages, and migrations (Bogue, 1969). Unlike contemporary demography where parameters are known or accurately estimated, paleodemographers must make several assumptions. One such assumption of paleodemographic reconstructions is that the age and sex distributions of the skeletal sample are accurate. Furthermore,

paleodemographers assume that these age and sex profiles provide an accurate representation of the death rate of the population. These assumptions cannot be readily validated by paleodemographers in the same way that demographers can been confident in their data. For these reasons among others, Howell (1976:25) remarked that paleodemography is a "devilishly difficult" field.

Paleodemographic analyses rely on the assumption of biological uniformitarianism (Howell, 1976), the assumption that biological processes associated with mortality and fertility were the same in past as they are in the present. In other words, variations in prehistoric demographic trends are constrained and are not expected to diverge much from processes seen today. However, Milner et al. (2008) do not contend that demographic processes such as gestation, maturation, and senescence were invariant across human populations, because otherwise there would be little interest in reconstructing past population dynamics. Rather, they argue that this variation in our human species is limited in predictable ways given particular demographic transitions. The biological uniformitarian principle needs to be accepted in order for paleodemographic analyses to be carried out.

As will be discussed in further detail throughout this chapter, there are a number of theoretical and methodological issues surrounding the practice of paleodemography. Despite its limitations, paleodemographic research has been a central focus among bioarcheologists. The following sections provide a historical overview of developments in paleodemography research within anthropology, from its inception to its rise and apparent downfall. The chapter will also discuss biases inherent in paleodemographic reconstructions and concludes with developments that have advanced the state of the

field, allowing the existing discipline to be more quantitatively robust and statistically sound.

## Early Paleodemography: The Contributions of Earnest A. Hooton and J. Lawrence Angel

Earnest Hooton was the first American biological anthropologist to contextualize skeletal remains within an archaeological framework, thereby informing questions about population dynamics. Hooton (1930) reconstructed the mortality profile of the Pecos Pueblo site in New Mexico, working alongside archaeologist A.V. Kidder. Kidder assigned temporal associations of over 2,000 burials which allowed Hooton to explore temporal changes in demography and disease. *The Indians of Pecos Pueblo* (Hooton, 1930) included assessments of age and sex, documentation of cranial deformation patterns and morphology, cranial and postcranial metrics, and descriptions of pathology. Hooton's use of the Pecos population as a unit of study was rather revolutionary as he went beyond the case studies and summary reports typical of his time. Despite his concern for evaluating survivorship from cemetery samples, Hooton chose not to incorporate life tables or was not aware of their applicability in anthropology. Though Hooton did not employ the most common tool of demographers, his report on Pecos Pueblo is widely accepted as having a profound influence on bioarchaeology today.

Hooton's interest in population dynamics was passed down to one of his students, J. Lawrence Angel. Like Hooton, Angel advocated for close working relationships between skeletal biologists and archaeologists. It was only through this kind of collaboration that effective interpretations of past population dynamics could be put forth. Angel was aware of life tables in demography research but rejected their use in paleodemographic contexts. He believed that the life table approach made three false

assumptions: 1) that the cemetery represents a single generation cohort, 2) that death rates are equal at all ages after infancy, and 3) that the population was biologically and socially stable during its use (Angel, 1969:428). He stated that life tables from cemetery data "falsify biological fact to a greater or lesser degree" (Angel, 1969:428). As such, he adopted other means of estimating life expectancy. Angel (1947) presented a frequency analysis of crania in broad age classes for his paleodemographic studies of ancient Greece. In his 1969 article, Angel made the assumption that the age distribution of the living was equal to the age distribution of the dead. Angel's calculations and assumptions have since been deemed obtuse and erroneous (Frankenberg and Konigsberg, 2006). Other physical anthropologists such as Howells (1960) and Johnston and Snow (1961) also shunned the use of life tables. Instead, they compared the age structure of the target sample with archaeological samples as a means to infer population size. Although early paleodemographers did not embrace the accepted approach of demography, their research was more sophisticated and was conducted within a population process framework by considering a population's growth and decline. Because they went beyond typology and description that typified biological anthropology during that time, their work is regarded as a step forward.

## The 1970s Boom of Life Table Calculations

Despite Angel's criticism of life tables, many researchers did not take heed to his advice. Acsádi and Nemeskéri's (1970) *History of Human Life Span and Mortality* was one of the first major discourses to employ life table calculations in paleodemography. They report results of paleodemographic studies of medieval and Neolithic cemeteries in Hungary and present life tables calculated for past populations. Their efforts to advance

the field of paleodemography were lauded, and the calculation of life tables became commonplace in the anthropological demography literature of the 1970s. Weiss's thesis and subsequent manuscript (1973) further highlighted the utility of life tables in biological anthropology. Ubelaker (1974) calculated life tables with 10-year intervals in his study of a Tidewater Potomac ossuary. Swedlund and Armelagos's book (1976) covered demographic theory and technique with an entire chapter devoted to paleodemography. Additionally, both Buikstra (1976) and Asch (1976) used Lower Illinois Valley Middle Woodland skeletal samples to calculate life tables, with Asch including his knowledge on the concept of stable population theory.

Moore et al. (1975) presented a step-by-step overview of how to construct life tables for paleodemography analysis. The authors also describe adjusting life tables for populations with nonzero growth rates, and discuss the consequences of under-enumeration in life table columns. Their findings reveal that with an under-enumeration of infants, the proportion of deaths in age classes ($d_x$) and survivorship ($l_x$) are affected throughout all age intervals, but life expectancy ($e_x$) and age-specific probability of death ($q_x$) are unaffected past the first age interval. Paleodemographic literature of the 1970s contributed to a gap in knowledge on small-scale societies. Life tables were used to compare human life experiences and mortality profiles across time and space. By using life tables, skeletal data were presented in a systematic manner as a means to document basic demographic processes of ancient peoples.

## Attacks on Paleodemography: Farewell to the Field?

By the mid-1970s, paleodemography experienced an explosion in the calculation of life tables, despite Angel's critiques (Angel, 1947; Angel, 1969) of its application in

biological anthropology. It was also during this time that the discipline began receiving some of its earliest criticisms. The first scathing critique came from William Peterson, a social demographer. Petersen (1975) was dissatisfied with the level of professional competence he witnessed and argued that anthropologists did not have the fundamental understanding of demographic theory necessary to apply it to past populations. For instance, he took issue with Hooton's (1930) comparison of Pecos Pueblo mortality to modern European mortality rates. Petersen was concerned with the small sample sizes anthropologists routinely work with, and paleodemography's reliance on flawed information, techniques, and samples. He did not believe that adequate paleodemographic parameters could be derived from a "paucity of archaeological data" (1975:228). Given Petersen's outsider status in biological anthropology, his critiques did not have much impact on the state of the field.

In the 1980s, criticisms of paleodemographic analyses from within the biological anthropology community emerged and gained traction. The debate began in 1982 with Bocquet-Appel and Masset's seminal paper "Farewell to Paleodemography" wherein they attacked the discipline on two fronts. First, the authors argued that the age-at-death profiles from archaeologically-derived skeletal remains are a product of the age distributions of the reference samples used to develop the age estimation method, henceforth referred to as "traditional" age estimation methods. This problem known as "age mimicry" is an issue that can systematically bias age-at-death distributions. Traditional methods of age estimation are focused on regressing age on a skeletal trait or suite of traits. This is done by using a reference collection composed of documented ages. Traditional methods of adult age estimation examine morphological changes in the pubic

symphysis, auricular surface of the ilium, cranial sutures, and the sternal end of the fourth rib, among other articular joint surfaces. Morphological changes of biological indicators are expected at different ages, given human aging processes. However, when these traditional age estimation approaches are applied to a skeleton or group of skeletons of unknown ages, the age estimates likely suffer from the phenomenon of age mimicry.

One commonly cited example of age mimicry is the age estimation method of McKern and Stewart (1957) This method investigates morphological changes of the pubic symphysis on a documented skeletal collection of Korean War Dead and is comprised primarily of young males. If the method is applied to a target (unknown) sample of diverse ages, the old males in the target sample will be systematically underaged (Bocquet-Appel and Masset, 1982). Since the reference sample is predominantly made up of young adult males, skeletal traits observed in the McKern and Stewart sample will be associated with young ages, even if a trait normally occurs in middle or old adults within the greater population. Depending on the characteristics of the reference sample, age mimicry may result in the systematic overaging of young adults in other age estimation approaches.

Bocquet-Appel and Masset's (1982) second concern rests on the idea that all age estimation techniques are imprecise. The authors posit that a correlation coefficient of at least 0.9 is needed in order for an age estimation technique to be useful in yielding accurate age estimates from a skeletal indicator. They are skeptical that an age estimation method exists that has such a high correlation due to the weak association between biological indicators and age-at-death. Furthermore, few age estimation approaches capture the age of individuals of the "oldest of the old," those grouped into an open-

ended “50+” age category. As the rate of misclassified skeletons by age is unknown and unknowable, Bocquet-Appel and Masset (1982) comment that data are often misinterpreted. The authors assert that any patterns detected in age distributions are simply random fluctuations and the result of error due to small sample sizes and the method employed. Additionally, most traditional age estimation methods lack the rigorous statistical framework necessary to reach reliable, accurate, and valid age-at-death estimates (Chamberlain, 2000). Bocquet-Appel and Masset caution that all paleodemographic age distributions published to date are warped by error and have extreme limitations. They do not believe researchers should abandon estimating age-at-death but contend that it is futile to interpret these age estimates. Bocquet-Appel and Masset advise that paleodemographers should not extrapolate much from age estimates because they are unreliable and uninformative. Given this, they propose that “scarcely anything positive” (1982:329) can be said about the field and are dubious of its utility in biological anthropology.

Age estimates from skeletal remains are used in life table analysis, which includes calculating parameters such as proportion of deaths and survivorship. Use of life tables in paleodemography works under the assumption that the population under investigation is stationary, i.e., fertility and mortality levels are equal, there is zero growth rate, and the population is closed to migration. However, paleodemographers have no reason to assume that a group is stationary. Sattenspiel and Harpending (1983) suggest that the mean age at death attained from the mortality profile is more indicative of fertility levels rather than mortality levels. The notion that birth rate, and not death rate, has a stronger relationship with mean age at death goes against nearly a decade of paleodemographic

research that found age-at-death profiles to be a reflection of mortality. Buikstra et al. (1986) agree with Sattenspiel and Harpending (1983), and established that mean age-at-death influences fertility levels more than mortality levels. In their examination of changes in diet and food processing in west-central Illinois during the Woodland and Mississippian Periods, Buikstra et al. (1986) discovered earlier weaning of infants compared to previous prehistoric times. The shift from foraging to agriculture allowed for increased sedentism and increased fertility rates, resulting in a lower mean age at death.

## Sources of Skeletal Assemblage Bias

As mentioned earlier in this chapter, paleodemographers cannot make the same assumptions as demographers. The absence of written historical accounts, vital records, and census data prohibits paleodemographers from making interpretations with the same degree of confidence as demographers. Paleodemographers must reconstruct mortality profiles from age-at-death and sex distributions, though these are not without their share of skeletal assemblage bias. The term "bias" is used to refer to a systematic departure of an estimated quantity from the expected value of that quantity (Orton, 2000). Paleodemographers must be aware of these potential biases and understand how they can distort the mortality profile of a sample.

### *Curation Bias*

The role that archaeologists and biological anthropologists play in creating biases during excavation and curation must first be considered. If skeletal remains are not recovered, they cannot be analyzed as part of the mortality profile. While secondary epiphyses of subadults are diagnostic to the trained eye, they may be overlooked during

excavation if an archaeologist is not skilled at properly identifying these elements. Excavators differ in their interest in finding bones and in their experience in distinguishing human bone from non-osseous material. As I'll discuss in subsequent sections on intrinsic and extrinsic factors of bone, the bone quality of subadults and elderly individuals is poor compared to that of young adults. Without proper screening measures, hasty or unskilled conduct in the field may fail to recover and retain all individuals in the sample (Lewis, 2007b; Jackes, 2011).

Furthermore, an emphasis on retaining material artifacts has led to uneven sampling of prehistoric populations, as the sites chosen for excavation were the locations thought to yield material culture. As a result, in hierarchically-ranked complex societies, graves belonging to the elite have typically been of greater interest to archaeologists rather than cemeteries comprised of the general population (Milner et al., 2008). In the nineteenth and early twentieth centuries, material culture was preferentially retained for study and curation. Obtaining skeletal elements was often not the primary objective of early archaeological projects, and when skeletal remains were kept, they were typically intact skulls that could be measured or pathological specimens. Therefore, even if skeletal remains were preserved for excavation, subjective biases by archaeologists may have dictated what was recovered long after death, and ultimately what researchers are able to study in the present day.

### *Sex Bias*

Given what is known about living populations, one would expect the sex ratio of skeletal assemblages from past populations to be approximately even. However, Weiss (1972) demonstrates a systematic bias in adult skeletal sex estimation, with females often

being misclassified as males. Weiss' comparison of a large series of adult skeletal samples found a 12% bias in favor of males with the bias being more pronounced in older skeletons. The mastoid process of the temporal bone and nuchal crest of the occipital bone are sexually dimorphic features of the cranium. One reason for the tendency of sex misclassification may be due to the fact that, as females age, these areas of muscle attachment become increasingly robust due to repeated activity. In pre-industrial populations, activity patterns were different and the amount of robusticity may have been greater on average than modern populations, with females taking a male appearance. Additionally, Bennike (1985) explains this tendency for females to be "lost" from the archaeological record given the relatively rapid disintegration of gracile bones typically associated with females compared to males. This is due in part to osteoporosis and postmenopausal changes occurring in older females, with increased craniofacial robusticity mirroring features of adult male skeletons. Microscopically, Cooper et al. (2007) exhibit how cortical bone width deceases and cortical porosity increases with age, particularly among elderly females. Cortical bone diagenesis due to osteoporosis makes the skeletal remains of older females more susceptible to postmortem cortical bone destruction. Waldron (1994) noted a similar sex ratio bias in favor of males in his research using Romano-British cemeteries. Reanalysis of previous research has served to mitigate some of this bias in sex estimation. For instance, Ruff (1981) reassessed a sample of skeletons excavated by Hooton (1930) from Pecos Pueblo. While Hooton recorded 60.4% of the sample being male, Ruff (1981) estimated 50.5% males, a proportion closer to the expected balanced sex ratio.

### *Age Bias*

Many scholars have argued that subadults are "hidden" in the archaeological record (Lewis, 2007a; Pinhasi and Bourbou, 2007; Halcrow and Tayles, 2008; Jackes, 2011). Use of the term "subadult" is based on biological age—individuals under the age of 18—and refers to infants, children, and juveniles (Halcrow and Tayles, 2008). Referring to these individuals as subadults does not imply a hierarchical relationship between subadults and adults. The reasons for the invisibility of subadults in the skeletal record are cultural, biological, and taphonomic in nature, as well as mediated by the skill of archaeologists and biological anthropologists. The notion of personhood is expected to have varied from culture to culture. Some cultures did not regard subadults as full members of society until certain milestones were reached. The transition from subadult to adult may entail a change in gender roles, cultural values, or a sex-based division of labor (Perry, 2005). For these reasons, subadults may have been afforded different or a lack of mortuary rites compared to adults. This could mean that they were not buried in the same location as adults in the community, which would hinder their detection in the archaeological record. It is also possible that the burial rites of subadults hastened exposure to the elements, with limited skeletal remains preserved for later discovery and excavation.

The interplay of intrinsic (biological) and extrinsic (taphonomic) factors further suggests that subadults are hidden in the archaeological record. Using skeletal remains from France and England, Bello et al. (2006) used three bone indices to investigate the preservation of subadult remains relative to their taphonomic surroundings. The anatomical preservation index (API) measures the quantity of bones preserved, the bone

preservation index (BPI) is a ratio of the frequency of bones preserved to the total number of elements expected to be found, and the qualitative bone index (QBI) is a ratio of well-preserved cortical bone relative to damaged cortical bone. The authors show that the depth of graves affected API and BPI; the deeper skeletal remains were found, better preservation was expected. However, grave depth did not contribute to the preservation of cortical bone (QBI). Bello and colleagues found that extrinsic factors did not act in isolation, and taphonomic conditions exacerbate the intrinsic properties of bone.

Bello et al. (2006) reported that juvenile and elderly remains were underrepresented in the cemetery samples. This can be explained by the loss of bone mineral density in the elderly due to osteopororsis and thinner cortical bone and increased trabecular bone in subadult skeletons. These conditions allow for more surface area to come into contact with the soil which aids in chemical exchange and deterioration. As such, under-enumeration of infants is not an unusual finding throughout the archaeological record. This may lead researchers to conclude that a population had low infant mortality, while it is possible that the bones simply did not preserve into the present day. Given the low biological immunity of infants, infant mortality is expected to be high in past populations, therefore this underenumeration of infants in the archaeological record is a serious issue (Goodman and Armelagos, 1989).

Another example of the relationship between intrinsic and extrinsic properties of bone is that of Walker et al. (1988) who investigated the age and sex biases in the preservation of skeletal remains from the Franciscan cemetery of Mission La Purisma in California. This research is unique as there were documented records of those buried in the cemetery, allowing for skeletal findings to be compared with written demographic

information. Walker and colleagues hypothesized that the sandy soil of the cemetery contributed to a seasonal soak-dry cycle. Rainfall predisposes skeletal elements to cyclical episodes of moisture and aridity, creating preservation biases in the skeletal assemblage. According to the written records, 32% of the cemetery sample consisted of subadults. Upon Walker et al.'s (1988) examination of the mortality profile through skeletal analysis, only 6% of the sample was estimated to be subadult age likely due to destruction of these remains from taphonomic conditions. Using a well-preserved prehistoric Late-Middle Period cemetery site in California, Walker et al. (1988) tested their hypothesis and found that subadult and elderly skeletal remains were poorly documented in the sample, suggesting that the bias was created by taphonomic factors and not a true lack of subadults in the mortality profile. The authors conclude that thinner cortical bone and greater surface area of trabecular bone found in subadults generates differential preservation of skeletal remains. Both Walker et al. (1988) and Bello et al. (2006) demonstrate that taphonomic conditions are biased in favor of young and middle aged adults, resulting in an underrepresentation of infants, children, and the elderly in the skeletal record. Reaching such conclusions has a profound impact on the demographic profile of past populations. Teeth tend to be more resilient to the aforementioned intrinsic and extrinsic factors during burial. However, the preservation of unprovenienced, isolated dentition offers little to contribute to the mortality profile of a sample.

Bioarchaeologists must make the assumption that a skeletal assemblage is, to some extent, representative of the once-living population from which it is derived. But given the number of biases and limitations of paleodemographic reconstructions discussed in this chapter, to what extent are archaeological skeletal samples truly

representative of past populations? It is not possible to quantify the levels of bias in preservation by age and sex since some degree of loss will have occurred over time. If a portion of a cemetery sample cannot be reliably aged or sexed due to differential loss of osseous material, the value of that site to make inferences about population dynamics is diminished by an unknown amount. Meindl and Russell (1998) argue that claims made on the effect of differential preservation by age, sex, or taphonomy are overstated. They contend that the potential for age or sex-specific bias should be recognizable by the analyst, and impact on the skeletal sample is negligible.

Figure 4.1 synthesizes the sources of bias that contribute to the creation of a skeletal assemblage (Hoppa, 1999:230). Given that the Mississippian Period Middle Cumberland Region skeletons represent both sexes and an array of ages, it is assumed that sources of bias do not play a sizeable role in the creation of the sites used in this dissertation.

## Paleodemography's Healthy Reexamination

Despite Bocquet-Appel and Masset's (1982) somber outlook, paleodemography research was not abandoned. Since the late 1980s, new methods have been put forth in direct response to the criticisms espoused by Bocquet-Appel and Masset. These research ventures have centered on two fronts. First, there has been prolific research on increasing the accuracy and limiting the bias of adult age estimation methods. Second, the utility of hazard models has been explored as an alternative to life table calculations. Both of these research endeavors represent significant advances to the field and have undoubtedly strengthened the state of paleodemography. My dissertation research uses elements from

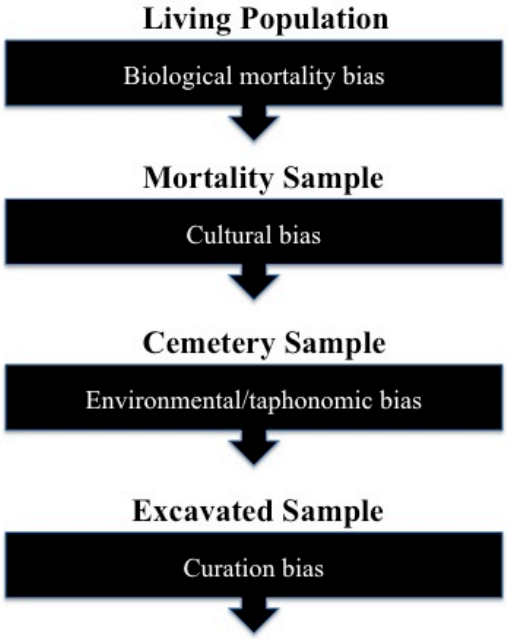


Figure 4.1 Sources of bias that create the skeletal assemblage

(modified from Hoppa, 1999:230)

these improved methodological and theoretical advances.

### *Adult Age Estimation Advances*

Age estimation critiques fall on two fronts: 1) the issue of age mimicry and 2) the imprecision of age estimation methods. This section will highlight recently developed and adopted paleodemographic methods that have responded to critiques put forth by Bocquet-Appel and Masset (1982).

Traditional age estimation methods have used the central tendency of age for certain skeletal indicators, or rely on a form of regression analysis; inverse regression involves regression of age on a skeletal indicator state to estimate age-at-death. In this way, the probability of observing a skeletal characteristic or suite of characteristics, *c*, given known age *a*, is examined: ($Pr(c|a)$). Then, the age estimation method is applied to skeletons of unknown ages to derive an age estimate. Bocquet-Appel and Masset (1982) are critical of any mortality profile derived from these traditional age estimation methods. Use of these age estimation methods is subject to the phenomenon of age mimicry, wherein the age-at-death distribution of the target population closely resembles the age distribution of the reference population used to generate the method. However, this issue of age mimicry is not novel; Buikstra and Konigsberg (1985) note that biological anthropologists were aware of the problem and have made ongoing efforts to develop more generally applicable techniques.

Two workshops hosted by the Laboratory of Survival and Longevity at the Max Planck Institute for Demographic Research represent collaborative efforts to advance paleodemographic methods. The workshops were held in 1999 and 2000 and brought demographers, biological anthropologists, and biostatisticians together to discuss better

ways to approach age distributions of skeletal samples. Workshop participants were given identical datasets based on individuals of known ages and applied age estimation methods to these data. While their statistical methods differed, they realized that the theoretical framework on which the methods were based on was of paramount importance. From these fruitful dialogues, a theoretical approach known as the "Rostock Manifesto" was introduced. These discussions were amassed in an edited volume by James Vaupel and Robert Hoppa in 2002. In the first chapter of *Paleodemography*, Hoppa and Vaupel (2002:2-3) detail the theoretical basis of age estimation methods that all researchers should focus their attention in order for paleodemography to move forward. The Rostock Manifesto contains four elements:

1. The need to better identify osteological features that relate skeletal morphology with age, in particular, methods that will capture the age of older individuals in a skeletal sample
2. The need for better skeletal reference samples of known ages
3. The realization that what is of interest is Pr($a|c$), the probability that an individual is a certain age given a suite of skeletal characteristics, and using Bayes' theorem to calculate this probability
4. The need to assess the age distribution in the target sample prior to assessing individuals ages

One of the more promising developments to emerge from this dialogue was the Transition Analysis method (henceforth abbreviated TA) developed by Boldsen et al. (2002). TA is a multifactorial, component-based system based on well-known age indicators. Its name refers to the method's process of modeling the age at which a particular skeletal characteristic 'transitions' from one phase to the next. Hoppa and Vaupel (2002) assert that the estimation of individual skeletal age should be the last step of obtaining a mortality profile rather than the first step as is the case with traditional age estimation methods. With TA, the probability of observing a set of skeletal characteristics

given age, Pr($c|a$), is the first step necessary to obtain a mortality profile. Love and Müller (2002) call these estimates "weight functions" since they can be obtained without bias from an appropriate reference sample. TA operates under the assumption that the skeletal characteristics chosen are informative of morphological changes occurring with age, and that the skeleton experiences a series of invariant, unidirectional changes during senescence. Through examination of skeletal characteristics from a reference collection, Pr($c|a$) can be calculated. In the current version of TA, the pubic symphysis, auricular surface of the ilium, and cranial sutures are the skeletal characteristics examined to estimate Pr($c|a$) (Boldsen et al., 2002). The Terry Collection at the National Museum of Natural History was the reference sample used to develop TA. The TA scoring protocols will be described in Chapter 6.

However, Pr($c|a$) is <u>not</u> what paleodemographers are ultimately interested in; instead, Pr($a|c$)—the probability of age, $a$, given a set of skeletal characteristics, $c$—is what is truly of interest. Pr($c|a$) is not equal to Pr($a|c$). To attain Pr($a|c$), TA uses Bayes' theorem, a classic theorem in probability theory first published in 1763. Using Bayes' theorem, it is a prerequisite to estimate or provide f($a$), the probability distribution of lifespans in the target population, which is used to calculate Pr($a|c$). In Bayesian analysis, f($a$) is called the prior probability, or the prior distribution of ages-at-death, since this information comes *prior* to estimating Pr($a|c$). It may seem paradoxical that the distribution one is trying to estimate, f($a$), is required before individual age estimation can proceed (Konigsberg and Frankenberg, 1994). In Boldsen and colleagues' (2002) Transition Analysis method, users can choose one of three mortality profiles from the computer program ADBOU that can be used as the f($a$). The three prior probabilities

(f($a$)) built into ADBOU are: 1) a 17$^{th}$ century rural parish mortality profile from Denmark, 2) 20$^{th}$ century homicide data from the United States, and 3) a flat, or uninformative prior, essentially a mortality profile with mean age at death being uniform across all ages. The Danish and homicide f($a$) mortality profiles are based on previously published mortality datasets in the literature. The Danish prior is typically used in prehistoric contexts, as is the case with the majority of paleodemographic research, while the 20$^{th}$ century prior may be employed in medicolegal contexts by forensic anthropologists.

Only after we use Pr($c|a$) and f($a$) in Bayes' Theorem can we attain what paleodemographers are truly interested in: the probability that an individual is a certain age, $a$, given a suite of skeletal characteristics, $c$ (Pr($a|c$)). Pr($a|c$) is proportional to the product of the prior probability (f($a$)) and the likelihood (Pr($c|a$)). By combining the prior probability and likelihood, the ADBOU computer program uses Bayes' theorem to obtain the highest posterior point estimate of age for each adult skeleton. Using maximum likelihood estimation, a point estimate and 95% confidence interval for each skeletal component (pubic symphysis, auricular surface, and cranial sutures) as well as for all three components can be estimated for each skeleton in the sample. The parameters calculated from MLE represent the highest probability density function "peaks" of the ages when we are most likely to observe the skeletal characteristics under investigation. With Transition Analysis, the estimation of individual skeletal age is the last step of obtaining a mortality profile rather than the first step, as is the case with traditional age estimation methods. The following equation illustrates the components of Bayes' theorem:

$$\Pr(a \mid c) = \frac{\Pr(c \mid a) f(a)}{\int \Pr(c \mid a) f(a) da} \tag{4.1}$$

The TA approach of Boldsen et al. (2002) offers an alternative means to derive age estimates for unknown skeletal remains. It is applicable to small samples, including those samples present in both forensic anthropology and bioarchaeology contexts. TA circumvents the problem of age mimicry through the use of a prior probability (f(*a*)), so the mortality profile of the reference sample does not affect the mortality profile of the target sample. However, great care must be placed so as not to introduce further bias, and for this reason, appropriate prior probabilities must be employed. TA addresses Bocquet-Appel and Masset's (1982) critique that age estimation methods are unable to bound the ages of the 'oldest of the old.' TA has the ability to estimate the age of older individuals in a target sample, and has the potential to demonstrate that prehistoric individuals survived into old age. In turn, TA demonstrates that morphological changes to the skeleton can be informative about age, particularly the pubic symphysis, which runs counter to Bocquet-Appel and Masset (1982) claim that no skeletal traits exist that can be routinely used to estimate age. Recent paleodemographic studies have utilized TA to estimate individual ages-of-death, which are then used to model mortality (DeWitte, 2009; DeWitte, 2010; Wilson, 2010).

### *Hazard Models: An Alternative to Modeling Mortality*

Once individual age-at-death estimates have been generated for each individual in the sample, the researcher must choose how to reconstruct the mortality profile of the target sample. Using skeletal age estimates with life tables presents a series of difficulties. Life table parameters such as life expectancy at birth and probability of dying

cannot be accurately computed from a death assemblage and their ability to accurately reflect past livelihoods becomes disputed (Buikstra and Konigsberg, 1985). Life table calculations involve estimating one parameter for every single age interval; few archaeological sites are adequate in size to support an approach that requires such a large appetite for data. Paleodemographic analyses based on life table data may therefore suffer from overparameterization, resulting in high variance (Wood et al., 2002).

Additionally, life tables operate under the assumption that the variation in each of the age categories is homogenous. For example, it is assumed that there is the same amount of variation around the mean in the age category of 0-4 years old as there is for a 50-54 year old category. This is known to be false, as developmental changes that take place in subadults are canalized and more predictable, rendering less variability (Scheuer and Black, 2000). This is in contrast to degenerative changes in adulthood that are extremely variable, even among individuals who are the same chronological age. Life tables do not optimize the ordinal quality of phase-based traditional age estimation methods or the continuous nature of age-at-death (Frankenberg and Konigsberg, 2006). Also, by lumping individuals into age categories, it is assumed that individuals in the same age category are subject to identical risks of death (Wood et al., 2002). Paleodemographic research that continues to use life tables, and does not appropriately address selective mortality or differential frailty, will be inaccurate. Life tables have little value in paleodemography today because they do not take into account how risk of death varies across a sample. This drawback is avoided when using a method like Transition Analysis which calculates individual age estimates grounded in maximum likelihood

theory. The concepts of selective mortality and heterogeneity in risk will be discussed further in the following chapter.

Several pioneering studies laid the groundwork for the replacement of life tables with parametric hazard models. Hazard models are mathematical equations that include a relatively small number of parameters whose values are estimated from the age distribution of the target sample. Hazard models examine mortality as a continuous function of age rather than a series of discrete values. There are a range of hazard models available. Researchers should be aware of the models that are applicable to demographic data and use the one that best captures the structure of the target sample. While some models represent mortality over the entire human lifespan, some specifically model adult mortality. A goodness-of-fit test can compare how well an age distribution fits. Hazard models provide an efficient means of smoothing mortality data and do not impose a predetermined age structure onto the data. Instead, the data drive the age pattern of mortality (Gage, 1988).

Hazard model parameter estimates correlate with parameters found in life tables. Table 4.2 describes the hazard functions and their analogs in life table analysis, with *a* denoting age. Based on the concept of renewal theory, all three hazard model parameters are mathematically related to each other. Once one function is estimated, the other two can be calculated (Cox, 1962; Wood et al., 2002). The hazard function is the force of mortality rate that occurs on a scale from zero to one. It is a non-negative function that is high during infancy, declines during young and middle adulthood, and steadily increases with advancing adult age. With age, the survival function decreases from one to zero. The slope of survival curves can be compared within and across samples, and inferences on

Table 4.2 Descriptions of hazard functions with analogous life table columns

| **Hazard function** | **Hazard function description** | **Replaces the following column in life table analysis** |
|---|---|---|
| *h(a)* | Hazard rate, the hazard of dying at age, *a* | $q_x$ |
| *S(a)* | Survival function, the probability of surviving to age, *a* | $l_x$ |
| *f(a)* | Probability density function for age-at-death | $d_x$ |

increased or decreased survivorship can be made. The probability density function estimates the mortality profile for the sample, given the hazard rate. Figure 4.2 illustrates the relationship of the three hazard functions for the typical age pattern of human mortality.

*Gompertz Model*

Gompertz (1825) developed the first mathematical model of human mortality. The Gompertz model has two parameters: the α (scale) parameter represents the overall level of mortality and β (shape) represents the risk of death increase with advancing age (Wood et al., 2002). In a Gompertz model, the hazard rate is represented by Equation 4.2, the survival function is written is Equation 4.3, and the probability density function is described in Equation 4.4.

$$h(a) = \alpha e^{\beta a} \tag{4.2}$$

$$S(a) = \exp\left[\frac{\alpha}{\beta}(1 - e^{\beta a})\right] \tag{4.3}$$

$$f(a) = \alpha \exp\left[\beta a + \frac{\alpha}{\beta}(1 - e^{\beta a})\right] \tag{4.4}$$

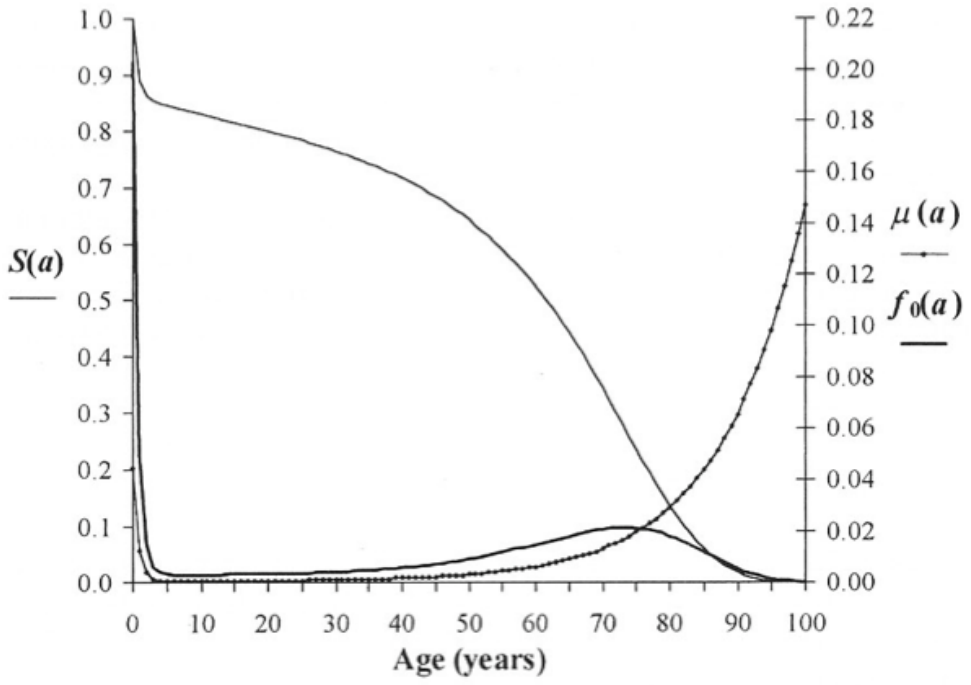


Figure 4.2 The relationship of hazard functions in a typical human mortality pattern (Wood et al., 2002: 139)

These parameters are optimized by computer algorithms to estimate the most likely values given the empirical data. Most hazard models for human mortality use the Gompertz model as its basis.

*Gompertz-Makeham model*

A modification to the Gompertz model was proposed by Makeham (1860) who added a third parameter to the Gompertz model. This parameter captures age-independent adult mortality resulting from accidents or other causes of death unrelated to the aging process. The Gompertz-Makeham model is said to provide the best fit for adults between 30 and 85 years old (Gage, 1988; Finch, 1990).

In a Gompertz-Makeham model, the hazard rate is represented by Equation 4.5, the survival function is written in Equation 4.6, and probability density function is described in Equation 4.7. The $\alpha_1$ parameter represents the residual, or age-independent component of mortality, while $\alpha_2$ refers to the senescent component of mortality that characterizes the Gompertz model.

$$h(a) = \alpha_1 + \alpha_2 e^{\beta a} \tag{4.5}$$

$$S(a) = \exp\left[-\alpha_1 a + \frac{\alpha_2}{\beta}(1 - e^{\beta a})\right] \tag{4.6}$$

$$f(a) = (\alpha_1 + \alpha_2 e^{\beta a})\exp\left[-\alpha_1 a + \frac{\alpha_2}{\beta}(1 - e^{\beta a})\right] \tag{4.7}$$

## Chapter Summary

Despite decades of critiques, interest in paleodemography remains high; in order to interpret the health of prehistoric groups, we must understand the underlying demographic profile. This is evidenced by the prolific number of peer-reviewed journal

articles, conference presentations, and dissertations devoted to the quest to investigate past human life ways. Given the inseparable link between demography and genetics in evolution, we should continue to take interest in paleodemography. As the greater part of humankind predates written documentation, it would be unwise to deem paleodemographic research as being too difficult to form inferences. Criticisms launched in the 1980s did not lead to the demise of paleodemography (Bocquet-Appel and Masset, 1982) but instead, have played a role in its "healthy maturation" (Konigsberg and Frankenberg, 1994:104). In fact, one of the most vehement opponents of paleodemography stated that "one can take an interest in paleodemography again" (Bocquet-Appel, 1994:201), as recent collaborative efforts have addressed shortcomings and built a stronger foundation on which to grow.

The Rostock Manifesto suggested refinements to paleodemographic reconstructions that have since been applied to bioarchaeological analysis. Although the constituents of the Rostock Manifesto are well over a decade old, the Transition Analysis age estimation method is one of the few multifactorial, component-based approaches in use today. The skeletal collections of the Middle Cumberland Region provide an opportunity to implement Rostock protocols and reassess previously-ascertained age estimates. Additionally, using hazard models affords a statistically-rigorous means to model mortality using a small number of parameters. As I will detail in the following chapter, the utility of epidemiological models to discern age- and sex-specific risks of death further contributes to a nuanced understanding of health and past population dynamics in the MCR during the Mississippian Period.

# Chapter 5: A Brief Treatise on Paleopathology Theory

Paleopathology is defined as the study of study of disease in antiquity (Ortner, 2003). In the last several decades, there has been a maturation of the field and a movement from purely descriptive accounts to more quantitative analyses driven by research questions. In this chapter, I will present an overview of the skeletal indicators used as stress markers in paleopathological research. My research centers on the effect that skeletal lesions, as well as cultural and environmental processes, have on risk of death. Researchers have been attentive to the difficulties of interpreting the relationship between skeletal lesions and mortality patterns, thereby complicating the ability to draw inferences about health. Different interpretations of skeletal lesions will be evaluated, as will a summary of recent research that has taken heed to the cautions of the osteological paradox. Additionally, a summary of the paleopathological research conducted in the Middle Cumberland Region is provided, as well as the current study's promise to contribute to a more regional, holistic approach to better understand health during the Mississippian period.

## Skeletal Indicators of Health

There are a number of dental and skeletal indicators suggestive of poor health. This section describes the theoretical basis of the markers of interest used in this research. They are separated into skeletal indicators of childhood physiological stress events and evidence of more recent health conditions in adulthood. Scoring methods will be detailed in Chapter 6.

### *Childhood Physiological Stress*

Studies have hypothesized that childhood stress events affect later adult morbidity and mortality (Larsen, 1997a; Armelagos et al., 2009). Teeth are nearly indestructible under normal taphonomic and burial conditions, and are well-preserved in the bioarchaeological record. Unlike bone, which has the ability to remodel, enamel retains evidence of stress episodes during tooth development and persists throughout life. Therefore, an examination of teeth serves as a record of childhood stress episodes.

A commonly used indicator of physiological stress in childhood is enamel hypoplasias. Enamel hypoplasias represent disruptions in the normal functioning of ameloblasts during secretion of enamel matrix. The most common type of enamel hypoplasias are linear enamel hypoplasias (LEH): horizontal lines, grooves, or pits of varying widths observed macroscopically around the crown of the tooth. Enamel hypoplasias are thought to be caused by nutritional deficiencies, disease, trauma, and/or congenital abnormalities and develop (at their peak) between 2-4 years of age. When the stress has been resolved, ameloblasts resume deposition of enamel in successive layers until crown development is complete. Therefore, the presence of LEHs serve as an indelible record of early childhood stress during permanent tooth development (Goodman and Rose, 1990; Larsen, 1997a; Hillson, 2008; Lukacs, 2012).

Armelagos et al. (2009) surveyed the relationship between the presence of enamel hypoplasias and early mortality within the bioarchaeological literature; they cite several studies that indicate an earlier risk of death among individuals with LEH compared to individuals without LEH (Rose et al., 1978; White, 1978; Cook and Buikstra, 1979; Goodman et al., 1984b). Armelagos and colleagues (2009) interpret these consistent

patterns as bioarchaeological support for the Barker Hypothesis (Barker and Osmond, 1986; Barker, 1989). The Barker Hypothesis stems from observations made in the 1980s, whereby babies born at low birth weights exhibit chronic diseases later in life. An association between low birth weight and Type II diabetes, hypertension, and cardiovascular disease was observed compared to babies born at average weights who lacked a strong correlation to these diseases in adulthood. Armelagos and colleagues (2009) use these bioarchaeological results to validate the idea that childhood stress events predispose individuals to later disease and early mortality.

Stress in subadult individuals during growth and development is typically caused by an interaction between nutrition and infection (Goodman et al., 1988; Larsen, 1997b; Pinhasi and Turner, 2007). Harris lines, cribra orbitalia, porotic hyperostosis, scurvy, rickets, and periostitis represent evidence of nonspecific stress related to nutritional deficiencies and/or infection. Given that bone remodels, the use of these skeletal indicators is less useful than dental indicators. However, cribra orbitalia and porotic hyperostosis serve as two of the most commonly observed skeletal markers of childhood stress (Stuart-Macadam, 1989; Walker et al., 2009). Research suggests that cribra orbitalia and porotic hyperostosis share a common etiology, with cribra orbitalia representing a milder precursor of the condition that produces lesions of the cranial vault (Stuart-Macadam, 1989). Because of their reported common etiology, I will refer to both conditions as “porotic hyperostosis” for the reminder of the discussion. Both conditions manifest as a result of hypertrophic activity of the inner table of cranial diploë with thinning of cortical bone being replaced concurrently with exposed diploic bone. The widening of the diploë is a result of the body’s need to produce and store additional red

cells. As the inner table becomes increasingly full with hematopoietic marrow, pressure is placed on the outer table of the cranium. These conditions develop exclusively in children as an increase in red blood cell production in adults does not involve the use of all available inner table diploë (Lewis, 2007a). Therefore, subadult individuals less than five years of age exhibit the highest frequencies of active porotic hyperostosis lesions (Huss-Ashmore et al., 1982). Lesions are remodeled at a slow rate such that healed porotic hyperostosis lesions may be observed in older juveniles and adults, though these may be more difficult to identify skeletally (Mensforth et al., 1978); this places limits on the inferences we are able to make about the stressors that cause porotic hyperostosis within adult survivors in a population. For this reason, evidence of porotic hyperostosis serves as a complementary marker of stress—alongside linear enamel hypoplasias—that persist in the skeletal record of adults.

A debate regarding the etiology of porotic hyperostosis has been renewed in the last decade. Since the mid-twentieth century, a wealth of studies widely accepted iron-deficiency anemia as the cause of porotic hyperostosis lesions (Britton et al., 1960; Moseley, 1965; Hengen, 1971; Huss-Ashmore et al., 1982; Kent, 1986; Stuart-Macadam and Kent, 1992; Ortner, 2003). The synergistic effects of sedentism, parasitic infections, physiological stress, and low bioavailability of iron have been cited in the clinical and epidemiological literature as causal. Research by Walker et al. (2009) demonstrates that iron deficiency actually results in the suppression of red blood cell production and storage and therefore cannot contribute to lesions associated with porotic hyperostosis. In contrast to iron-deficiency anemia, megaloblastic and hemolytic anemias have the potential to trigger marrow hypertrophic-inducing overproduction of red blood cells in

the marrow, such that porotic hyperostosis lesions are produced. Using hematological research, Walker and colleagues (2009) contend that maternal and childhood diets low in folic acid (vitamin $B_9$) and vitamin $B_{12}$ provide more likely explanations for the high rates of porotic hyperostosis in the bioarchaeological record. To support their claims, the authors use evidence from modern vegans and pregnant mothers who are vegetarian to provide a model for prehistoric populations in which dietary needs are not met. The findings of Walker et al. (2009) suggest that porotic hyperostosis lesions are the result of megaloblastic and hemolytic anemias from a nutrient-deficient diet.

### *Dental Health as a Proxy for Overall Health*

Evidence of an individual's more recent health during adulthood is once again best recognized by the dentition. Dental plaque deposits are made up of large colonies of micro-organisms. The formation of mineralized plaque—dental calculus—is the result of the accumulation of micro-organisms and calcification, which produce an immune response. Bacterial fermentation can lead to focal demineralization, and a cavity or carious lesion, can form. Carious lesions are characterized by focal demineralization of the enamel, dentine, or cement by organic acid found in starchy carbohydrates (Smith, 1991; Larsen, 1997a; Hillson, 2002).

The development of dental caries is not limited to our species, as evidence of lesions similar to caries have been observed in carnivores and domesticated animals (Wiggs and Lobprise, 1997). Dental caries, while rare, was also present among our early human ancestors (Tillier et al., 1995; Caselitz, 1998; Trinkaus and Pinilla, 2009; Walker et al., 2011). Caries is a slowly progressing condition that is strongly related to age (Hillson, 2008). Caries manifests in several states, beginning as microscopic enamel

opacities before forming a cavity in the crown or root surface. They are unidirectional in their progression with the final stage being tooth loss due to tooth necrosis. Caries also presents itself differently according to the type of tooth; the development of caries relates to surface area, developmental factors, and masticatory demands. The posterior teeth are affected by caries more frequently than the anterior teeth, and the maxillary dentition are affected more frequently than the mandibular teeth. The occlusal fissures and pits of molars are common initiation sites, and as such, these teeth are the most susceptible to caries. More specifically, the first molars appear to be the most affected tooth (Hillson, 2008). First molars are the first teeth of the permanent dentition to erupt, have the greatest surface area of all teeth, and must withstand considerable masticatory demands. Following the first molars are second molars, and then premolars and incisors for caries susceptibility. In populations with high caries presence, all teeth may be affected but molars are at the greatest risk.

Dental abscesses result from an inflammatory response as bacteria and their toxins enter the pulp chamber from carious lesions or attrition (Ogden, 2008). This infection generates fluid that collects in the pulp cavity. If one's immune response can fight the infection, inflammation can subside and the tissues return to normal. If the infection persists, inflammation can increase in pressure and compress blood vessels, and may lead to pulp death (Dias and Tayles, 1997; Hillson, 2002). Periodontal tissues and surrounding bone become resorbed as granulation tissue builds. Pressure is relieved by draining through an abscess. The abscess can be located on the lingual, or more commonly, buccal alveolar bone. The affected tooth is commonly lost when the periodontal ligament is damaged and adjacent, unaffected teeth may be shed as well.

As a carious lesion progresses from a microscopic opacity to a cavity that persists into the dentine and underlying pulp chamber, there is a great likelihood that bacteria will enter the bloodstream. This may lead to an inflammatory response that may result in destruction of the supporting alveolar bone and complete loss of the tooth if left untreated. Antemortem tooth loss (AMTL) can also result from impaction, trauma, and extensive dental attrition that exposes the pulp chamber. Additionally, AMTL can occur following periodontal disease and pulpoalveolar disease, both attributed to oral infections. These inflammatory responses to the gingiva extend to the alveolar processes under the gums. Soft tissue heals and remodeling of the alveolar bone reduces its size. Therefore, AMTL has a complex relationship with caries, abscesses, attrition, and periodontal disease, making it difficult to pinpoint the exact etiology within an individual (Larsen, 1997a; Cucina and Tiesler, 2003; Lukacs, 2007).

## The Transition to Agriculture: Was It Truly Humankind's Worst Mistake?

The transition to agriculture began approximately 10,000 years ago in the Fertile Crescent, marking the Neolithic Revolution (Hershkovitz and Gopher, 2008). Barrett et al. (1998) argue for the existence of three epidemiological transitions, each defined by a unique pattern of disease expression that is tied to distinct forms of subsistence and social organization. While the second and third epidemiological transitions concern more recent experiences related to industrialization and newly-emerging drug-resistant pathogens, respectively, the first epidemiological transition involves the shift to agriculture. A change to more permanent settlements created an environment for acute diseases to proliferate among neighbors in closer quarters. The accretion of human waste from towns

and villages also allowed for the spread of gastrointestinal infections and macroparasites (Ewald, 1994).

Traditionally, the frequency of skeletal lesions has served as markers of poor health. In *Paleopathology at the Origins of Agriculture*, many of the contributors argued that the adoption of agriculture was not a technological advancement, but rather, a poor choice for the human condition (Cohen and Armelagos, 1984). Researchers used geographic sites from across the globe and found that a general deterioration in health, as measured by lesion frequency, appeared to accompany the transition from foraging subsistence to maize agriculture. Six sites were from the Old World, and the United States represented the bulk of studies with nine in the Eastern Woodlands alone. As stated in Chapter 2, the intensification of agriculture was likely due in part to demographic pressures placed on existing wild resources in the Eastern Woodlands and other regions when agriculture was adopted.

Goodman et al. (1984a) examined the skeletal collections of the Dickson Mounds site of Illinois. The authors use life table analysis to derive mortality profiles and inferred that mortality increased significantly during the Mississippian period. They found demonstrable increases in the presence and severity of porotic hyperostosis, trauma, infectious lesions, and degenerative lesions in the Mississippian period compared to the Late Woodland period. Goodman et al. (1984) and other contributors to the book were the first to underscore the major adaptive shift of agriculture and its perceived health consequences. The authors observed a myriad of stress indicators to reach this conclusion, including linear enamel hypoplasias, antemortem tooth loss, Harris lines, periostitis, long bone length, traumatic lesions, and evidence of infectious disease. In

doing so, Cohen and Armelagos' edited volume (1984) catalyzed a generation of bioarchaeologists to investigate past human lifeways, specifically with regard to health.

Many of these interpretations use poor oral health as a proxy for poor overall health. This has been documented extensively in the archaeological record of the Americas, as many studies have shown a marked increase in caries rates associated with the shift from a hunter gatherer diet to a diet high in starch-rich carbohydrates following the intensification of maize agriculture (Smith, 1982; Milner, 1984; Buikstra and Mielke, 1985; Powell, 1985; Lambert, 2000; Lanfranco and Eggers, 2012). Sugary starches—particularly sucrose—found in carbohydrates increase the levels of plaque bacteria found in the oral cavity.

The edited volume *Ancient Health: Skeletal Indicators of Agricultural and Economic Intensification* (Cohen and Crane-Kramer, 2007) serves as a follow-up to studies reported in *Paleopathology at the Origins of Agriculture* (Cohen and Armelagos, 1984). Contributions to this book include new technological and methodological approaches developed in the preceding two decades such as stable isotope and DNA analysis (Hutchinson et al., 2007; Krigbaum, 2007; Pechenkina et al., 2007). Additionally, the volume expands its geographic focus to include regions not investigated in the earlier edited book. Some of the studies in this updated volume as well as other research suggest that a simple cause-effect model equating the adoption of agriculture with poor health cannot be advocated. Several prehistoric Asian cultures that relied on rice farming report low caries rates (Turner, 1979; Pietrusewsky and Tsang, 2003; Oxenham and Tayles, 2006; Tayles et al., 2009). This suggests that rice is not as cariogenic as other domesticated plants like maize. Other patterns are noted in

contemporary indigenous cultures where modern diets high in refined sugars supplant traditional diets during processes of globalization and market integration (Hobdell, 2001; Gaspar, 2010; Vega Lizama and Cucina, 2014; White, 2015).

The notion that the transition to agriculture signaled a general decline in health emerged as the take-home message of *Paleopathology at the Origins of Agriculture*, and has become entrenched within anthropology and the general public. The influential popular science writer Jared Diamond (1987) claims that agriculture was the worst mistake in the history of the human race. He cites heavily from research on the Dickson Mounds skeletal evidence by Goodman and colleagues (1984). In the preface of the reprinted edition of the Cohen and Armelagos (1984) volume the editors remark that when the volume was conceived, "we were not interested in finding a universal outcome of subsistence transformation. We were championing a method (multiple stress indicators) to test hypotheses" (Armelagos and Cohen, 2013:xxvii). Research conducted by individuals external to the Goodman-Cohen-Armelagos school of thought emphasizes the importance of contextualizing regional, environmental, and cultural processes in order to understand the effect of agriculture. *Human Bioarchaeology of the Transition to Agriculture* (Pinhasi and Stock, 2011) represents the most recent tome to reflect on agriculture's effect on the human condition. The contributors to this volume offer multidisciplinary evidence to understand the transition to agriculture in addition to the oft-relied upon paleopathological route. The case studies in this book use a wide array of approaches from biomechanics, paleogenetics, and body size to infer mobility, behavior, and movement (Auerbach, 2011; Marchi et al., 2011; Stock et al., 2011). The

contributions to Pinhasi and Stock (2011) argue that negative effects of agriculture were not universal.

Goodman, Cohen, and Armelagos are dismissive of alternative interpretations that try to explain the health patterns observed in the skeletal record. They believe that a high prevalence of lesions must equate to poor health that coincides with the shift to agriculture. As I previously mentioned, studies in Asia (Pietrusewsky and Tsang, 2003; Oxenham and Tayles, 2006) ascertain that the shift to rice farming did not lead to deleterious health. These studies and those of the Pinhasi and Stock volume (2011) demonstrate that poor overall health was not the ubiquitous result of the agricultural transition in all times and places. While the normative interpretation that a high prevalence of skeletal lesions indicative of poor health may hold weight in some contexts, other interpretations must be seriously considered or can co-exist alongside the traditional interpretation. The traditional interpretation that the frequency of lesions equates to poor health has been called into question and alternative explanations for the presence of skeletal lesions have been put forth.

## The Osteological Paradox

The two-step degradation model of health advocated by contributors to the *Paleopathology at the Origins of Agriculture* volume has been challenged by the osteological paradox (Wood et al., 1992). The osteological paradox contends that there are three analytical issues with inferring prehistoric health from skeletal samples: 1) demographic nonstationarity, 2) selective mortality, and 3) heterogeneity in risk. Of the three, the latter two are the foci of Wood et al.'s paper, as questions regarding migration

and stationary populations are not novel concepts in paleodemography. Additionally, the current research focuses on the latter two concepts, as they affect prehistoric health more directly, and are pertinent to the study at hand.

Wood et al. (1992) assert that we cannot assume that cemetery samples are representative of the living population, as individuals who comprise the mortality sample are dead for a reason. Given this, the skeletal samples that bioarchaeologists are faced with are inherently biased representatives of the once-living population. Wood and colleagues (1992) refer to this concept as *selective mortality*, and it concerns the processes by which individuals enter the skeletal sample. These processes relate to innate biological differences, or differences in cultural attributes or environment, among other factors. *Heterogeneity in risk* refers to the notion that individuals vary in their susceptibility to disease and death. The term "frailty" is also used to describe the susceptibility to morbidity and mortality that varies by age and sex. The idea that frailty is "hidden" refers to that fact that risk of death is unable to be observed directly when we examine all individuals in the same state: death. While the traditional interpretation of skeletal lesions is to assume that their presence is indicative of poor health, we must also consider the notion that individuals with many skeletal lesions represent individuals who adapted to physiological disruptions successfully and survived, suggesting that they were actually less frail than individuals without lesions. Therein lies the "paradox" of paleopathology, making skeletal lesions difficult to interpret.

Selective mortality acts upon heterogeneous frailty (Vaupel and Yashin, 1985; Wood et al., 1992; DeWitte and Stojanowski, 2015). Death is not expected to be uniform across the landscape. Under normal attritional mortality, death is not random but

selective, selecting individuals for entry into the mortality sample who are the frailest individuals at their age cohort; in other words, the individuals we study in bioarchaeological contexts are the individuals the most likely to die at those ages because they have the highest frailty. Every individual possesses different risks of death. No universal explanation for health exists for individuals lacking skeletal lesions from gross examination. However, the absence of skeletal lesions may indicate two possibilities that are not mutually exclusive of one another: 1) the person was healthy: the individual never suffered from the disease/condition under investigation, as it was never encountered or the immune system was strong enough to resist it, or 2) the person was very frail and died before skeletal lesions had an opportunity to manifest. Therefore, the interpretation of the presence and absence of lesions is complicated by the fact that it may take a long time for some lesions to form (Ortner, 1991; Wood et al., 1992). Again, this relates directly to the notion of hidden heterogeneity in frailty, the idea that individuals have varying susceptibility to disease and death. These risks are age- and sex-specific, as well as contingent on pre-existing health conditions and lived experiences.

Because of selective mortality, crude frequencies of skeletal indicators of stress are not useful to estimate the prevalence of stress or disease in the living population. By equating the prevalence of lesions with the prevalence of the associated lesion's condition, we would overestimate the number of cases in the living population. For the aforementioned reasons, as well as the paleodemographic issues raised in the previous chapter, life tables are not appropriate to derive mortality profiles for paleopathological contexts. We need models that will relate risk of death, including events that took place

early in life and even *in utero*, with adult disease and death. Therefore, we need to take into account the mortality profile of the sample.

Wood and colleagues' (1992) concept of the osteological paradox stimulated contentious debates throughout the field of paleopathology and continues to enter dialogues in the present day. Many of the comments immediately following their *Current Anthropology* paper were positive and with agreement that selective mortality and heterogeneous frailty should be explored in earnest. However, several others saw Wood and colleagues (1992) publication as an attack on the field. The call for the development of more robust methods fell short on the critics who were blinded by the critique of the agricultural transition health debate, when in fact, that was not the main issue raised by Wood et al. (1992). Cohen (Cohen et al., 1994; Cohen, 1997) argues that, while the theoretical approach of the osteological paradox may be something to mull over, he is doubtful that hidden heterogeneity in risks and selective mortality play influential roles in the creation of cemetery samples. He believes that a cemetery sample can be representative of the once-living population. As such, Cohen does not believe that the osteological paradox should have widespread applicability in bioarchaeological contexts. Cohen (1997) states that the osteological paradox cannot explain the broad pattern of a two-step degradation model in which high frequencies of skeletal lesions accompany the intensification of maize agriculture in the Americas. Additionally, because these patterns were consistent, Cohen (1997) assumes that seemingly poorer health with the agricultural transition must indicate that the traditional interpretation is correct.

Some comments to the original osteological paradox paper mistakenly interpret the article's take-home message to imply that the presence of skeletal lesions indicates

good health (Eisenberg, 1992; McGrath, 1992; Wilkinson, 1992). While Wood et al. (1992) propose that this interpretation is one plausible hypothesis, there are multiple explanations to consider, each appropriate for different circumstances. The authors urge researchers to move past simplistic binary distinctions concerning the presence or absence of lesions, or poor health or good health. Despite their attempts to clarify that they do not completely dismiss the traditional interpretation of lesions, many scholars continue to characterize the osteological paradox in terms of the skeletal lesions indicating healthy individuals (DeWitte and Stojanowski, 2015:409). Additionally, few took heed to the osteological paradox's call to incorporate demography into skeletal lesion interpretation. Many recent studies continue to report crude frequencies with disregard to age and sex specific risks of death (Hubbe et al., 2012; Nicklisch et al., 2012; Turner and Armelagos, 2012; Da-Gloria and Larsen, 2014). Responding to Cohen (1994), Wood and Milner (1994) assert that if heterogeneous frailty and selective mortality were truly inconsequential concepts, the work of demographers and epidemiologists would be considered futile, as their findings would not contribute much value to the idea that risk of death is selective according to age, sex, and prior health conditions. DeWitte and Stojanowski (2015) remark that bioarchaeologists are empowered with the ability to move between analytical scales—from health interpretations on the individual level, to the community level, to the regional level and beyond. As such, efforts have been carried out to make comparisons across time and space.

## Attempts to Standardize Health

The Western Hemisphere Project and subsequent Global History of Health Project (GHHP) represent attempts to analyze long-term trends and standardize health in order to

make cross-cultural comparisons. Steckel et al. (2002a; Steckel et al., 2002b) found the coding scheme used by Goodman et al. (1984) to be inconsistent and unstandardized, which makes comparisons across disparate sites a difficult task. In Steckel's project, each individual in the sample was scored on the basis of seven health indicators using a universal coding scale from 0 to 100, with 0 representing the poorest health and 100 representing the best health. These health indicators were used alongside model life table data to derive age-specific rates of death. The seven health indicators examined were dental caries, linear enamel hypoplasias, anemia, traumatic lesions, degenerative joint disease, infectious disease, and stature from over 12,000 skeletons from 65 geographical areas. These data were collected by an international team of researchers with support from the National Science Foundation. Each of the seven health indicators was believed to have equal weight and the findings were aggregated to a single number—the Mark I index—which could be compared systematically and objectively across populations. Through the use of a standardized coding scheme, the researchers believe they were able to quantify "health," making it possible to compare apples to apples, so to speak. Their findings comprise Steckel and Rose's (2002) *Backbone of History* volume, which largely mirrors the findings of Goodman and colleagues (1984) with regard to agriculture: a decline in health accompanied the intensification of agriculture.

There are a host of limitations to Steckel et al.'s (2002) Mark I index. By reducing health conditions to a single index, heterogeneous risks of death cannot be discerned, as mortality does undoubtedly vary among distinct populations, and between ages and sexes. In its current iteration, the health indicators are weighed evenly and one cannot determine whether the presence of one indicator places greater selective pressure on

disease expression, ultimately putting that individual at a greater risk of death. Additionally, the potential for interobserver error exists as many researchers worked on the project, each with dissimilar experience and training of the method. While the authors argue that overall consistency in methods is less important than internal consistency within the research group involved, the project's reliability will be questioned when the health index is applied by external researchers.

Dabbs (2009) was the first researcher not directly involved in the Global History of Health Project to utilize the protocols proposed by Steckel et al. (2002). The overall health status of the Ipiutak (100 B.C.-500 A.D.) and Tigara (1300-1700 A.D.) archaeological populations from Point Hope, Alaska, were calculated. Dabbs (2009) found no difference in the two groups with regard to their health statuses, despite the fact that many of the component health indicator scores were significantly different for the two groups. Likewise, males and females from both groups have health indices that were functionally identical, despite having different component scores for the health indicators. One major critique was the inclusion of stature in the health index. Given sexual dimorphism, the stature component scores for females will be lower than that of males yet this component was not scaled for size, resulting in an automatic "health handicap" for females (Dabbs, 2009:175). Use of the health index suffers from pervasive generalizations and should be employed with caution. It neither considers the complexity of one's cultural and physical environment, nor does it allow for nuances in morbidity and mortality to be fully realized.

## Social and Environmental Indicators of Stress

It is necessary to move past a simplistic assumption that reliance on agriculture as a primary means of subsistence precipitated poor health. A nuanced appreciation of non-biological variables such as interpersonal violence and extreme climatic conditions is required in order for a holistic perspective on health to be made. Research by Hsiang et al. (2013) demonstrates a strong causal relationship between climatic events and human conflict. They use data from multiple disciplines, including archaeology, geography, history, and political science to illustrate that for every one standard deviation change in climate (either warmer temperatures or extreme rainfall), the frequency of interpersonal violence rises 4% and the frequency of intergroup conflict increases by 14%. These findings are profound and suggest that the environment plays a role in causing conflict and political instability. Given Mississippian period reliance on maize as a staple crop, subtle changes in climate may have created conditions that were either too warm or too wet for sufficient harvests. This may have created an unfavorable backdrop wherein the climate fluctuated and groups struggled for favorable land for cultivation.

Conflict should not be viewed merely as a supplemental source of trauma and death (Martin et al., 2012). Interpersonal violence or the threat of violence can have profound impacts on settlement patterns, access to resources, and other variables that may exacerbate disease and physiological stress. Skeletal trauma provides a record of social relationships, be it interpersonal (personal attacks) or intergroup (between discrete groups of people). Additionally, using evidence of skeletal trauma allows us to shed light on human behavior. Given that violence has an effect on the well-being of individuals, the psychosocial effects of warfare must be incorporated into models of risk of death.

Bioarchaeologists must implement models that account for social and environmental constraints, and consider them as covariates of health. Doing so follows Goodman's (1993) suggestion to consider multiple lines of evidence when considering health. Goodman and colleagues (Goodman et al., 1984b; Goodman and Rose, 1990) proposed a generalized stress model to reflect on biocultural perspectives of health in prehistoric societies. Figure 5.1 illustrates that the model begins with the environment serving as an interactive background, able to shape the lives of individuals by providing stressors or limiting resources on which to adapt. Stressors can include extreme heat or cold or limiting resources such as a shortage of food and key nutrients. Cultural processes can serve to buffer existing environmental constraints or exacerbate the environmental conditions. If cultural processes fail to curtail environmental pressures, physiological disruption may result and the host's immune response may be weakened. Any number of stress responses can take effect, including growth disruption, disease, or ultimately, death. The cumulative effects of stress can have drastic impacts on the demographics of a population, manifesting as a rise of infant mortality or low mean age-at-death. Skeletal indicators are a product of physiological stress, but are not the cause of functional injury (Temple and Goodman, 2014). The last box of the model, "Impact of stress on population" represents the potential consequences that generalized stress have on a population. This model is presented as a feedback loop, as the results of demographic manifestations can, in turn, influence the environment and cultural system. The ways in which social and ecological dynamics coalesced with physiological stressors will be clarified in the current research. The current study expands upon the National Science

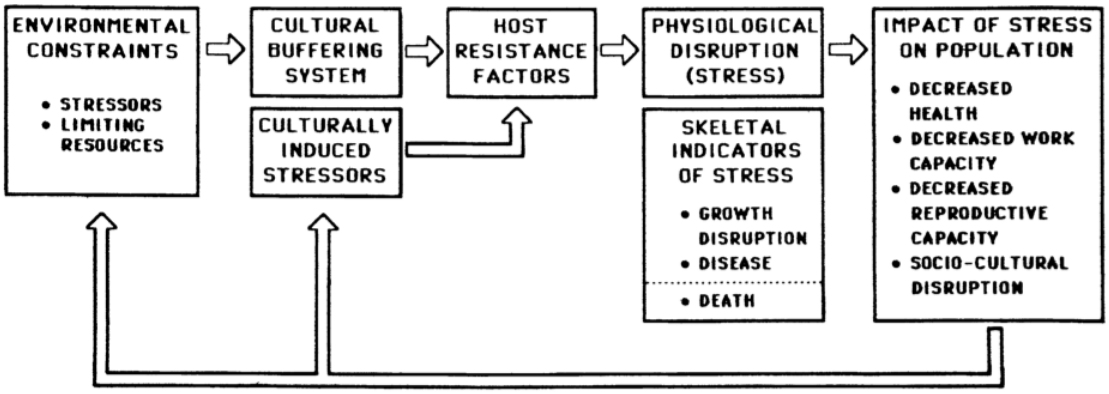


Figure 5.1 Generalized stress model presented as a feedback loop

Goodman and Armelagos (1989:226)

Foundation Grant "Topographies of Mississippian Conflict and Health in the Middle Cumberland Region" awarded to Dawnie Steadman and Charles Cobb in 2006. Frailty analyses provide one means to elucidate risk of death in past populations.

## Advances in Frailty Analyses

A number of researchers have found success employing frailty analyses in order to evaluate age- and sex-specific risks of mortality. One approach that analyzes how early childhood stress affects adult mortality is the work of Boldsen (2007). Boldsen (2007) conducted a frailty analysis looking at LEH in the Tirup cemetery of Denmark. Boldsen (2007) appropriately demonstrates an increased hazard rate of male adults, a continuation of the age-independent hazard rate; this put males at a greater risk of death in adulthood if found to have the presence of LEH developed in childhood, typifying the notion that conditions later in life are a continuation of earlier stress episodes.

Other than tracking childhood stress, several others have employed frailty analyses to discern the effects of pathological conditions from adulthood and their relationship with risk of death. Notably, Sharon DeWitte has used hazard models to glean prehistoric mortality profiles in London before and after the Black Death (Dewitte, 2014). DeWitte has also published many works on the relationship between age- and sex-specific risks of death given conditions such as periodontal disease, periostitis, and dental caries, comparing the exclusively Black Death sample of the East Smithfield cemetery in London with cemetery samples unaffected by the Black Death in Denmark (DeWitte and Wood, 2008; DeWitte, 2009; DeWitte, 2010). While many have hypothesized that an event such as the Black Death was so virulent that it killed people regardless of age, sex, or pre-existing health conditions, DeWitte and colleagues have discovered that selective mortality was still in effect, though perhaps not as strong as selective mortality in an attritional mortality sample. To conduct these frailty analyses, she used a combination of Gompertz-Makeham and Siler models, as well as Usher's (2000) multistate model of morbidity and mortality, which draws on principles of the Siler model.

Wilson (Wilson, 2010; Wilson, 2014) used hazard analyses to examine the paleodemography and paleoepidemiology of the Mississippian central Illinois valley. He found differences in sex-specific risk of death, illustrating the presence of heterogeneous frailty between males and females. Such frailty analyses provide examples of demographic and epidemiologic models that allow for the effect of early childhood stress events on adult morbidity and mortality to be realized.

The current research conducts frailty analyses on twelve sites from the Mississippian Middle Cumberland Region. By separating MCR sites into different time

periods, it is possible to detect mortality patterns, specifically, whether risk of death increased from the Early to Late Mississippian period. Additionally, by incorporating the demographic profile of the MCR sample when interpreting skeletal lesions, I am able to investigate age- and sex-specific risks of death given the presence and severity of health co-variates.

## Previous Paleopathological Research in the MCR

Compared to sites like Cahokia and Moundville, Mississippian MCR sites have not been studied extensively by bioarchaeologists. Research on the Arnold and Ganier sites have generated basic demographic profiles, but scarce interest has been given to prehistoric health assessments (Broster, 1972; Ferguson, 1972a). The Averbuch site has received the most attention with regard to both paleodemography and paleopathology; this can be attributed to its large, well-preserved skeletal sample as well as the site's systematic excavation and documentation in the 1970s by the University of Tennessee. Berryman's (1981) dissertation evaluated biological and social stress of individuals from the Averbuch site. He used a life table approach and calculated vital statistics such as mortality, survivorship, and life expectancy. He found a significantly high infant mortality rate with low life expectancy, though these findings may be due to under-enumeration of infants and juveniles in the skeletal record. A second peak in Averbuch adult mortality is evident between 20 and 30 years of age. Berryman used a decrease in mean stature, and the presence of Harris lines and linear enamel hypoplasias to evaluate stress of the Averbuch sample (Klippel and Bass, 1984). In more recent paleopathological studies, there has been a movement away from the use of stature and Harris lines as stress markers. The "normal" stature of prehistoric populations is unknown, and using Harris

lines is problematic as they remodel and are no longer thought to verify physiological stress.

Berryman (1981) examined differences between the sexes and cemeteries among the age distributions. He discovered elevated mortality rates for females 20-25 years old from Cemetery 3, the oldest cemetery of the three. Berryman (1981) found that the Averbuch sample experienced extreme physiological stress, with 93% of males and 88% of females exhibiting linear enamel hypoplasias during the first 4.5 years of life. Results of Harris line observations mirror the LEH finding that males were more stressed than females, however these differences were not statistically significant. He concluded that individuals from Averbuch were chronically stressed throughout the site's occupation, and did not detect any significant increase or decrease in the occurrence of physiological stress events. Stress remained high during the existence of the site, which suggests that individuals who occupied the site early during the initial settlement experienced equally elevated stress episodes as those who occupied the site later and closer to the site's abandonment.

Eisenberg (1986) used Berryman's life table parameters and mortality profiles in her dissertation centered on Averbuch. Her research investigated evidence of porotic hyperostosis and periostitis. Additionally, she evaluated the skeletal record for evidence of infections, namely osteomyelitis, blastomycosis and tuberculosis (Kelly and Eisenberg, 1987). Of particular significance is that over half of the anterior tibiae observed demonstrate new bone formation in the form of periostitis or osteomyelitis (Eisenberg, 1991). Generalized and treponemal infections, trauma-induced infections, and fungal disease may explain the second peak between the age of 20 and 30 in Berryman's

mortality profile. Porotic hyperostosis and cribra orbitalia were observed in high frequencies: 39% or the sample exhibited porotic hyperostosis and over 20% of the sample had cribra orbitalia lesions. The high prevalence of physiological stress markers indicate chronic disease conditions experienced by individuals who occupied the Averbuch site, substantiating Berryman's (1981) findings.

While the works of Berryman and Eisenberg are commended for their biocultural analyses of health, recent advances in paleodemography and paleopathology warrant the reanalysis of Averbuch and other MCR sites. The prior research's reliance on life tables to discern mortality and survivorship curves may suffer from overparameterization. Life table calculations also operate under the assumption that the variation in each of the age categories is homogeneous. This approach does not address selective mortality. New radiocarbon dates of the Averbuch cemeteries from Cobb et al. (2015) provide an opportunity for a refined analysis of demographic changes in a Late Mississippian period site that, along with the application of hazard models, may be detected skeletally. Additionally, Berryman (1981) and Eisenberg's (1986) research is confined to the Averbuch site and does not take a regional perspective to examining health in the MCR. Berryman (1981:187) suggests that future research needs to explore biological and social stress of MCR sites located on more favorable, arable land. Though the high phosphate content of Averbuch soils would have been sufficient for agricultural productivity, its continual exploitation through the years may have created a backdrop of undesirable social and environmental pressures (Eisenberg, 1986).

## Chapter Summary

There have been an influx of paleopathology books and papers in the last several decades. The Paleopathology Association's creation of the *International Journal of Paleopathology* in 2011 serves as a testament to the continued interest in the topic within the biological anthropology community. The field has made significant advances, away from descriptive differential diagnoses of isolated cases and toward robust research inquiries questioning the biological and evolutionary significance of results.

Rather than recount the prevalence of disease conditions, the current study uses MCR skeletal samples to understand the biological, social, and ecological processes that put some individuals in the community at a greater risk of death than others. To this end, biological signals of childhood physiological stress, poor oral health, skeletal evidence of interpersonal violence, and proxies for crop failures are utilized to more fully comprehend abandonment in the MCR during the Late Mississippian period. The current study's methods will be detailed in the following chapter. Furthermore, these skeletal indicators are studied in tandem with the demographic data to discern whether there are age- and sex-specific risks of death. By situating Averbuch and the eleven additional Mississippian MCR sites into Early, Middle, and Late Mississippian period categories, a regional and broadly diachronic approach to health can be gleaned. To date, such a synthesis has not been conducted with Mississippian MCR samples. Work by Worne (2011) and Vidoli (2012) represent bioarchaeological approaches of the entire Mississippian period MCR, but their research focuses on warfare and population movement, respectively. The current research represents a holistic approach to model risk of death during this time in prehistory.

# Chapter 6: Paleodemography and Paleopathology Methods

## Paleodemography Component

A key component in the present research is the reconstruction of the demographic and mortality profiles of the Middle Cumberland Region. It is necessary for age and sex estimates to be accurate in order to effectively model any existing heterogeneity in frailty within and between skeletal samples. If the goal is to acquire accurate demographic profiles, appropriate statistical models must be chosen that combine the demographic and pathological data in such a way that patterns of community health and the complexity of physiological stress can be gleaned. Boldsen (1997) calls the marriage of the fields of paleodemography and paleopathology "paleoepidemiology."

Basic demographic data were collected in 2006 and 2007 by Dawnie Steadman, Giovanna Vidoli, and Heather Worne as part of the National Science Foundation project "Topographies of Mississippian Conflict and Health in the Middle Cumberland Region" awarded to Dawnie Steadman and Charles Cobb. I was not involved in this phase of data collection. Given that the methods for estimating sex have not advanced radically in recent years, the sex estimates generated from the NSF project were utilized for my dissertation. The use of these previously-collected demographic data significantly reduced the amount of time spent at curation facilities. As such, this let me maximize my time on applying TA to refine adult age estimates. I devoted my time scoring skeletal indicators of adult age using the Transition Analysis method as well as a focused analysis

of childhood stress and poor dental health in the MCR. All data collection methods used in the current research will be detailed in the subsequent sections.

### *Adult Sex Estimation*

The sex of adult skeletons was estimated using the methods detailed in Buikstra and Ubelaker (1994). These include differences in subpubic concavity and ischiopublic ridge, and the presence or absence of a ventral arc in the case of the os coxae (Phenice, 1969). In situations where the pubis and ischium were poorly preserved or absent, the greater sciatic notch was used with reservation. Walker (2005) notes that the chance of error when using the greater sciatic notch for the exclusive estimation of sex is quite large. However, if the greater sciatic notch was the only region of the os coxa available, it was considered for sex estimation. Morphological characteristics of the crania were scored to complement sex estimations derived from pelvic morphology. The supraorbital region, mastoid process, nuchal crest, and mental eminence were utilized to estimate sex (Walker, 2008). If the os coxa or skull were not present or insufficiently preserved, postcranial measurements were taken to estimate sex. These measurements include the maximum diameter of the femoral head and vertical and transverse diameters of the humeral head (France, 1998).

Individuals were classified as “female,” “probable female,” “ambiguous,” “probable male,” “male,” or “indeterminate.” Skeletal elements do not accurately exhibit sexual dimorphism until after adolescence, therefore the sex of subadults was not estimated. Estimation of adult sex is a vital component of frailty analysis, as mortality profiles and propensity to stress and disease manifest differently in males and females.

### *Adult Age Estimation*

Since Steadman and Cobb's NSF study was completed, there has been increased utilization of the Transition Analysis (TA) age estimation method (Boldsen et al., 2002) in bioarchaeology, with its full potential not realized during the original data collection undertaking in 2006-2007. TA orders morphological changes of three skeletal indicators into invariant senescent stages. An essential component of my dissertation reanalyzes the age structure of the MCR using Transition Analysis. I was trained on the method by one of TA's developers, Dr. George Milner.

Following Boldsen et al. (2002), morphological features of the pubic symphysis (Table 6.1) and auricular surface (Table 6.2) of the os coxa and cranial sutures (Table 6.3) were scored. Use of all three indicators achieves the best results, but it is not necessary for all three to be present and scored if one or two of the components are lacking or the features are poorly preserved. In addition, bones from either side of the skeleton were observed. I scored all available adult individuals in my sample with the TA method. The ADBOU age estimation software developed by Boldsen was used to determine individual ages-at-death. 17$^{th}$ century rural Danish parish records were used as the prior age distribution in the ADBOU software. Use of the 17$^{th}$ century Danish prior is not ideal, as it assumes that the MCR and Danish sample have similar age-at-death distributions. However, the uniform prior is not optimal either, since it is improbable that all ages are equally represented in the age-at-death distribution. To date, using the Danish prior in ABDOU offers the best approach to derive individual adult age estimates for prehistoric skeletal samples.

Table 6.1. Transition Analysis Coding System for Pubic Symphysis

(Boldsen et al., 2002: 97-100)

| **PUBIC SYMPHYSIS** *component* | **SCORE** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** |
| **Symphyseal Relief** | Sharp billows | Soft, deep billows | Soft, shallow billows | Residual billows | Flat | Irregular | |
| **Symphyseal Texture** | Smooth | Coarse | Microporosity | Macroporosity | | | |
| **Superior Apex** | No protuberance | Early protuberance | Late protuberance | Integrated | | | |
| **Ventral Symphyseal Margin** | Serrated | Beveled | Rampart formation I | Rampart completion I | Rampart completion II | Rim | Breakdown |
| **Dorsal Symphyseal Margin** | Serrated | Flattening incomplete | Flattening complete | Rim | Breakdown | | |

Table 6.2 Transition Analysis Coding System for Auricular Surface

(Boldsen et al., 2002: 100-103)

| **AURICULAR SURFACE** *component* | **SCORE** | | | | | |
|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** |
| **Superior and Inferior Demiface Topography** | Undulating | Median elevation | Flat to irregular | | | |
| **Superior, Apical, and Inferior Surface Morphology** | > 2/3 covered by billows | 1/3 to 2/3 covered by billows | < 1/3 covered by billows | Flat (no billows) | Bumps | |
| **Inferior Surface Texture** | Smooth | Microporosity | Macroporosity | | | |
| **Superior and Inferior Posterior Iliac Exostoses** | Smooth | Rounded bony elevations | Pointed exostoses | Jagged exostoses | Touched exostoses | Fusion |
| **Posterior Spicules** | Smooth | Rounded spicules | Pointed spicules | | | |

Table 6.3 Transition Analysis Coding System for Cranial Sutures

(Boldsen, et al., 2002: 103-104)

| **CRANIAL SUTURES** *component* | **SCORE** | | | | |
|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** |
| **Coronal Pterica** | Open | Juxtaposed | Partially obliterated | Punctuated | Obliterated |
| **Sagittal Obelica** | Open | Juxtaposed | Partially obliterated | Punctuated | Obliterated |
| **Lambdoidal Asterica** | Open | Juxtaposed | Partially obliterated | Punctuated | Obliterated |
| **Zygomaticomaxillary** | Open | Juxtaposed | Partially obliterated | Punctuated | Obliterated |
| **Interpalatine** | Open | | Partially obliterated | Punctuated | Obliterated |

### *Adult Mortality Patterns*

To reconstruct the mortality profile of MCR adults, hazard modeling was conducted. Gompertz and Gompertz-Makeham models were chosen as they model human adult mortality. As discussed in Chapter 4, the Gompertz model is a two-parameter model where the risk of death increases with advanced age. The Gompertz-Makeham model adds a third parameter, capturing age-independent mortality resulting from accidents, infectious diseases, and risky behavior unrelated to the aging process. Hazard parameters were optimized using the maximum likelihood-generated age estimates from Transition Analysis. Optimization was carried out by using the "optim" function in R. Hazard modeling was successful if the model reached convergence (maximization). Log-likelihood values were used to calculate the Akaike Information Criterion (AIC). The AIC for each model was compared to determine whether the Gompertz or Gompertz-Makeham model fits the data best. Smaller AIC values indicate a better fitting model.

Separate analyses were carried out to assess Early, Middle, and Late Mississippian adult mortality. I examined the effect of age and sex on the mortality profile for each time period, and present the mean age-at-death and survival curves. Mean age-at-death was calculated using numerical integration of survivorship. The mortality profiles were also examined temporally across the Mississippian period, allowing for an investigation into differences in age- and sex-specific survivorship. In this way, I am able to test my paleodemography research hypothesis of whether mortality was elevated in the Late Mississippian MCR compared to the Early Mississippian MCR.

**Paleopathology Component**

An equally important objective of this research combines the demographic and pathological data to reveal epidemiological patterns. In addition to scoring skeletal indicators for age using Transition Analysis, markers of dental and skeletal health of each individual were examined and scored. Though Steadman and Cobb's project recorded skeletal and dental health in their original NSF-funded research, the current research employs ordinal scoring following previous paleoepidemiological research (Wilson, 2010) not implemented in their research. A move beyond descriptive analysis and toward formal scoring is more informative than the life table approach employed by Berryman (1981) on the Averbuch site and allows for the use of hazard modeling.

Linear enamel hypoplasias and porotic hyperostosis were examined as indicators of childhood stress. These dental and skeletal markers were chosen as they are diagnostic macroscopically and argued to reduce age at death, in effect, predisposing individuals with these markers to greater risk of death than individuals of similar ages lacking these indicators (Duray, 1996; Palubeckaitė et al., 2002). In addition to the examination of skeletal and dental markers indicative of childhood stress episodes, dental markers were examined that, according to the clinical literature, correspond with stress, diet, and disease episodes that occur later in adulthood (Hillson, 2002; Hillson, 2008; Padilha et al., 2008; Thorstensson and Johansson, 2009). For the purposes of this research, dental caries, abscesses, and antemortem tooth loss were evaluated in the MCR sample. The focus on dentition to assess more recent dental health events derives from the unidirectional effects of physiological, disease, and masticatory processes during life. The mouth harbors bacteria and other microbes but their ability to colonize the orifice is

limited by the continuous shedding of mucosa. Teeth are unique in their hard, non-shedding surface, providing ample opportunities for microbial communities to build up in fissures and gingival crevices (Hillson, 2002). It is assumed that enamel hypoplasias and porotic hyperostosis are capable of detecting heterogeneity in frailty and inferring stress events during childhood while dental caries, abscesses, and antemortem tooth loss reflect diet, stress, and frailty levels later in adulthood (Lukacs, 2007; Lukacs, 2012; Watts, 2015b; Yaussy et al., 2016). Examination of skeletal samples with an eye to the temporal scale allows for comparison of how age-specific risk of death associated with a particular pathological condition changed through time in response to biological, social, and ecological conditions. Justification of the methods used and a detailed description of data collection procedures follow in the subsequent sections. Kaplan-Meier analyses and log-rank tests were performed in SPSS version 22 for each pathological condition, and figures were created in R. These analyses test my paleoepidemiology research hypothesis of whether individuals without dental and skeletal markers of childhood stress, poor oral health, and skeletal trauma have increased risk of death compared to similarly-aged individuals with these markers. In this way, heterogeneity in frailty and the impact of selective mortality can be discerned.

### *Linear Enamel Hypoplasias*

Enamel hypoplasias (LEH) are linear defects in tooth enamel resulting from non-specific systemic metabolic disturbances experienced during the process of amelogenesis (Huss-Ashmore et al., 1982; Suckling, 1989; Larsen, 1997a). Specifically, they are due to interruption of amelogenesis when the adult enamel is developing and are produced when the magnitude of ameloblast disruption surpasses a normal threshold for a given tooth

(Suckling, 1989; Goodman and Rose, 1990). LEH defects vary in appearance and range from single or multiple pits to small fissures or deep grooves of reduced enamel thickness. Because of enamel's inability to remodel, teeth serve as a valuable indicator of stress episodes resulting in growth retardation experienced during childhood, when the enamel of the anterior dentition are forming between two and five years of age (Hillson, 2008). The causal stressors associated with enamel hypoplasias are numerous and include nutritional deprivation, infectious disease, physiological perturbations, and social stressors (Pindborg, 1982; Suckling, 1989; Goodman and Rose, 1990). While hereditary anomalies and localized trauma may also result in enamel disruption, such instances are scarcely documented in prehistoric and contemporary populations (Hillson, 2002). As such, in the current research it is assumed that the etiology of enamel hypoplasias stems from factors related to systemic metabolic stress during childhood.

The anterior dentition have been frequently cited to be most susceptible to stress events (Goodman and Rose, 1990; Wright, 1997). This finding suggests that incisors and canines are increasingly prone to developmental perturbations, perhaps because of their development being under stronger genetic control. Condon and Rose (1992) posit that this differential susceptibility may be due to tooth-specific variation in the rate of enamel formation, and teeth with slower deposition rates are at higher risk for developmental defects.

The labial surface of permanent incisor and canine crowns were observed macroscopically and scored for enamel hypoplasias (Buikstra and Ubelaker, 1994). While other studies have incorporated linear vertical grooves and pits, for the purposes of this research only horizontal linear enamel hypoplasias were scored. If present, LEH were

scored as ‘1’ and ‘0’ if no LEH were observed. Following the suggestion of Goodman and Rose (1990), LEH were scored conservatively, as it is better to have some false-negatives and risk excluding minor hypoplasias rather than define all surface anomalies as hypoplasias with results suffering poor validity and reliability. In this way, the LEH identified represent a minimum estimate of individuals that experienced stress events. Skeletons lacking anterior teeth and those with poorly preserved dentition or with severe attrition were not included in the LEH analysis.

***Porotic Hyperostosis***

Another measure of childhood stress observed in this research is porotic hyperostosis lesions. While LEH is an excellent indicator of stress events in teeth, cribra orbitalia and porotic hyperostosis serve as two of the most frequently observed markers of childhood stress in the skeletal record (Stuart-Macadam, 1985; Walker et al., 2009; Meyer, 2016). Named for the porous and hypertrophic lesions that manifest on the cranial vault or the anterolateral orbital roof of the frontal in the case of cribra orbitalia (Angel, 1966), porotic hyperostosis is most commonly attributed to an anemic response (Walker et al., 2009).

Visually, porotic hyperostosis can vary in size and distribution from fine, pin-prick lesions to large, coalescing apertures that compromise the integrity of the affected cortical bone (Stuart-Macadam, 1982; Stuart-Macadam, 1985). Cribra orbitalia and porotic hyperostosis were scored as present (1) or absent (0) following Buikstra and Ubelaker (1994). In order for an individual to be included in the porotic hyperostosis analysis, it was necessary for a substantial portion of the frontal, parietals, or occipital bones to be present. Porotic hyperostosis is typically a bilateral condition, therefore

sufficient preservation (75%-100%) of at least one of the orbits, occipital, and/or either parietal bone was necessary for inclusion in the analysis. If the cranium was absent, poorly preserved, or fragmentary to the extent that these elements could not be confidently identified, the individual was not included.

### *Carious Lesions*

In addition to childhood health indicators, dental caries, abscesses, and antemortem tooth loss were examined as markers of an individual's more recent health status in adulthood. These conditions are taken to represent stress and frailty levels later in life. Because these indicators are readily observable in skeletal collections, there has been a multitude of research on oral health across temporal and geographic scales in prehistory (Caselitz, 1998; Nelson et al., 1999; Larsen, 2006; DeWitte and Bekvalac, 2010).

The progression of dental caries was recorded on the occlusal surface of permanent molars using the ordinal scoring system in Table 6.4 following Boldsen (1997). The scoring system codes progression from a healthy molar with no evidence of caries to a molar with a carious lesion that involves the pulp cavity. Only individuals with more than half of the permanent molar dentition present were included in the sample. As scores in the upper limits of this ordinal scoring system represent active carious lesions, this may suggest an untreated condition at work at or near an individual's death. In this way, the relationship between poor dental health and risk of death can be gleaned.

Table 6.4 Definitions of Scores for Carious Lesions of Permanent Molars

| Score | Observation |
|---|---|
| **1** | Absence (healthy molar with no caries) |
| **2** | Caries with involvement of enamel or dentine |
| **3** | Caries with involvement of pulp cavity |

### *Dental Abscesses*

Bacteria in the oral cavity can lead to an accumulation of plaque on the teeth, and inflammation of the gingiva and underlying alveolar bone. Periodontal disease and the increase in pressure due to an inflammatory response can be alleviated by the draining through an abscess. The current study models research by Boldsen (1998) in his investigation into whether the risk of having an abscess was related to sex and age-at-death. In order for an assessment of abscesses to be made, at least 50% of the alveolar bone needed to be present. Abscesses were recorded and counted on the alveolar processes of the entire dentition, not exclusively the posterior teeth as Boldsen (1998) did in his research. The total number of abscesses were summed and transformed to an ordinal score ranging from zero (no abscesses) to three (three or more abscesses) for each individual.

### *Antemortem Tooth Loss*

Larsen (1997) illustrates that populations with high caries rates also have high rates of antemortem tooth loss (AMTL), demonstrating an association between the two conditions. As with dental caries and abscesses, the shift from foraging to farming was accompanied by an increase in AMTL. Lukacs (2007) examines AMTL as a result of trauma and found evidence of tooth loss due interpersonal combat and accidental falls

due to the hazardous terrain of the Canary Islands. In my research, it is assumed that AMTL was attributed to poor oral health and not traumatic injury, accidents, or interpersonal violence.

AMTL was recorded following the procedures in Buikstra and Ubelaker (1994). For statistical analysis, the number of teeth lost antemortem were counted and calculated as a ratio, i.e., the total number of teeth lost over the total number of teeth in the dentition. A ratio of "0" indicates no AMTL and a ratio of "1" is a completely edentulous individual. AMTL ratios were only calculated for individuals with nearly complete maxillary or mandibular bone present (≥50%) and without substantial postmortem tooth loss.

Although it is improbable that any of the childhood stress or recent dental pathologies under examination contributed directly to the demise of an individual in the sample, prior bioarchaeological research demonstrates that they are liable to co-vary with age-at-death and underlying frailty levels (DeWitte and Wood, 2008; DeWitte, 2009; Wilson, 2010; DeWitte and Bekvalac, 2011). The explicit ways in which they may have co-varied are explored through rigorous analytical methods, in addition to incorporating social and ecological factors at work in the MCR during the Late Mississippian period.

### *Non-Biological Markers as Health Covariates*

In addition to biological markers of health, social and ecological factors were explored as possible co-variates in the hazards analysis. Part of my research is interested in whether conflict increased closer to the timing of regional abandonment, hinting at increased political and social strife that may have accelerated population decline. Skeletal

markers were used that suggest warfare-related trauma for each individual in the sample, which may have intensified temporally from the Early to Late Mississippian period. Chronic violence can have a lasting effect on the well-being of individuals, as repeated threats of conflict have contributed to an increased risk of physiological stress in modern day populations and is theorized to have health implications in antiquity (Milner et al., 1991; Felitti et al., 1998; Krug et al., 2002).

Worne (2011) identified four osteological manifestations of interpersonal violence in the MCR that was used in the current research. The data Worne collected included 1) cutmarks associated with scalping, 2) evidence of decapitation or dismemberment, 3) cranial blunt force trauma, and 4) projectile point injuries. Osteological evidence associated with scalping was based on the presence of v-shaped cutmarks on any bones of the calvarium, i.e., bones of the frontal, parietals, temporals, and occipital (Walker, 2001). Evidence of decapitation was identified based on cutmarks to the cervical vertebrae, adjacent occipital bone, and mandible (Andrushko et al., 2010). Cranial blunt force trauma in the form of depression fractures were examined for shape, location, and extent of healing, if any (Smith, 2003). Projectile points embedded in bone were considered evidence of interpersonal violence. Postcranial fractures were not included in the analysis, as such fractures may occur accidentally and not definitively imply warfare-related violence (Steadman, 2008).

Instead of coding for each condition individually, the presence of any of the four skeletal markers for warfare was coded “1” while no skeletal trauma observations were coded “0.” This was done to increase the sample size, making the analysis more robust by

pooling the conditions. The relationship between evidence of skeletal trauma, age-at-death, and sex were analyzed. In this way, it was examined whether individuals occupying Late Mississippian cemeteries had more traumatic lesions and were at a greater risk of death than individuals from Early Mississippian MCR cemeteries.

To explore whether risk of death was affected by extreme climatic conditions proposed in the Late Mississippian period, tree-ring derived Palmer Drought Severity Index (PDSI) reconstructions of water availability were analyzed for the area that encompasses the MCR. The PDSI takes into account temperature and precipitation values to measure normal soil moisture supplies as well as deviations from normal conditions (Palmer, 1965). PDSI values range from -6.0 to +6.0, with negative numbers corresponding to drought episodes and positive numbers indicative of wet seasons.

PDSI datasets were freely available from the National Oceanic and Atmospheric Administration (NOAA) Paleoclimatology National Climatic Data Center (Cook and Krusic, 2004). The Palmer Drought Severity Index partitions the continental United States into 286 2.5°x2.5° grid points (Figure 6.1). Two grid points were chosen: grid point 219 (87.5W, 37.5N) and grid point 220 (87.5W, 35.0N). These grid points were used to bracket the general area that encompasses the Middle Cumberland Region in Central Tennessee (Figure 6.2). The PDSI values for grid points 219 and 220 were averaged for each year from 1000 to 1500 A.D.. The years were divided into Early Mississippian (1000-1325 A.D., Regional Periods I-III *sensu* Moore and Smith, 2009) and Late Mississippian periods (1325-1500 A.D., Regional Periods IV-V *sensu* Moore and Smith, 2009).

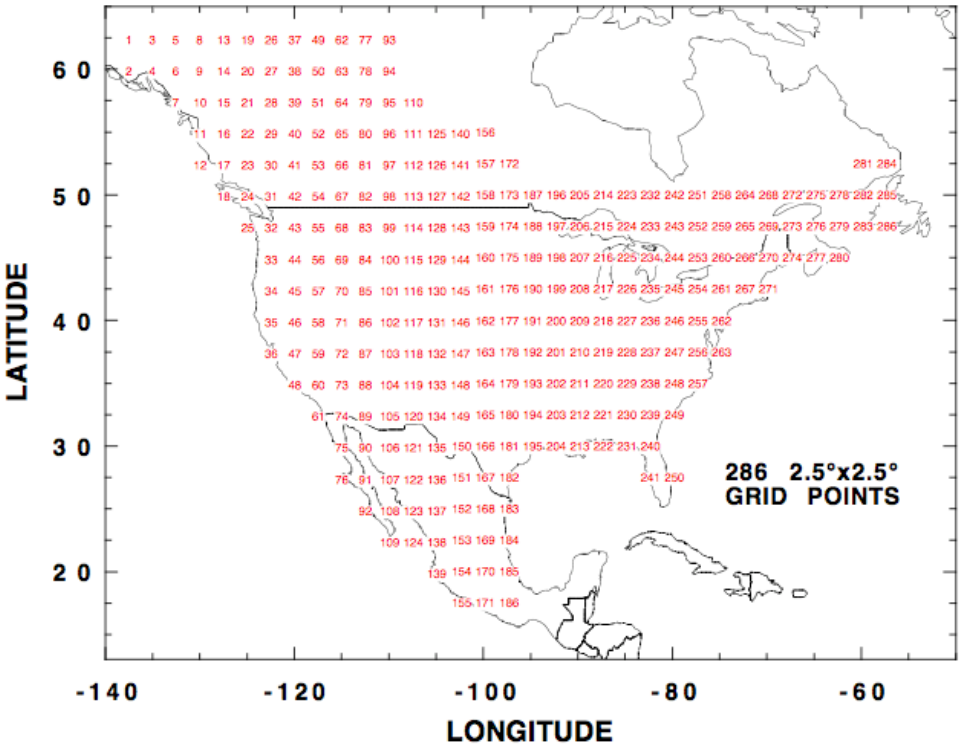


Figure 6.1 PDSI Grid for Drought Reconstructions in North America

(Cook and Krusic, 2004)

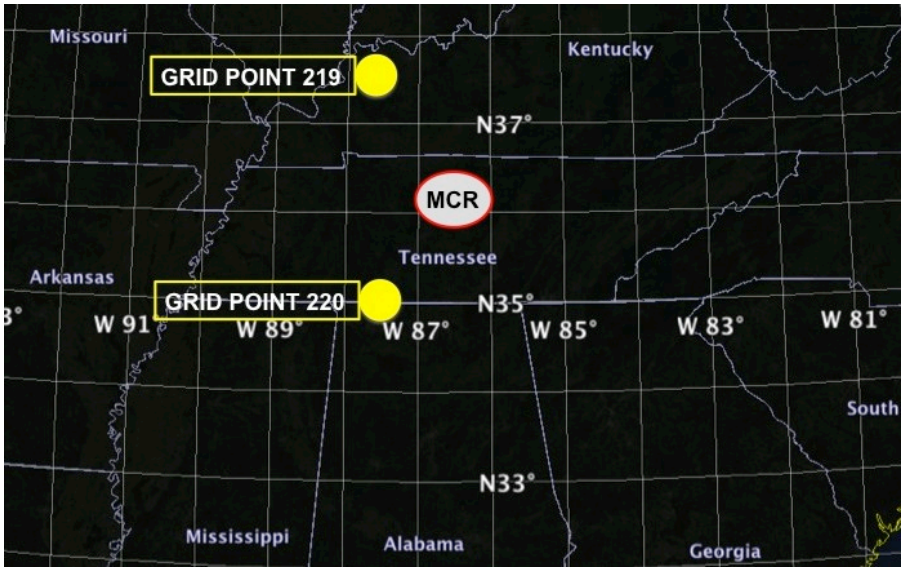


Figure 6.2 Proximity of the Middle Cumberland Region to PDSI Grid Points 219 and 220

Mean PDSI values were used to determine whether individuals from the Late Mississippian period correspond with either drought or extreme rainfall conditions for the time frame leading up the MCR site abandonments. If differences in PDSI values—and by proxy—crop yields, were found, they were used in a Kaplan-Meier analysis to determine of risk of death increased as groups began to depopulate the region. If this is the case, it would suggest that climatic conditions may have contributed to a greater risk of death, as extreme weather would have resulted in decreased maize yields and possible crop failures. Famine would have been likely, as crop yields would not be sufficient to support a growing population. Furthermore, crop shortages would disrupt the economic redistribution system that characterized Mississippian chiefdoms, in effect, transforming the sociopolitical landscape; this may have contributed to an interrelated domino effect of adverse health for MCR communities in the Late Mississippian period.

## Chapter Summary

While the Middle Cumberland Region has been the focus of attention for bioarchaeologists for several decades, the current research is the first to utilize advanced methods in paleopathology and paleoepidemiology developed more recently. Using the Transition Analysis method holds promise to attain more accurate adult age estimates, as well as capture ages of older individuals in my sample, ones who would traditionally be categorized as "50+." Hazard modeling generates robust parametric mortality profiles, and is not subjected to overparameterization and the same limitations as life table analyses. Survival analysis allows for the examination of survivorship by age, sex, and time period given the presence of childhood stress and dental health markers. As such, selective mortality and frailty can be more appropriately determined, more so than the

calculation of crude frequencies typically relied upon in paleopathology. The consideration of multiple lines of evidence—biological, cultural, and environmental—as well as reliance on updated methods, assures a more holistic understanding of health in the Mississippian MCR.

# Chapter 7: Paleodemography Results

Analyses are presented separately in two chapters: paleodemographic results and paleoepidemiological results (Chapter 8). The current chapter reconstructs adult survivorship using hazard models. The presentation of adult mortality patterns has two parts. First, the synchronic analyses examine differences in mortality within each time period by age and by sex in the MCR. As discussed in Chapter 3, the twelve MCR sites were divided into Early, Middle, and Late Mississippian period groups. In separate sections, I present the results within each time period, examining the effect of age and sex on the adult mortality sample. In addition to presenting the mean ages-at-death, hazard model parameters, and survival curves, I compare the Akaike Information Criterion (AIC) between the Gompertz and Gompertz-Makeham models to determine which hazard model best fits the data. Second, the mortality profiles are examined temporally across the Mississippian period. These diachronic analyses make it possible to discern broad differences in survivorship in the Middle Cumberland Region between 1000 and 1500 A.D.

## Adult Mortality Patterns: Synchronic Analyses

### *Overall Adult Mortality in the Middle Cumberland Region (1000-1500 A.D.)*

Before I present the synchronic results by time period, I will discuss the overall adult mortality of the entire MCR Mississippian sample. The age-at-death for 545 adults was calculated using the Transition Analysis aging method. Transition Analysis is

capable of estimating age of individuals aged 15 and older, which is distinguished by the horizontal line at 100% survivorship. The sample includes all individuals ages 15 and older. The solid line in the Kaplan-Meier plot signifies the entire sample and tracks the age-at-death estimates as a percentage by age (Figure 7.1). Each descending "step" of the solid line illustrates the 545 adults that make up the skeletal sample. The dotted lines bounding the solid line represent the 95% confidence interval around the sample. Survivorship is seen to decrease as age increases.

Using the same age-at-death point estimates, Gompertz and Gompertz-Makeham model parameters were calculated and survival curves generated. Figure 7.2 shows these survival curves plotted on top of the Kaplan-Meier survivorship curve. The Kaplan-Meier curves are included in the figure to illustrate the fit of the Gompertz and Gompertz-Makeham models with the skeletal assemblage. While both curves appear similar in shape and scale, a quantitative comparison of the models can be achieved by using the log-likelihood values to calculate the Akaike Information Criterion (AIC). AIC values reveal that the Gompertz-Makeham model fits the data better, as the AIC value for the Gompertz-Makeham model is smaller than the Gompertz AIC value (Table 7.1). This suggests that the inclusion of the age-independent mortality parameter ($\alpha_2$) is an important factor to the sample, indicating that prime adult deaths (approximately 15-35 years old) may have been a common occurrence during the Mississippian period. Mean age-at-death was calculated using numerical integration of survivorship. Mean age-at-death for the Gompertz model is 42.97 years, and 43.05 years for the Gompertz-Makeham model. Use of the Transition Analysis aging method allowed for the assessment of age of older adults.

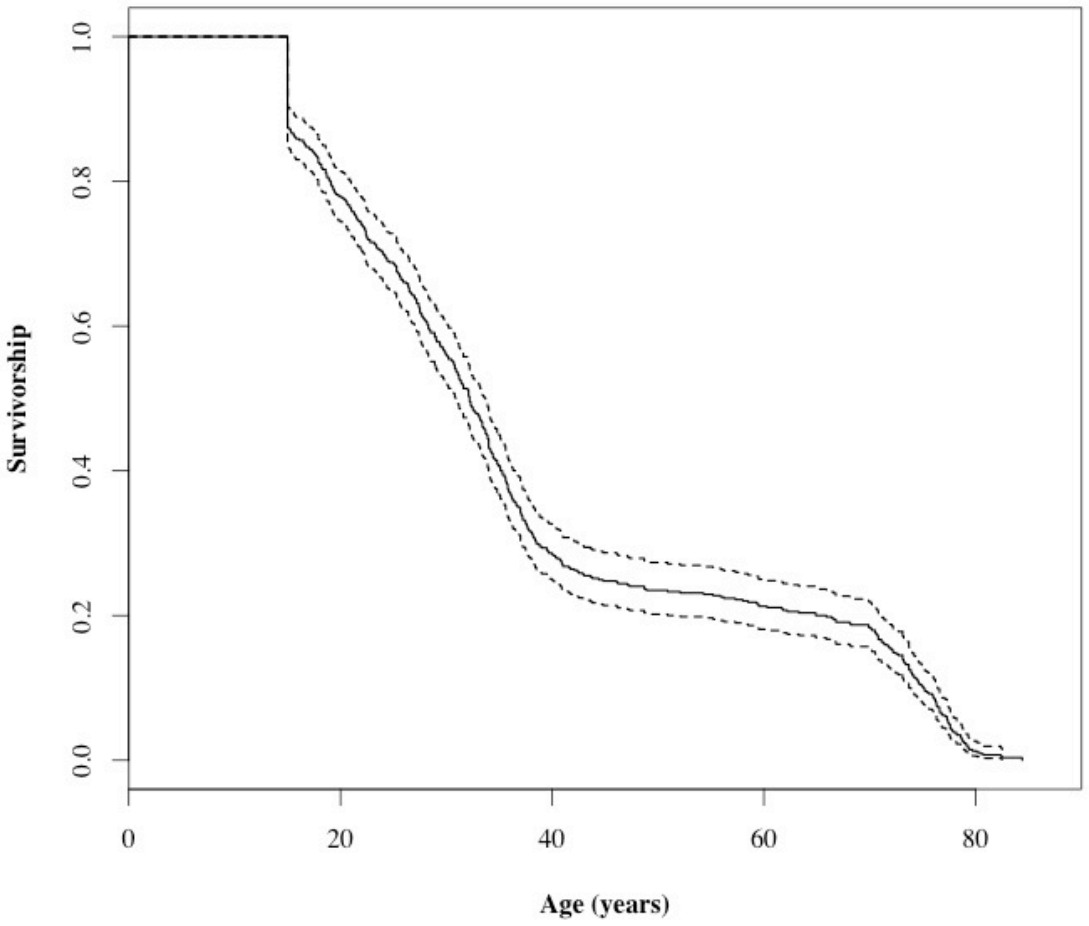


Figure 7.1 Kaplan-Meier survivorship plot for adult mortality of the entire MCR adult sample, n=545

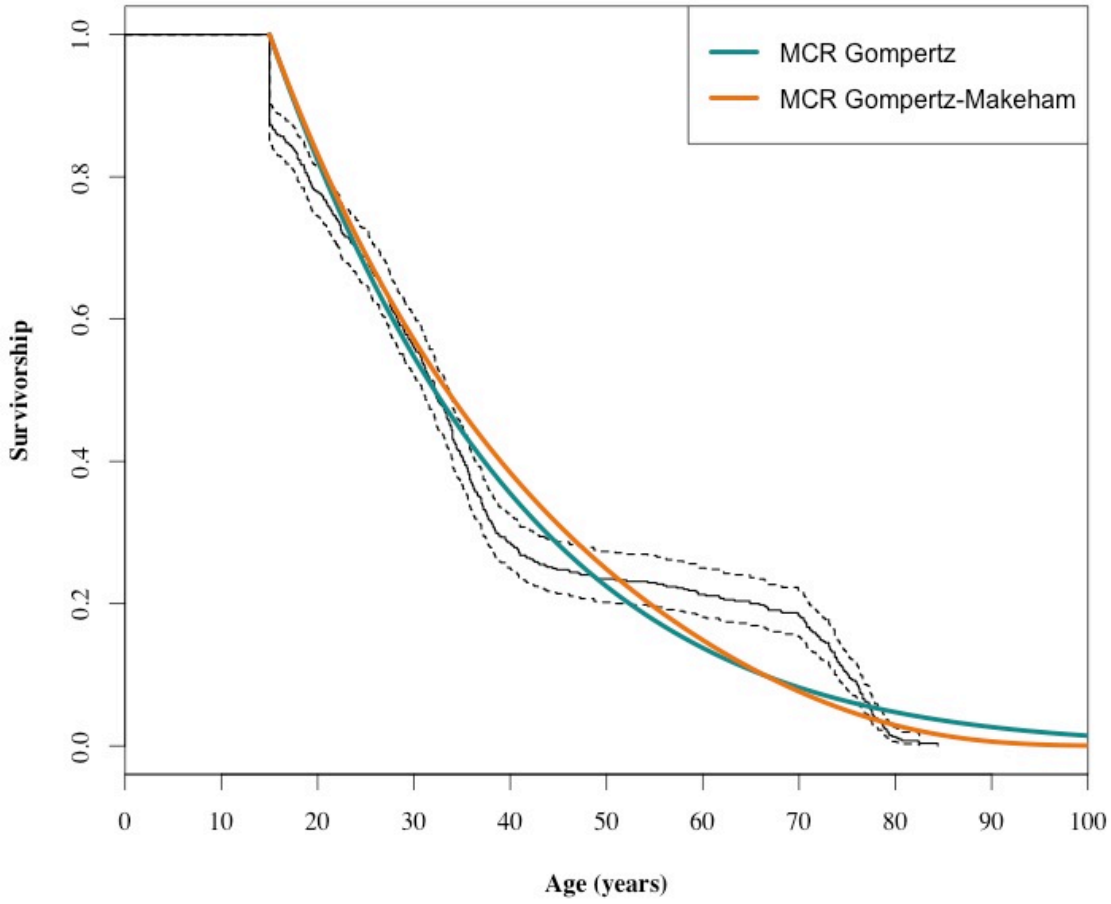


Figure 7.2 Gompertz and Gompertz-Makeham survival curves for the entire MCR sample

Table 7.1 Gompertz and Gompertz-Makeham hazard parameters for the entire MCR sample

| | $\alpha_2$ | $\alpha_3$ | $\beta_3$ | **Log-likelihood** | **AIC** |
|---|---|---|---|---|---|
| Gompertz | N/A | 0.0384337 | 0.0059395 | -2247.033 | 4498.066 |
| **Gompertz-Makeham** | **0.0355638** | **0.0010303** | **0.0677391** | **-2226.774** | **4459.55** |

Investigating differences between males and females with regard to mortality is crucial in paleodemographic analyses. Prior to examining differences in mortality between the sexes, it is necessary to discern which model provides a better fit for both males and females. Table 7.2 presents the model parameters for all females in the sample (n=223). The Gompertz-Makeham model did not converge with optimization of the maximum number of iterations and therefore was not considered in this analysis, nor was its survival curve plotted. Figure 7.3 illustrates the Gompertz survival curve overlaid on the Kaplan-Meier plot of the entire pooled sex sample. The mean age-at-death of females in the entire Mississippian sample is 41.63 years.

Table 7.3 presents the model parameters for all males in the sample (n=310). A comparison of AIC values determines that the Gompertz-Makeham is the better fitting model. Figure 7.4 illustrates the Gompertz and Gompertz-Makeham survival curves overlaid on the Kaplan-Meier plot of the entire pooled sex sample. The mean age-at-death for males surviving to adulthood was 46.39 years.

Table 7.2 Gompertz and Gompertz-Makeham model parameters for all females in the sample

| | $\alpha_2$ | $\alpha_3$ | $\beta_3$ | **Log-likelihood** |
|---|---|---|---|---|
| **Gompertz** | **N/A** | **5.38267e-02** | **1.00000e-10** | **-874.6283** |
| Gompertz-Makeham | 0.0508865396 | 0.0001237108 | 0.0894742934 | -870.121 |

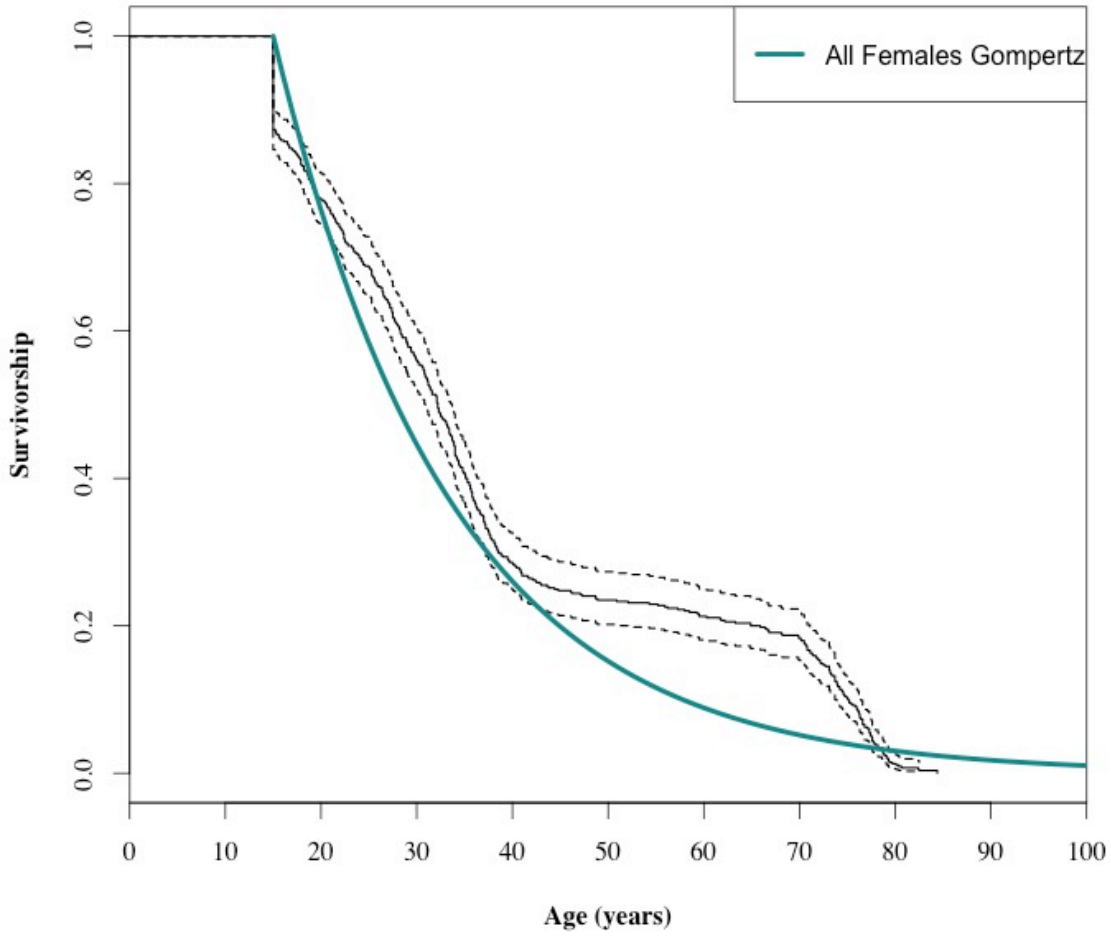


Figure 7.3 Survival curve for all females using the Gompertz model

Table 7.3 Gompertz and Gompertz-Makeham model parameters for all males in the sample

| | $\alpha_2$ | $\alpha_3$ | $\beta_3$ | **Log-likelihood** | **AIC** |
|---|---|---|---|---|---|
| Gompertz | N/A | 0.0283995 | 0.0128403 | -1310.734 | 2625.468 |
| **Gompertz-Makeham** | **3.123904e-02** | **9.221331e-11** | **3.503900e-01** | **-1245.156** | **2496.312** |

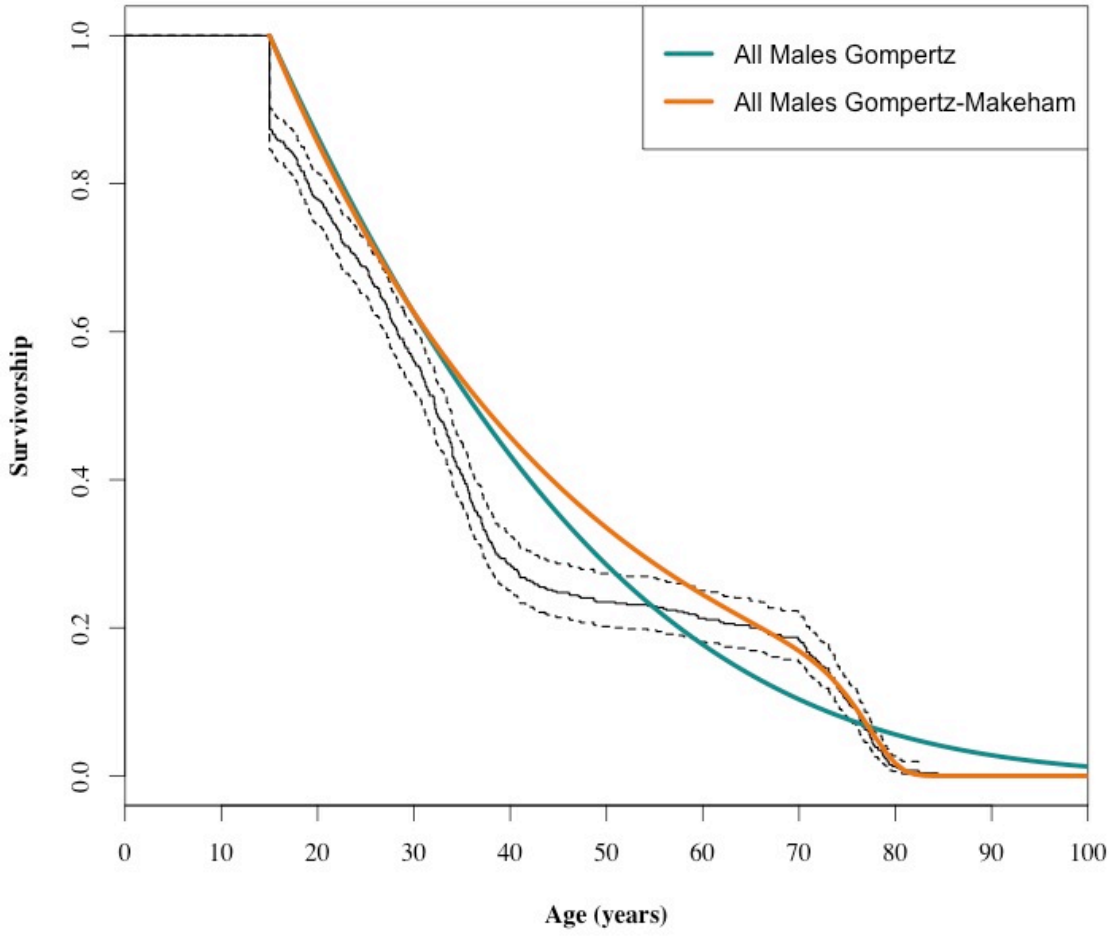


Figure 7.4 Gompertz and Gompertz-Makeham survival curves for all males in the sampl

A likelihood ratio test was carried out to determine whether sex should be modeled separately or if a pooled sex model fits the data better. This analysis revealed that males and females should be modeled differently (*likelihood ratio*: 213.9794, *df*=2, $p<0.001$). Plotting the optimal female hazard model (Gompertz) and optimal male hazard model (Gompertz-Makeham) exemplifies that females have lower survivorship than males throughout the lifespan (Figure 7.5). This is also apparent given the discrepancies in mean age-at-death: 41.63 for females and 46.39 for males. In old age, after approximately 80 years, females appear to have slightly higher survivorship than males. While the results of the pooled sex and sex-specific mortality profiles of the overall MCR sample are of interest, even more illuminating are the subsequent analyses by time period, and further, looking at temporal trends across the Mississippian period.

***Early Mississippian Adult Mortality (MCR Regional Periods I-III)***

Age-at-death estimates derived from 75 adults (≥ 15 years old from Transition Analysis) from Bowling Farm (n=29), Noel Cemetery (n=25), Moss-Wright (n=13), Mound Bottom (n=4), and Sellars (n=4) were used to reconstruct the Early Mississippian adult mortality pattern in the Middle Cumberland Region. As seen in Figure 7.6, the solid line in the Kaplan-Meier plot signifies the skeletal sample, and the dotted lines illustrate the 95% confidence interval. The flat line between 42-65 years denotes that no individuals were represented skeletally in this age range. This is likely attributed to the limited skeletal samples from Early Mississippian sites rather than a true lack of individuals dying in middle age.

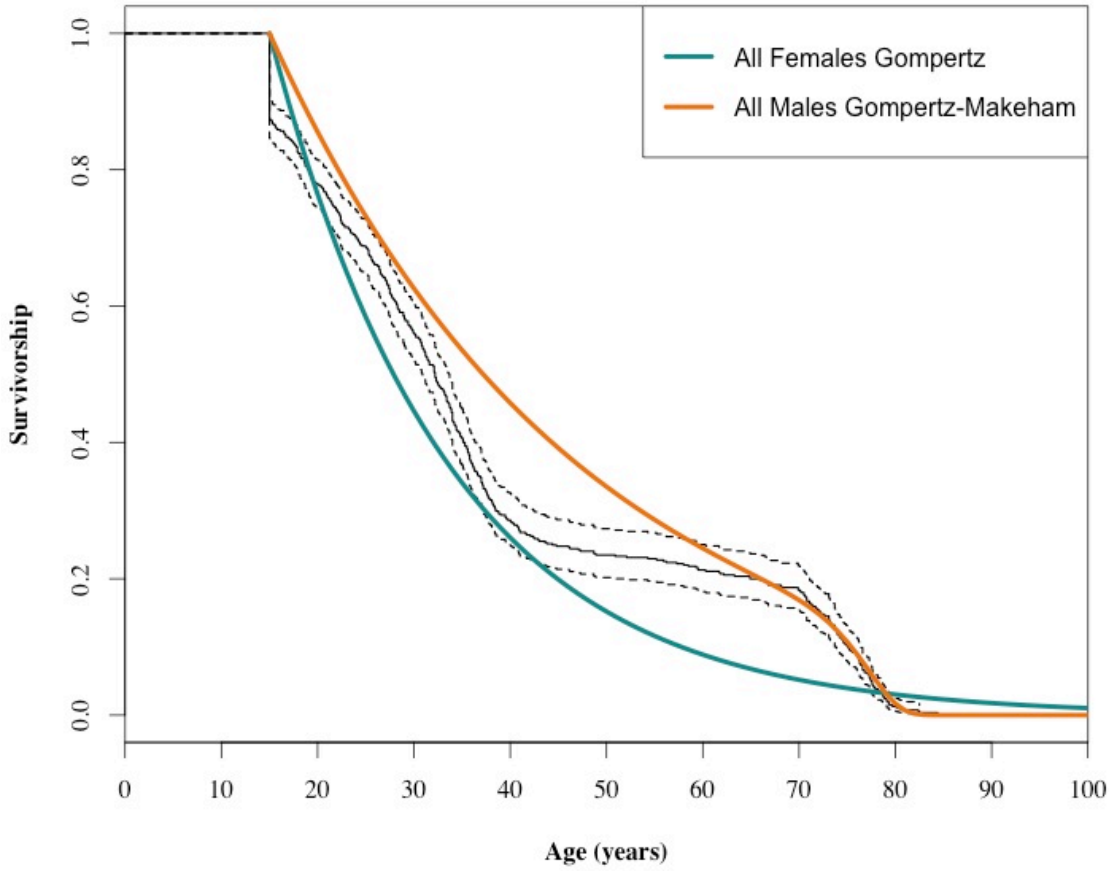


Figure 7.5 Female Gompertz and Male Gompertz-Makeham survival curves for the entire MCR sample

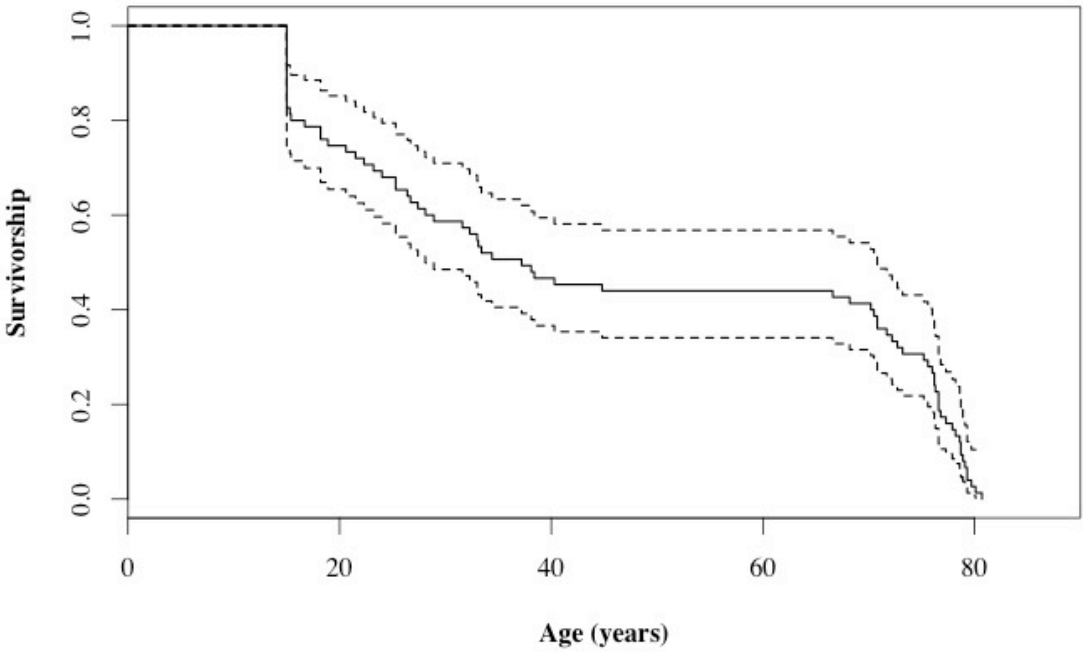


Figure 7.6 Kaplan-Meier plot of survivorship in the Early Mississippian period

The Gompertz and Gompertz-Makeham model parameters are presented in Table 7.4. The Gompertz-Makeham model parameters failed to converge after the maximum 1,000 iterations allowed in R. For this reason, the Gompertz model was determined to be the best fitting model. Figure 7.7 illustrates the survival curves for the Early Mississippian period plotted over the Kaplan-Meier survivorship data. Numerical integration of survivorship estimates the mean age-at-death to have been 49.43 years in the Early Mississippian MCR.

When analyzing the Early Mississippian sample by sex, a markedly different pattern emerges. Table 7.5 compares the Gompertz and Gompertz-Makeham model parameters for Early Mississippian females (n=31). Figure 7.8 shows that the two survival curves nearly completely overlap one another. However, the Gompertz model optimally fits the data, as its AIC value is smaller than the Gompertz-Makeham AIC. Furthermore, when the log-likelihood values of two models are very similar, the most parsimonious model (i.e., the model with the fewest parameters) should be chosen.

Table 7.4 Gompertz and Gompertz-Makeham model parameters for the Early Mississippian period

| | $\alpha_2$ | $\alpha_3$ | $\beta_3$ | **Log-likelihood** |
|---|---|---|---|---|
| **Gompertz** | **N/A** | **0.02159826** | **0.01312005** | **-331.614** |
| Gompertz-Makeham | 1.732105e-2 | 2.481377e-12 | 4.106705e-01 | -290.856 |

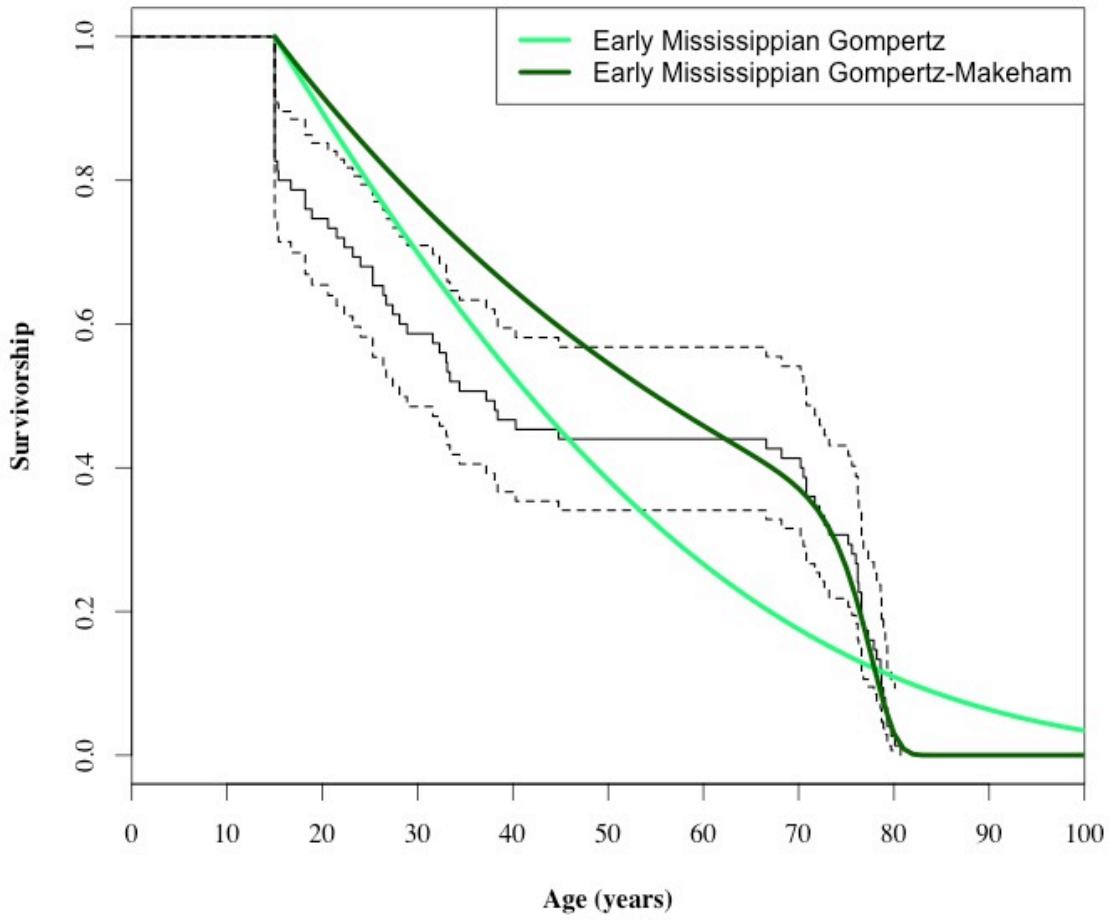


Figure 7.7 Gompertz and Gompertz-Makeham survival curves for the Early Mississippian period, pooled sex sample

Table 7.5 Gompertz and Gompertz-Makeham model parameters for Early Mississippian females

| | $\alpha_2$ | $\alpha_3$ | $\beta_3$ | **Log-likelihood** | **AIC** |
|---|---|---|---|---|---|
| **Gompertz** | **N/A** | **0.05283521** | **0.0000000001** | **-122.162** | **248.324** |
| Gompertz-Makeham | 0.05200599 | 0.00021042 | 0.05304777 | -122.057 | 250.114 |

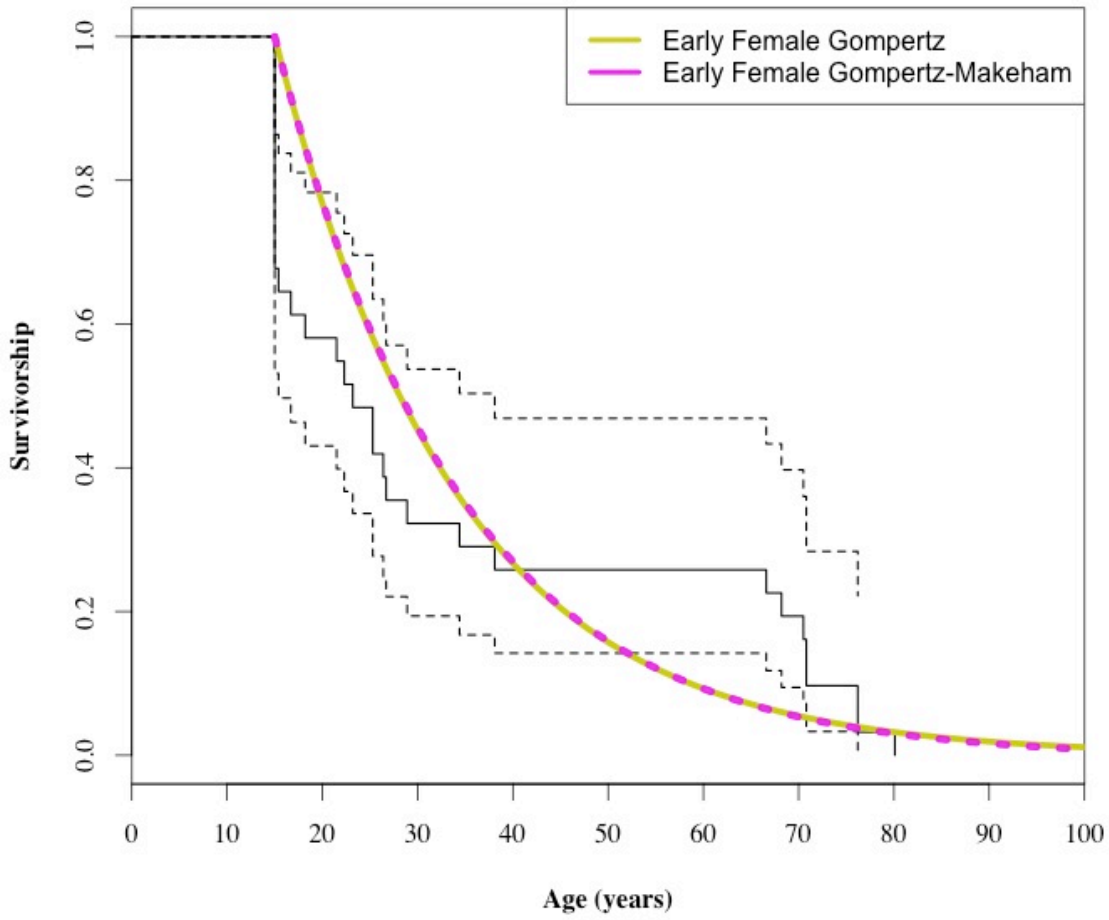


Figure 7.8 Gompertz and Gompertz-Makeham survival curves for Early Mississippian females

Table 7.6 compares the Gompertz and Gompertz-Makeham model parameters for Early Mississippian males (n=40). The survival curves of both models are illustrated in Figure 7.9. Visually, it appears that the Gompertz-Makeham model fits the data the best. However, the Gompertz-Makeham model failed to converge during optimization and for this reason, the Gompertz model was determined to be the best fitting model for Early Mississippian males.

When the best fitting models for Early Mississippian adults are plotted in the same figure, it is apparent that there is a significant difference in survivorship by sex (Figure 7.10). The hazard curves demonstrate that the risk of death is constant across all ages for females but increases exponentially in males (Figure 7.11). This is further supported by calculations of mean age-at death. The mean age-of-death for Early Mississippian MCR females was 41.81 years, while the mean age-of-death for Early Mississippian MCR males is much higher: 57.99 years.

Table 7.6 Gompertz and Gompertz-Makeham model parameters for Early Mississippian males

| | $\alpha_2$ | $\alpha_3$ | $\beta_3$ | **Log-likelihood** |
|---|---|---|---|---|
| **Gompertz** | **N/A** | **0.0060615** | **0.0398749** | **-178.598** |
| Gompertz-Makeham | 9.887323e-03 | 7.971621e-12 | 3.90139e-01 | -146.767 |

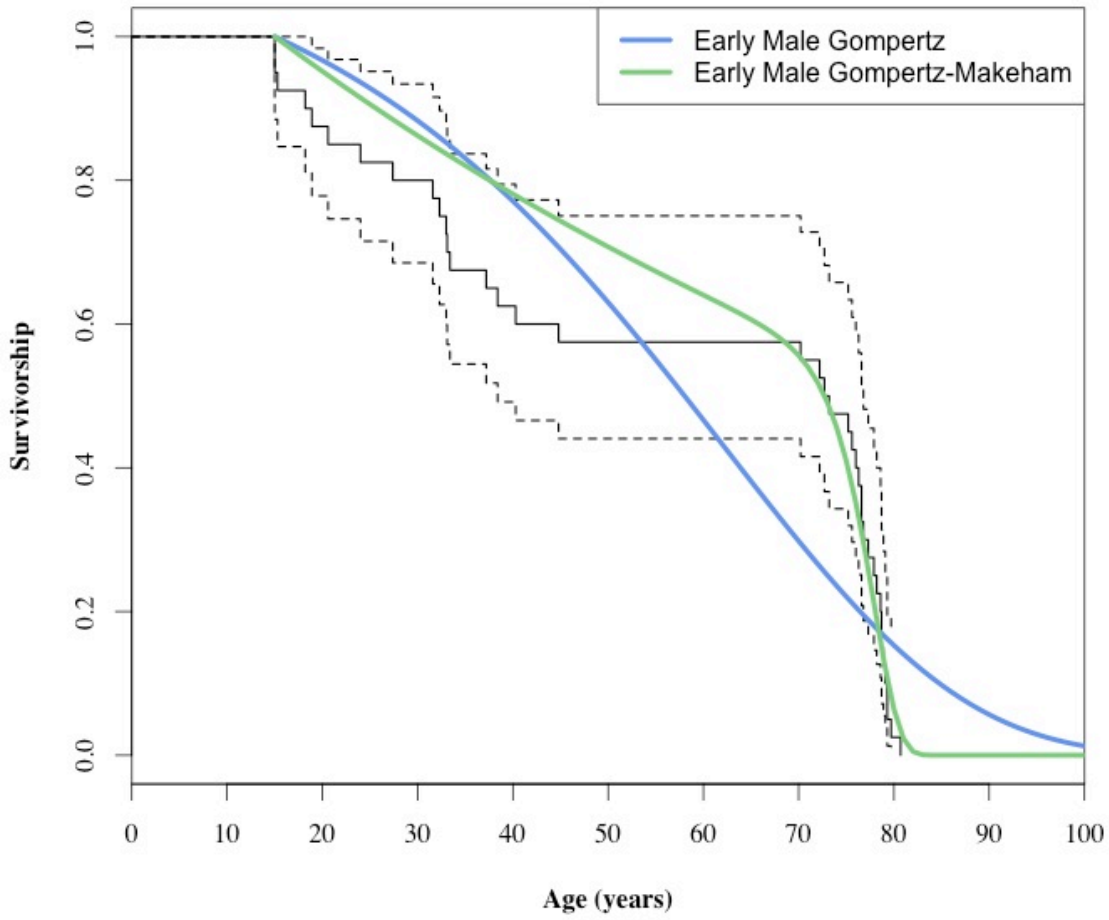


Figure 7.9 Gompertz and Gompertz-Makeham survival curves for Early Mississippian males

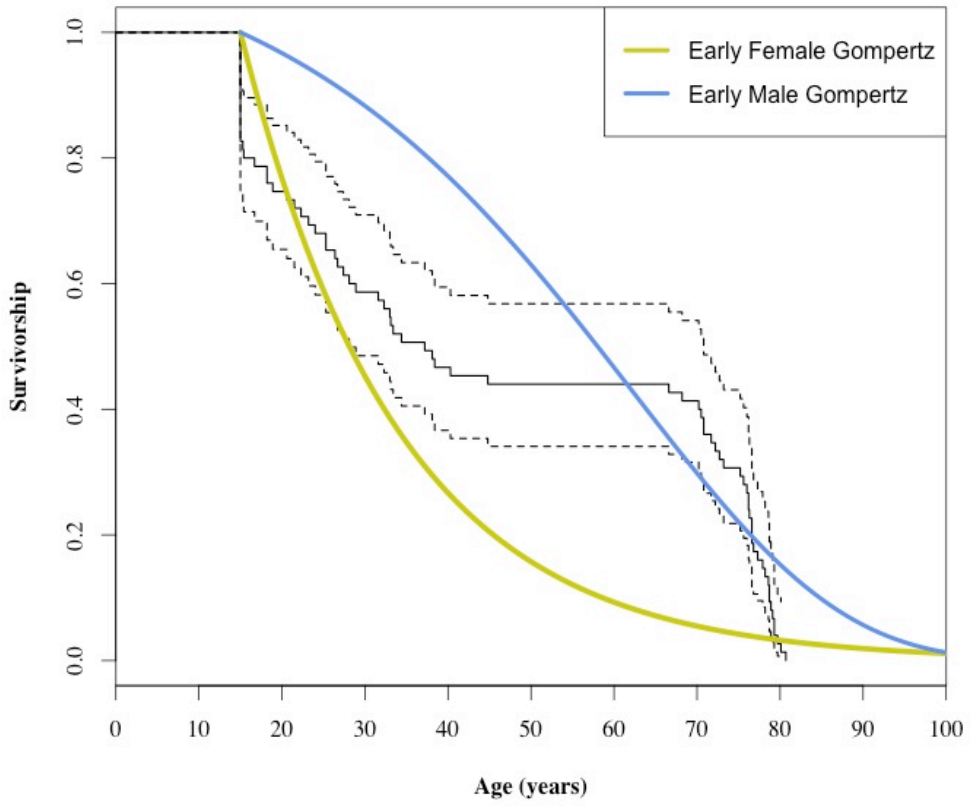


Figure 7.10 Early Mississippian Female Gompertz and Early Mississippian Male Gompertz survival curves

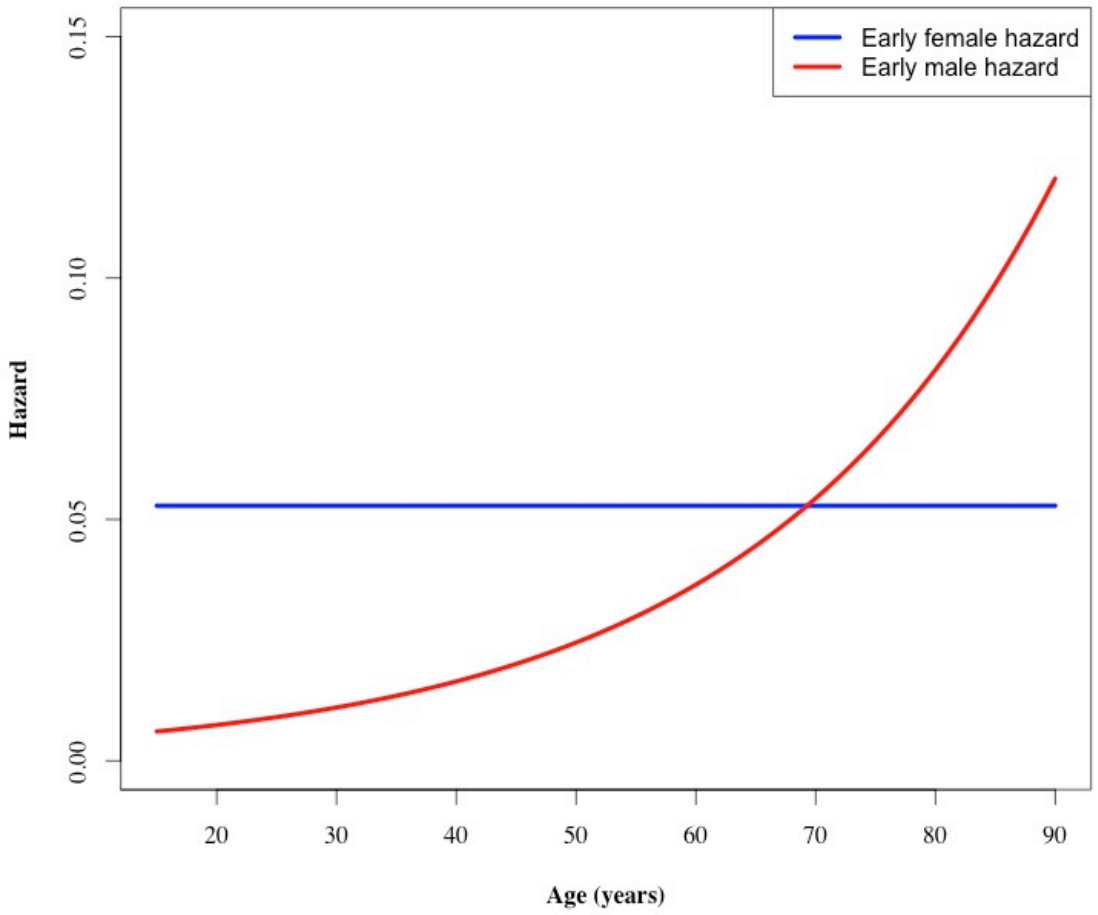


Figure 7.11 Hazard curves for early females and males

### *Middle Mississippian Adult Mortality (MCR Regional Periods III-V)*

Age-at-death estimates derived from 86 adults (≥ 15 years old) from Arnold (n=61), Gray's Farm (n=21), and Ganier (n=4) were used to reconstruct the Middle Mississippian adult mortality pattern in the Middle Cumberland Region. Figure 7.12 illustrates the Kaplan-Meier survival plot for the 86 adults that make up the Middle Mississippian sample. As with the Early Mississippian MCR sample, survivorship decreases with age. The hazard model parameters are reported in Table 7.7. The survival curves for the Gompertz and Gompertz-Makeham models are illustrated in Figure 7.13. The Gompertz-Makeham model provides a better fit to the data, as represented by both the AIC value and graphical visualization. Numerical integration of survivorship estimates the mean age-at-death to have been 42.60 years in the Middle Mississippian MCR.

Table 7.8 compares the Gompertz and Gompertz-Makeham model parameters for Middle Mississippian females (n=30). The Gompertz model offers the most parsimonious and best fitting model and the Gompertz AIC is smaller than the Gompertz-Makeham AIC value. The survival curves for both models are illustrated in Figure 7.14.

The Gompertz and Gompertz-Makeham model parameters for Middle Mississippian males (n=44) are presented in Table 7.9. Figure 7.15 demonstrates the survival curves plotted with Kaplan-Meier survivorship. The inclusion of the age-independent parameter allows for better fitting of the data, and the Gompertz-Makeham model is the most optimal.

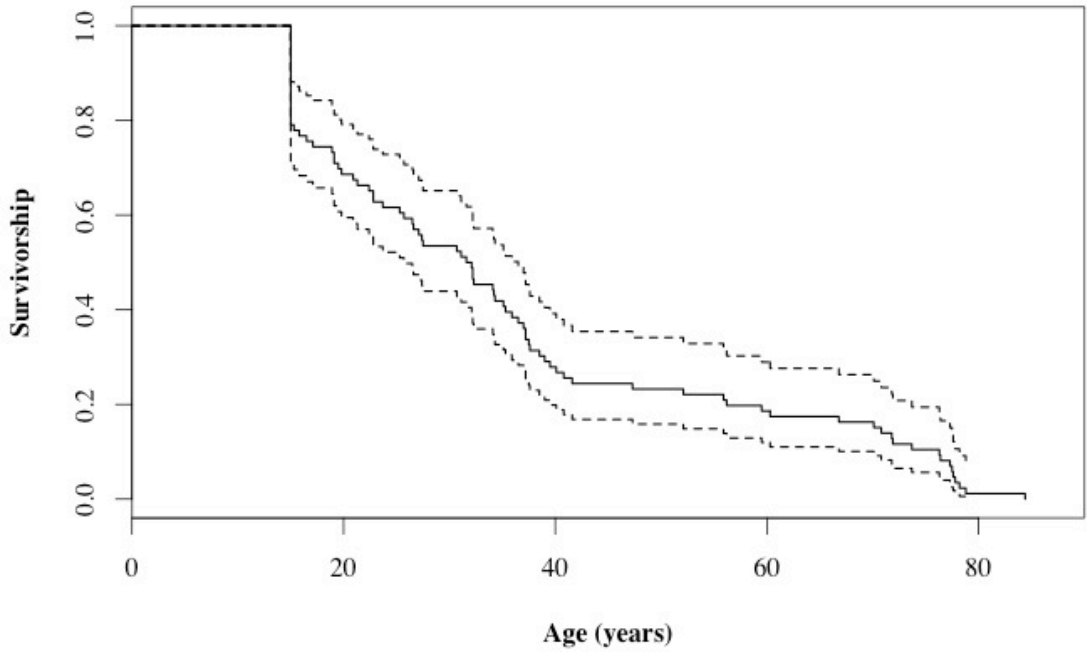


Figure 7.12 Kaplan-Meier survival plot of the Middle Mississippian period

Table 7.7 Gompertz and Gompertz-Makeham model parameters for the Middle Mississippian period

| | $\alpha_2$ | $\alpha_3$ | $\beta_3$ | **Log-likelihood** | **AIC** |
|---|---|---|---|---|---|
| Gompertz | N/A | 0.04737952 | 0.0000000001 | -348.275 | 700.55 |
| **Gompertz-Makeham** | **0.04283759** | **0.00027889** | **0.07594157** | **-345.665** | **697.33** |

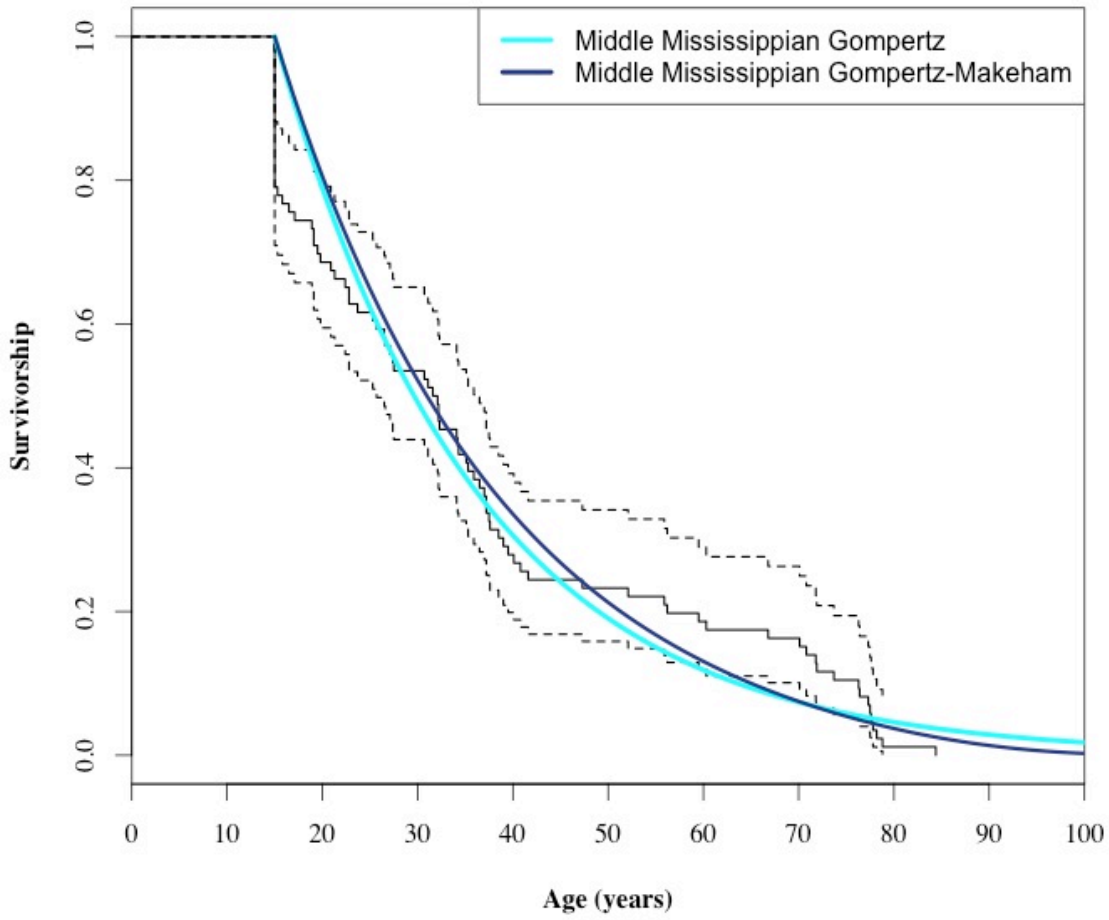


Figure 7.13 Gompertz and Gompertz-Makeham survival curves for the Middle Mississippian period

Table 7.8 Gompertz and Gompertz-Makeham model parameters for Middle Mississippian females

| | $\alpha_2$ | $\alpha_3$ | $\beta_3$ | **Log-likelihood** | **AIC** |
|---|---|---|---|---|---|
| **Gompertz** | **N/A** | **0.05626996** | **0.0000000001** | **-116.331** | **236.662** |
| Gompertz-Makeham | 0.4601956 | 0.00023623 | 0.09341256 | -115.521 | 237.042 |

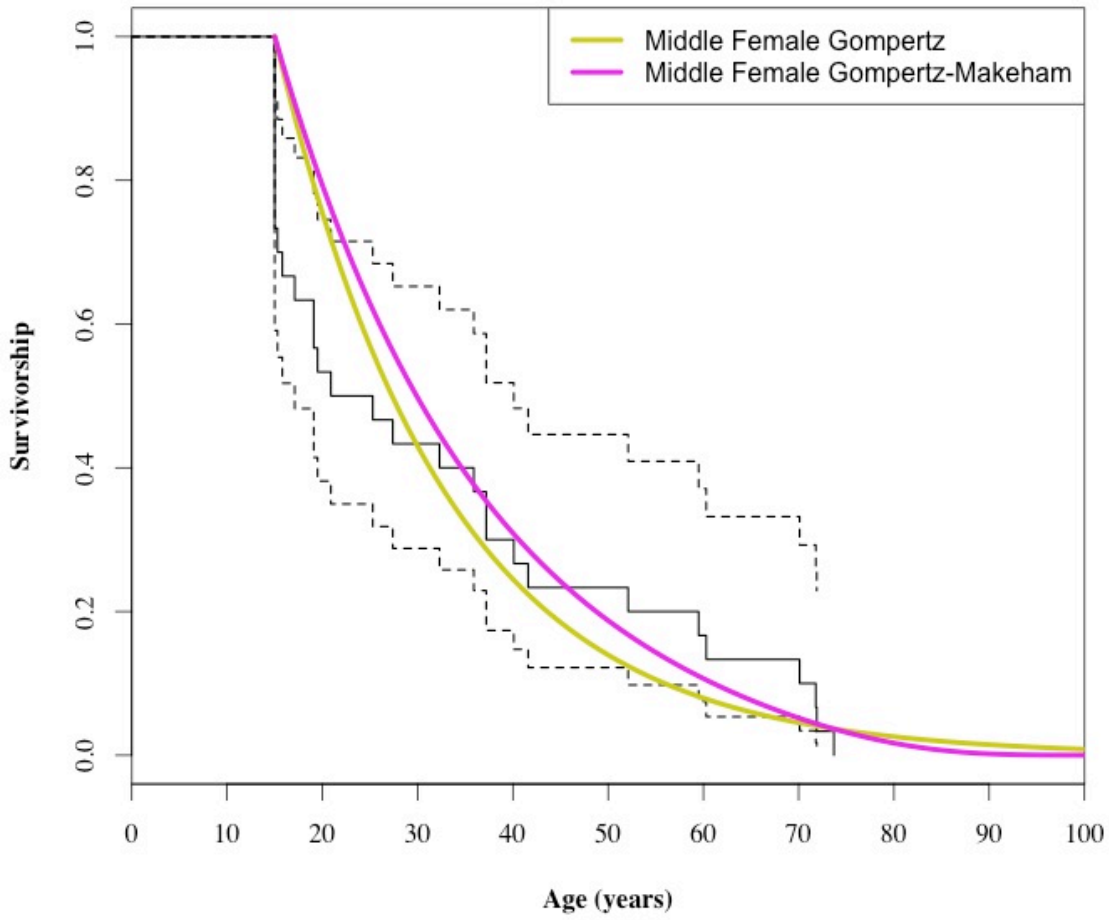


Figure 7.14 Gompertz and Gompertz-Makeham survival curves for Middle Mississippian females

Table 7.9 Gompertz and Gompertz-Makeham model parameters for Middle Mississippian males

| | $\alpha_2$ | $\alpha_3$ | $\beta_3$ | **Log-likelihood** | **AIC** |
|---|---|---|---|---|---|
| Gompertz | N/A | 0.03353514 | 0.0084463 | -184.27 | 372.54 |
| **Gompertz-Makeham** | **3.427828e-02** | **6.402737e-10** | **3.070415e-01** | **-177.093** | **360.186** |

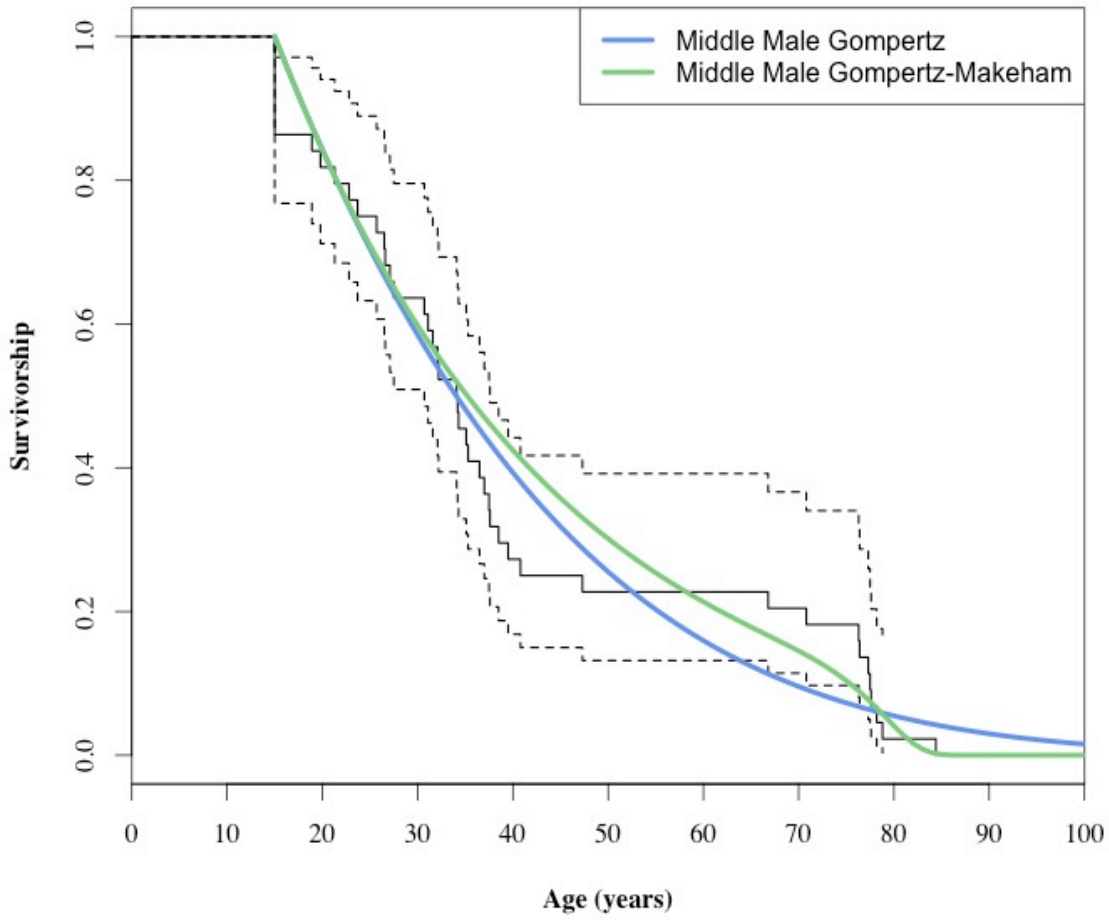


Figure 7.15 Gompertz and Gompertz-Makeham survival curves for Middle Mississippian Males

When the most optimal models for Middle Mississippian males and females are plotted in the same figure, survivorship differences by sex can be discerned, though they are not as obvious as the Early Mississippian sample (Figure 7.16). A comparison of the mean ages-at-death is further evidence for this finding. The mean age-of-death for Middle Mississippian MCR females was 41.33 years, while the mean age-of-death for Middle Mississippian MCR males is only four more years: 45.41.

***Late Mississippian Adult Mortality (MCR Regional Periods IV-V)***

Age-at-death estimates from 384 adults (≥ 15 years old) from Averbuch (n=306), Brentwood Library (n=36), Gordontown (n=31), and Rutherford-Kizer (n=11) were used to reconstruct the Late Mississippian adult mortality pattern in the Middle Cumberland Region. The considerable sample size is attributed to the extensive archaeological excavations of Averbuch, which dominates the sample. Figure 7.17 illustrates the Kaplan-Meier survival plot for the 384 adults that make up the Late Mississippian MCR sample. As with both the Early and Middle Mississippian MCR samples, survivorship decreases with age. The plateau between 40 and 70 years suggests that the Transition Analysis method has accounted for few individuals in this age range. Numerical integration of survivorship estimates the mean age-at-death to have been 42.99 years in the Late Mississippian MCR.

Table 7.10 compares the Gompertz and Gompertz-Makeham model parameters, log-likelihood, and AIC values. Comparison of the Akaike Information Criteria support the Gompertz-Makeham model as the best fitting model. Both hazard model survival curves are illustrated in Figure 7.18.

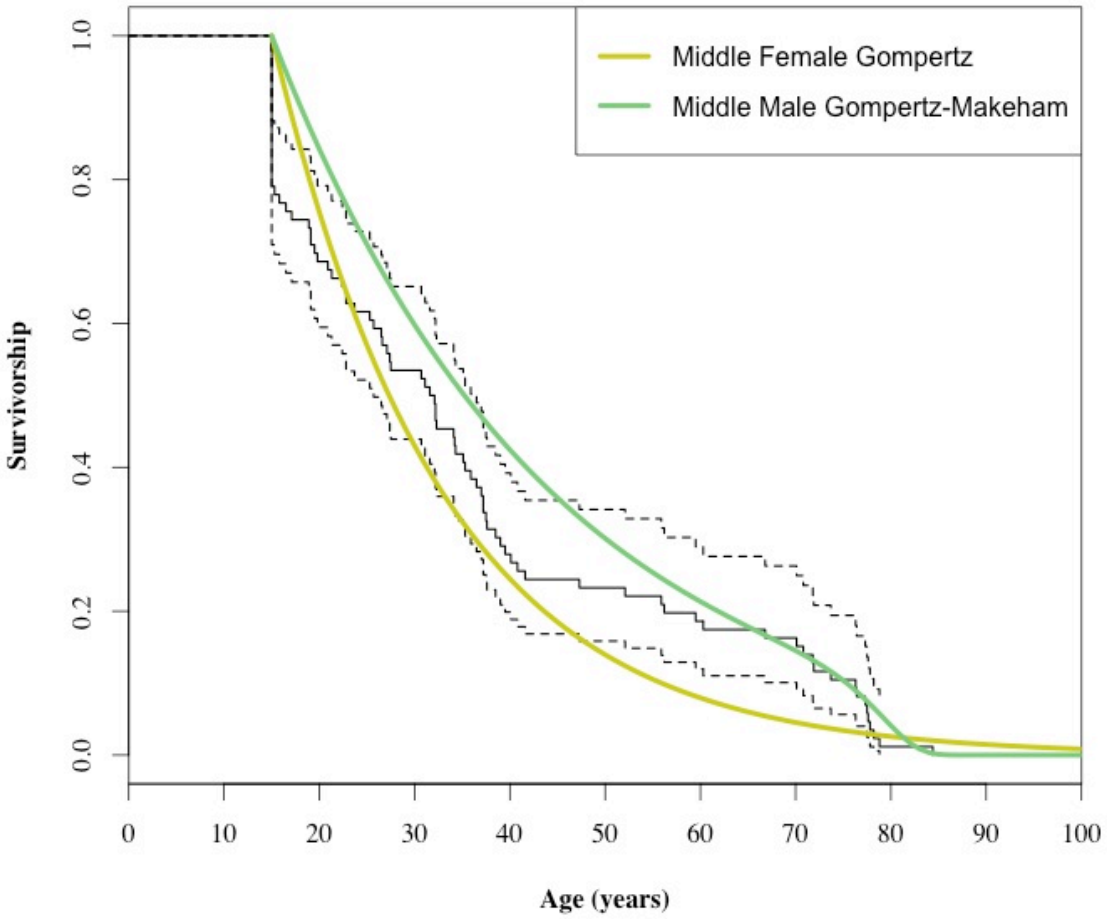


Figure 7.16 Middle Mississippian Gompertz Females and Gompertz-Makeham Males survival curves

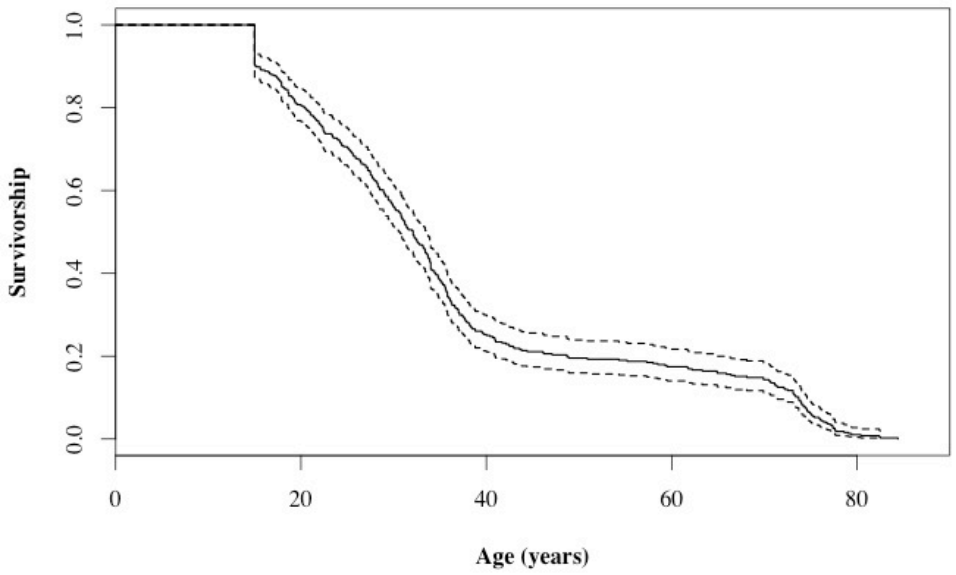


Figure 7.17 Kaplan-Meier survivorship in the Late Mississippian MCR

Table 7.10 Gompertz and Gompertz-Makeham model parameters for the Late Mississippian period

| | $\alpha_2$ | $\alpha_3$ | $\beta_3$ | **Log-likelihood** | **AIC** |
|---|---|---|---|---|---|
| Gompertz | N/A | 0.0394835 | 0.0079701 | -1559.122 | 3122.244 |
| **Gompertz-Makeham** | **4.120688e-02** | **5.12215e-09** | **2.84578e-01** | **-1521.278** | **3048.556** |

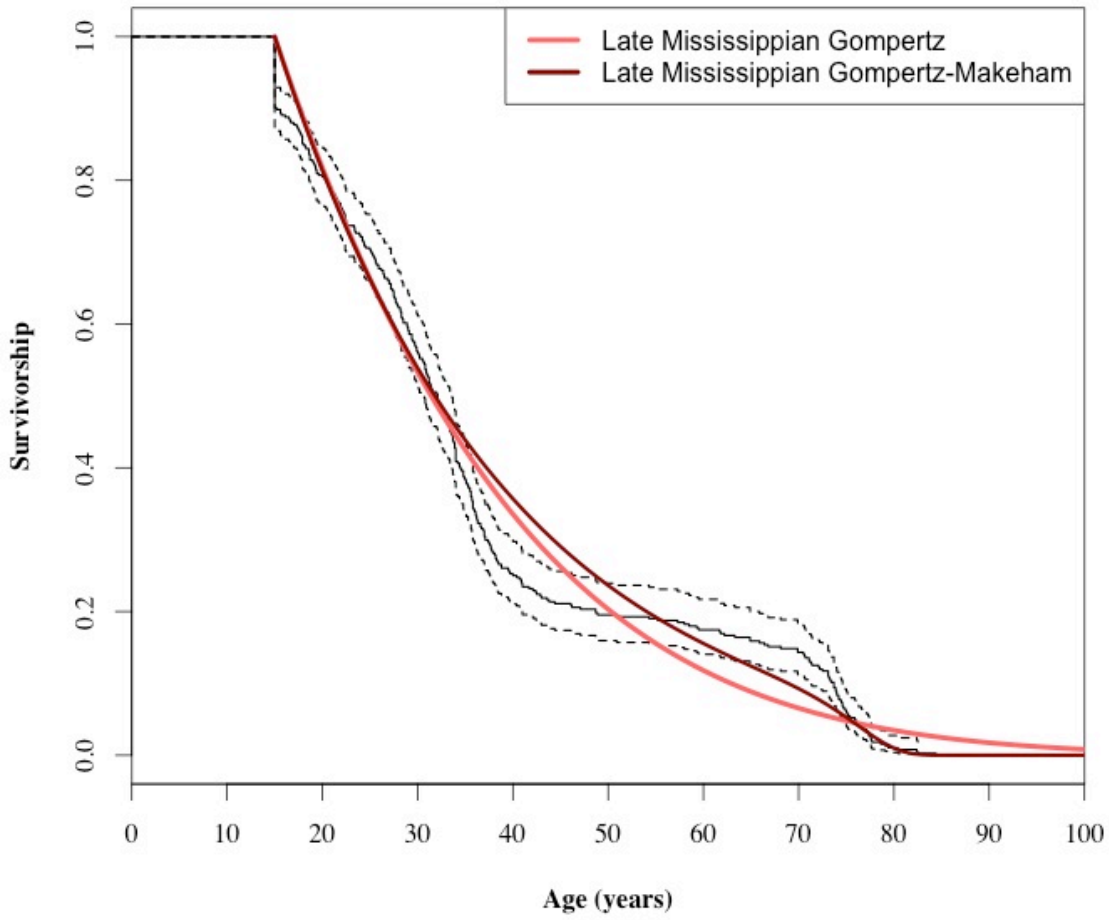


Figure 7.18 Gompertz and Gompertz-Makeham survival curves for the Late Mississippian period

The Gompertz and Gompertz-Makeham model parameters for Late Mississippian females (n=155) are recorded in Table 7.11. A comparison of AIC values reveal that the Gompertz model fits the data best. Figure 7.19 illustrates how similar the survival curves are for these models when plotted with Kaplan-Meier survivorship.

Table 7.12 presents the model parameters for Late Mississippian males (n=222). The addition of the age-independent parameter to the Gompertz model provides the best fit, with the Gompertz-Makeham model deemed the most optimal. The survival curves for Late Mississippian males are plotted in Figure 7.20.

When the best fitting models for Late Mississippian males and females are plotted together, differences in survivorship by sex are apparent (Figure 7.21). As with the previous analyses, females have lower survivorship than males. However, these differences are not as apparent as the Early Mississippian sample. The similar mean ages-at-death further support this. The mean age-of-death for Late Mississippian MCR females was 41.39 years, while the mean age-of-death for Late Mississippian MCR males is only three additional years (44.45).

Table 7.11 Gompertz and Gompertz-Makeham model parameters for Late Mississippian females

| | $\alpha_2$ | $\alpha_3$ | $\beta_3$ | **Log-likelihood** | **AIC** |
|---|---|---|---|---|---|
| **Gompertz** | **N/A** | **0.051495534** | **0.0015993** | **-610.059** | **1224.118** |
| Gompertz-Makeham | 0.0300702 | 0.020615945 | 0.00056918 | -610.026 | 1226.052 |

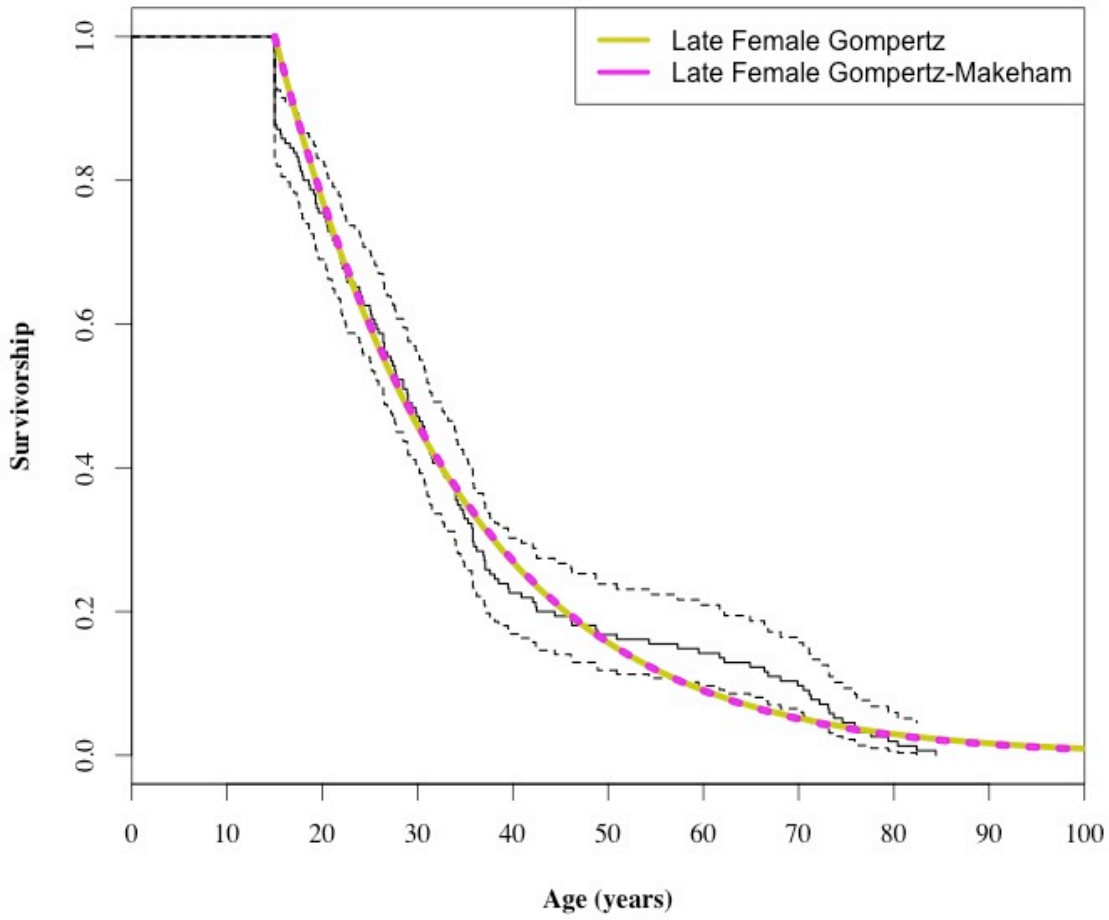


Figure 7.19 Gompertz and Gompertz-Makeham survival curves for Late Mississippian females

Table 7.12 Gompertz and Gompertz-Makeham model parameters for Late Mississippian males

| | $\alpha_2$ | $\alpha_3$ | $\beta_3$ | **Log-likelihood** | **AIC** |
|---|---|---|---|---|---|
| Gompertz | N/A | 0.0.032471 | 0.01226198 | -918.641 | 1841.282 |
| **Gompertz-Makeham** | **3.60266e-02** | **6.51529e-11** | **3.63427e-01** | **-883.668** | **1773.336** |

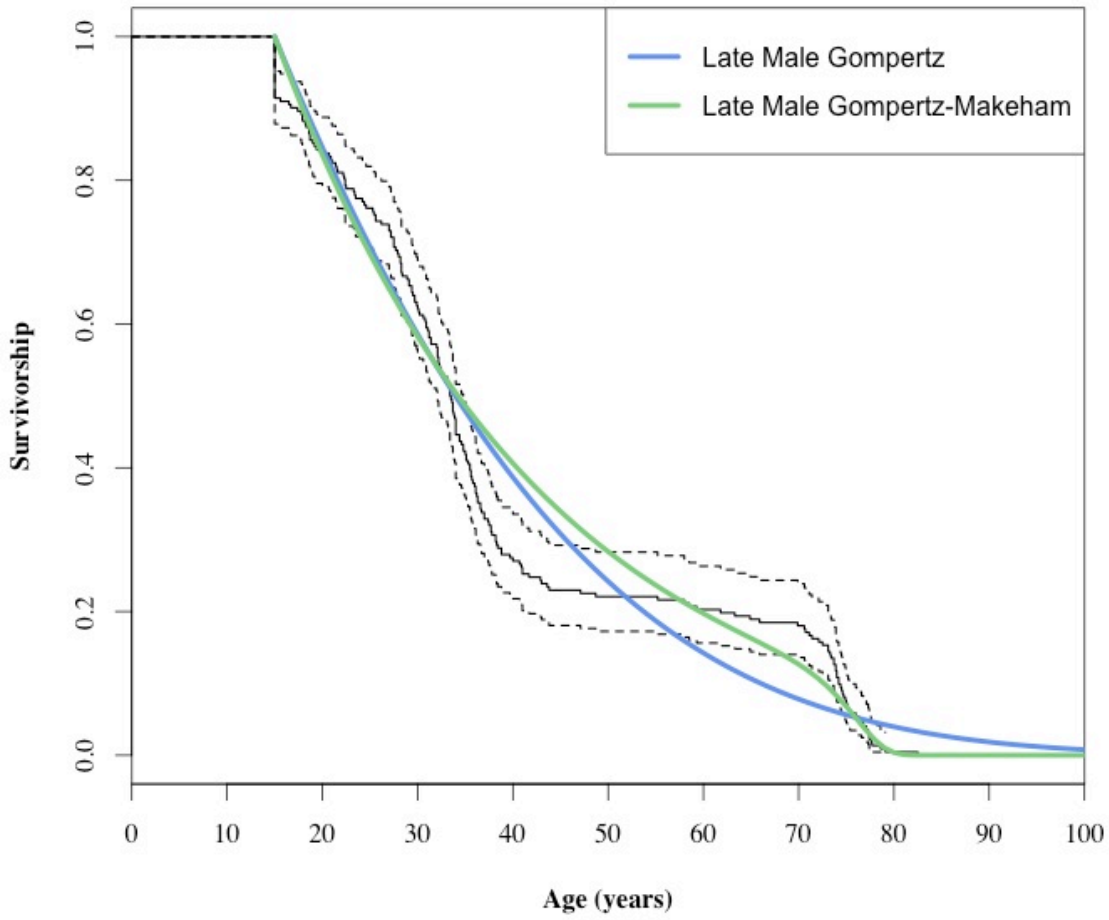


Figure 7.20 Gompertz and Gompertz-Makeham survival curves for Late Mississippian males

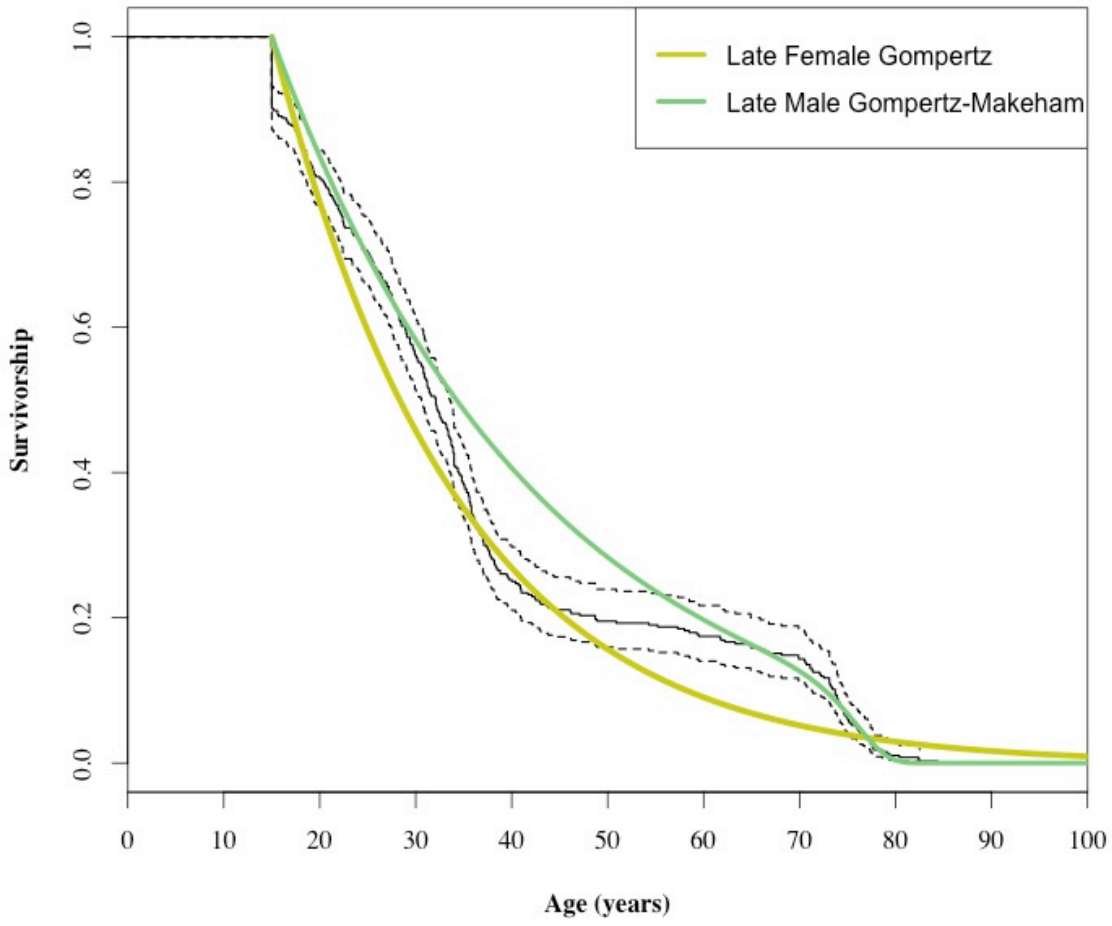


Figure 7.21 Late Mississippian Female Gompertz and Male Gompertz-Makeham survival curves

## Adult Mortality Patterns: Temporal Trends

The previous section focused on differences in mortality by age and sex within the Early, Middle, and Late Mississippian periods. Additionally, a comparison of the hazard models was first required in order to attain the best fitting model for each time period and by sex. This section synthesizes findings from the previous synchronic analyses to detect broad changes in adult mortality throughout time.

Table 7.13 presents the best fitting models for each of the Mississippian groupings in this sample, as well as the mean ages-at-death. A 6-7 year decrease in mean age-at-death is observed when comparing the Early and Middle/Late Mississippian pooled sex groups. This increase in mortality and decrease in survivorship is further illustrated in Figure 7.22 with the Middle and Late groups experienced decreased survivorship compared to the Early Mississippian sample. A likelihood ratio test was carried out to determine whether time period should be examined as separate models or one model. The likelihood ratio test revealed that Early, Middle, and Late Mississippian time periods should be modeled separately (*likelihood ratio*: 56.434, *df*=6, $p<0.001$).

Table 7.13 Best fitting models and mean ages-at-death for each Mississippian period

| MCR Mississippian Period | Optimal Hazard Model | Mean Age-at-Death |
|---|---|---|
| Early | Gompertz | 49.43 |
| Middle | Gompertz-Makeham | 42.60 |
| Late | Gompertz-Makeham | 42.99 |

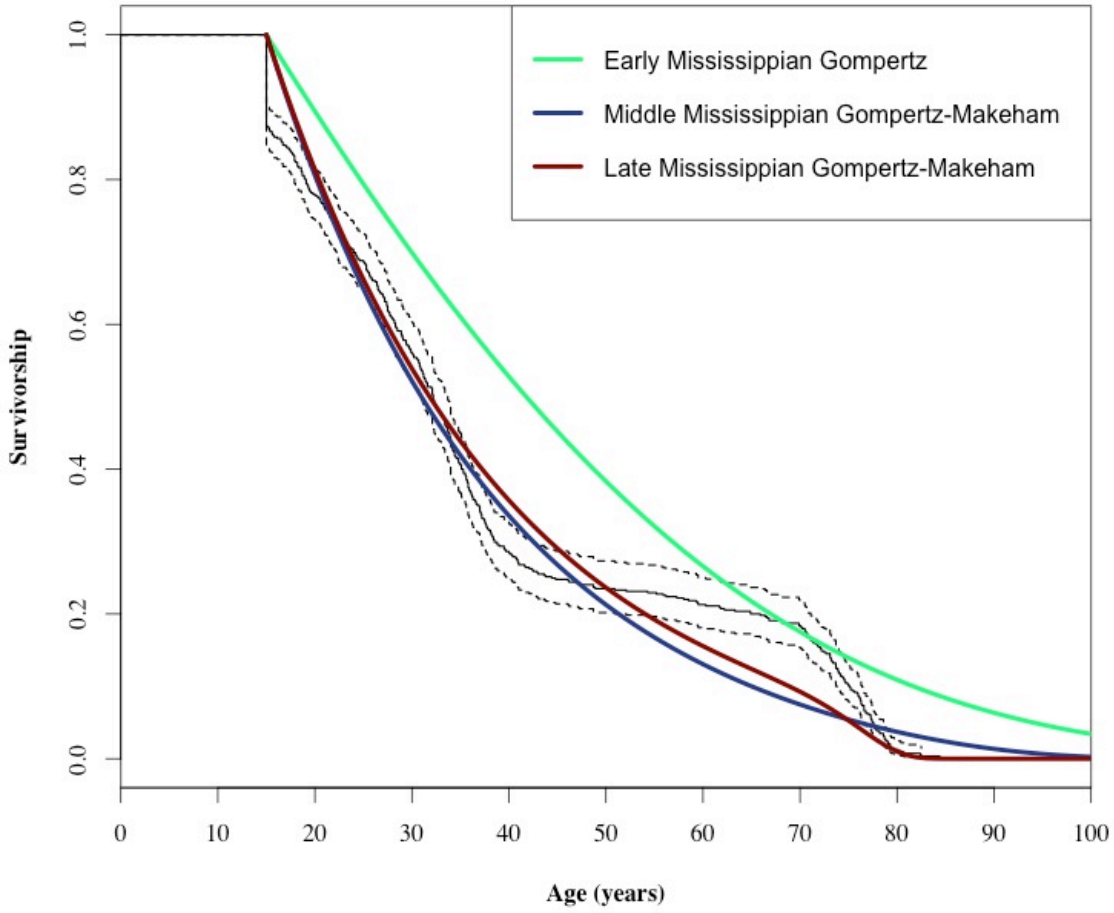


Figure 7.22 Survivorship differences in the Early, Middle, and Late Mississippian MCR sites

When sex-specific analyses are conducted, more nuanced patterns are detected. For Mississippian MCR females, the mean age-at-death remains virtually unchanged at 41 years old (Table 7.14). This constant level of mortality is elucidated in Figure 7.23, with the Early, Middle, and Late survival curves closely overlapping one another.

The constant mortality levels of females across the Mississippian period is contrasted with the pattern evident in the male sample. The mean age-at-death for males decreased by an average of twelve years between the Early and Middle/Late Mississippian periods (Table 7.15). The survival curves for males are plotted by time in Figure 7.24, with Early Mississippian males experiencing increased survivorship compared to Middle and Late males. Additionally, it is worth noting that the model that fits the Middle and Late Mississippian males best was Gompertz-Makeham. This supports the notion that social and environmental pressures—factors unrelated to the aging process—may have selected males in the Late Mississippian period to earlier death from accidents or risky behavior. This may have been the result of climatic changes and/or increased warfare, pressures on a magnitude that were not previously encountered.

Table 7.14 Best fitting models and mean ages-at-death for the Early, Middle, and Late Mississippian female sample

| **MCR Mississippian Females** | **Optimal Hazard Model** | **Mean Age-at-Death** |
|---|---|---|
| Early | Gompertz | 41.81 |
| Middle | Gompertz | 41.33 |
| Late | Gompertz | 41.39 |

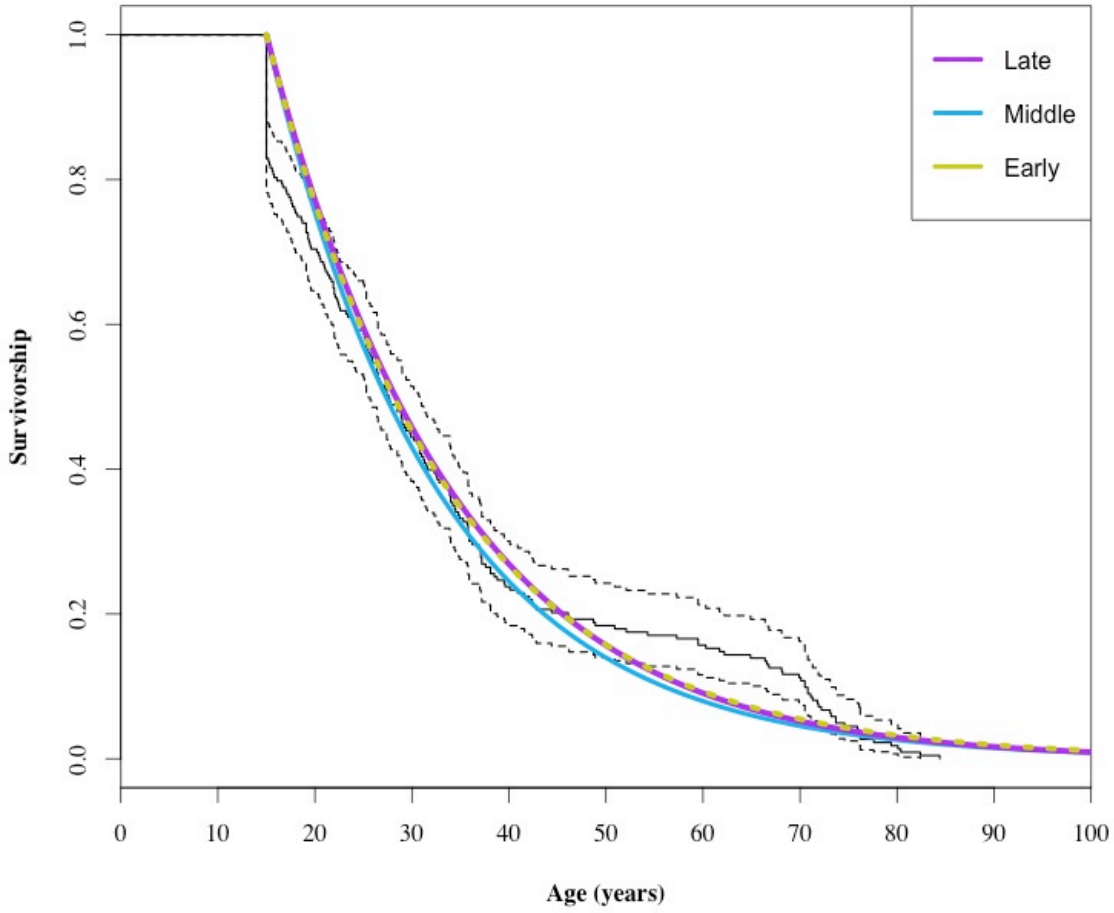


Figure 7.23 Survival curves for Early, Middle, and Late Mississippian MCR females

Table 7.15 Best fitting models and mean ages-at-death for Mississippian MCR Males

| MCR Mississippian Males | Optimal Hazard Model | Mean Age-at-Death |
|---|---|---|
| Early | Gompertz | 57.99 |
| Middle | Gompertz-Makeham | 45.41 |
| Late | Gompertz-Makeham | 44.45 |

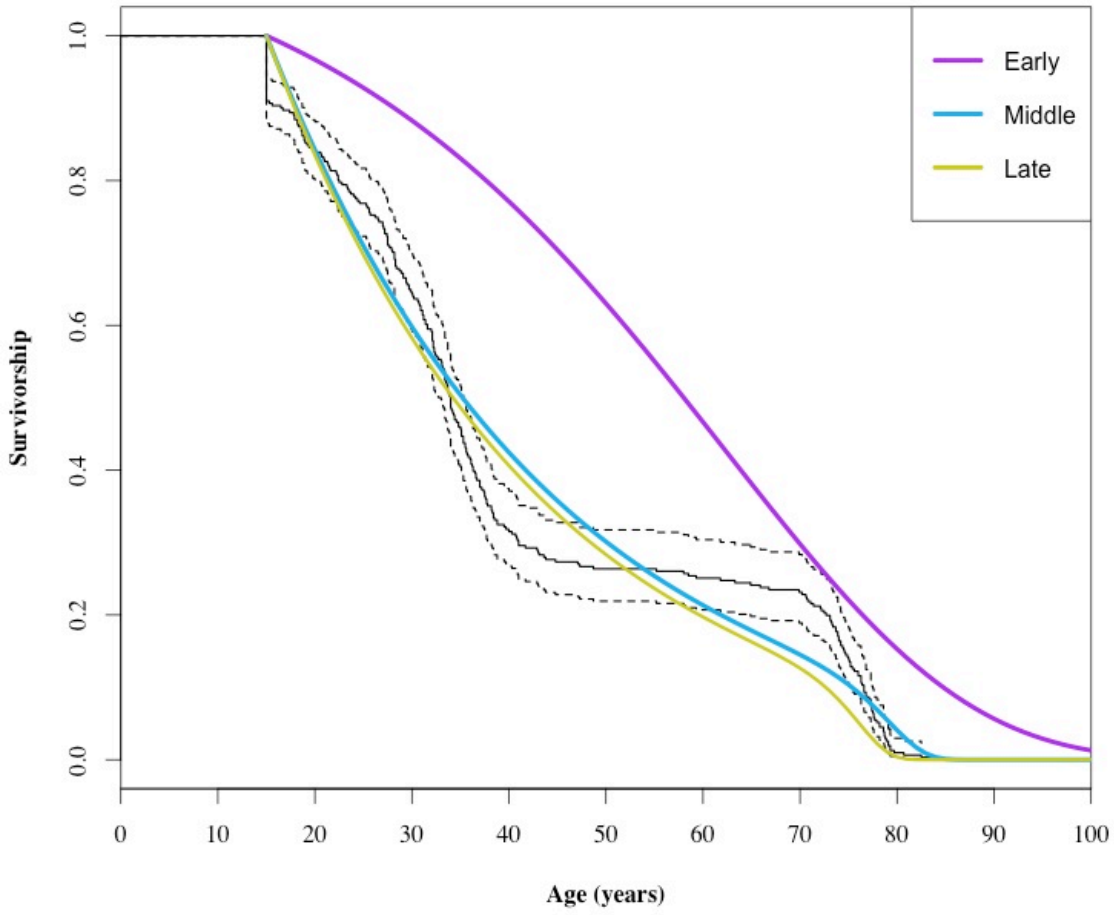


Figure 7.24 Survival curves for Early, Middle, and Late Mississippian MCR Males

## Chapter Summary

Paleodemographic results suggest that survivorship did not simply decrease with age. Marked differences between the sexes indicate that females had increased mortality compared to males. A low but constant mortality level contributed to a mean age-at-death of approximately 41 years for Mississippian females in the MCR. Males eventually encountered a similar average life expectancy (44.45) during the Late Mississippian period; this is in stark contrast with a mean age-at-death that approached 60 years during the Early Mississippian period. Furthermore, application of the Transition Analysis aging method included age estimates from older individuals. Using these maximum-likelihood estimates allowed for a mortality pattern more in line with pre-industrial, historic populations, with many individuals living into old age. It is evident that risk of death was not uniform across the Middle Cumberland Region during the Mississippian period. The following chapter presents paleoepidemiology findings. It examines physiological, social, and environmental factors that may have contributed to increased age- and sex-specific mortality, and ultimately, the depopulation of the Nashville Basin during the 15$^{th}$ century

# Chapter 8: Paleoepidemiology Results

This chapter presents paleoepidemiology results, following the order presented in the Methods chapter. The focus of this chapter is to document differences in survivorship given the presence or absence of skeletal and dental markers, age-at-death, sex, and time period. Kaplan-Meier analyses and log-rank tests explore the effect of these health covariates on mortality during the Mississippian period in the Middle Cumberland Region.

## Linear Enamel Hypoplasias

A total of 362 adults from the MCR sample were available to score for the presence or absence of linear enamel hypoplasias (LEH). These include individuals that were scored using Transition Analysis and presented sufficient anterior dentition for the assessment of enamel hypoplasias. These data were divided into smaller data sets in order for separate analyses to be run. Table 8.1 presents the analyses of the pooled sex sample of 362 adults. The log-rank test reveals a slight difference in survivorship among adults who had LEH and those who did not present any evidence of LEH ($p=0.045$). Figure 8.1 demonstrates that survivorship of those with and without LEH is virtually indistinguishable until the mid-30s when individuals with LEH survived longer than similarly-aged individuals without LEH. This indicates that childhood stress events that disrupted amelogenesis did not negatively affect survivorship of those who lived into adulthood. This finding goes against the traditional interpretation of early childhood

Table 8.1 Relationship between LEH presence and adult survivorship

| | **Mean Age-at-Death** | **SE** | **95% CI** |
|---|---|---|---|
| **No LEH (n=116)** | 32.68 | 1.50 | 29.75 - 35.61 |
| **LEH (n=246)** | 36.57 | 1.30 | 34.01 - 39.13 |
| | | | $\chi^2$=4.01 |
| | | | p=0.045 |

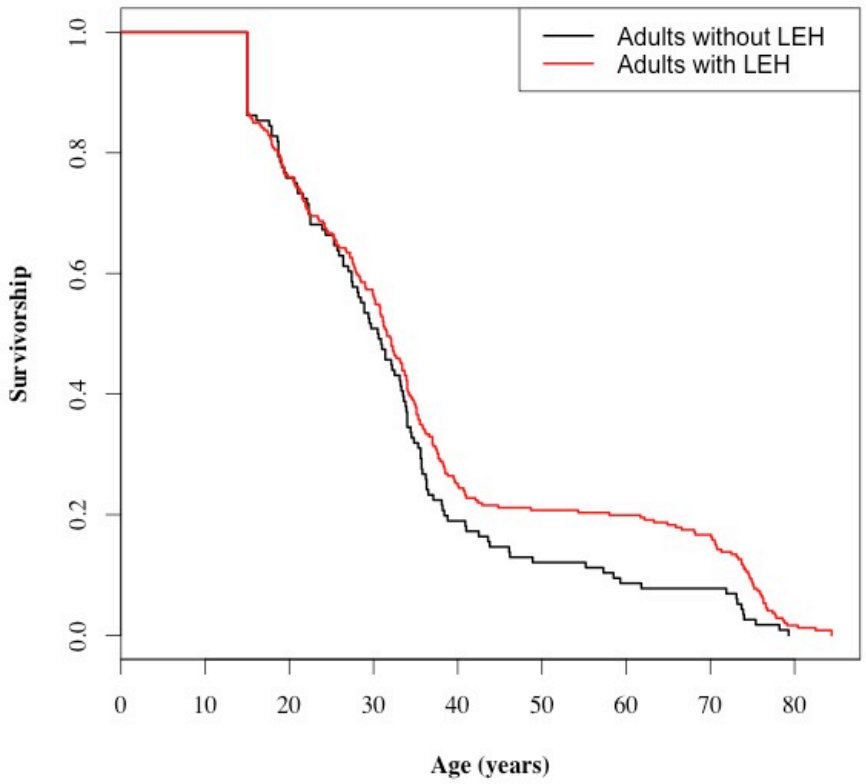


Figure 8.1 Kaplan-Meier survival plot for adults with and without LEH

experiences. These results suggest that overcoming periods of stress early in life may have bolstered the immune response of individuals with LEH, allowing them to better cope with disease and hardships later in life. This finding lends credence to interpretations put forth by the osteological paradox (Wood et al., 1992), and will be explored in greater detail in the Discussion chapter.

No statistical differences in survivorship were found among females with and without LEH (Table 8.2). The survival curves of females with and without LEH are not different from one another until approximately 40 years when the curves begin to diverge, however this difference is not statistically significant (Figure 8.2). Similar to the findings for female survivorship, no statistical differences were found in the survivorship of males with LEH compared to those without LEH (Table 8.3; Figure 8.3). These results imply that the presence of LEH does not have a discernable impact on survivorship within each sex.

Table 8.2 Relationship between LEH presence and female survivorship

| | **Mean Age-at-Death** | **SE** | **95% CI** |
|---|---|---|---|
| **Females without LEH (n=48)** | 29.49 | 2.23 | 25.11 - 33.87 |
| **Females with LEH (n=93)** | 32.42 | 1.95 | 28.61 - 36.24 |
| | | | $\chi^2$=0.784 |
| | | | p=0.376 |

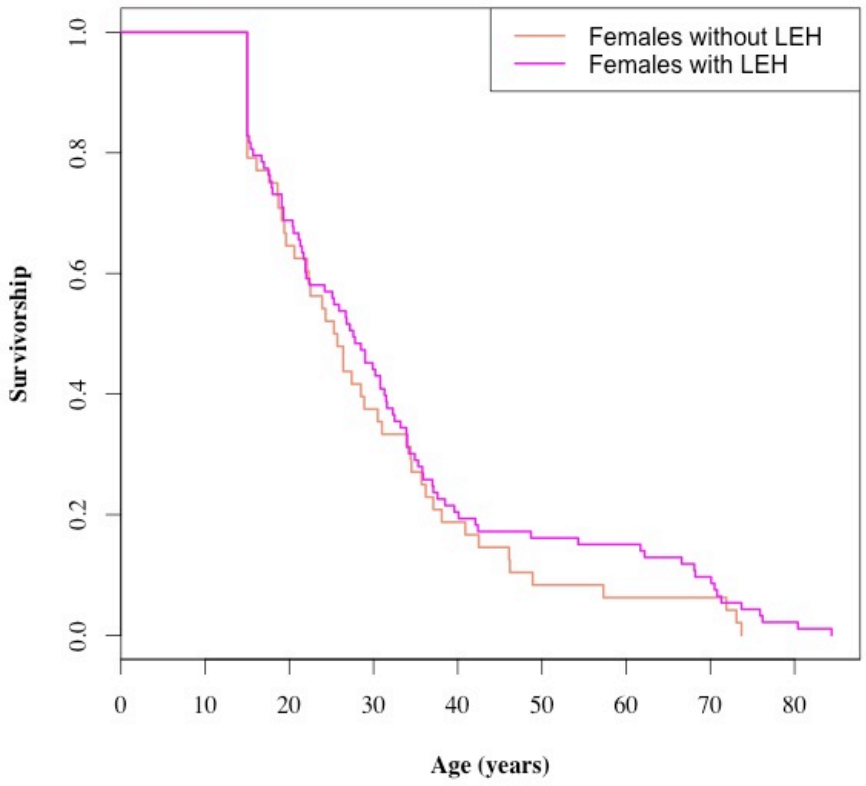


Figure 8.2 Kaplan-Meier survival plot for females with and without LEH

Table 8.3 Relationship between LEH presence and male survivorship

| | **Mean Age-at-Death** | **SE** | **95% CI** |
|---|---|---|---|
| **Males without LEH (n=64)** | 35.76 | 2.05 | 31.74 - 39.78 |
| **Males with LEH (n=147)** | 39.31 | 1.74 | 35.91 - 42.71 |
| | | | $\chi^2$=1.74 |
| | | | p=0.187 |

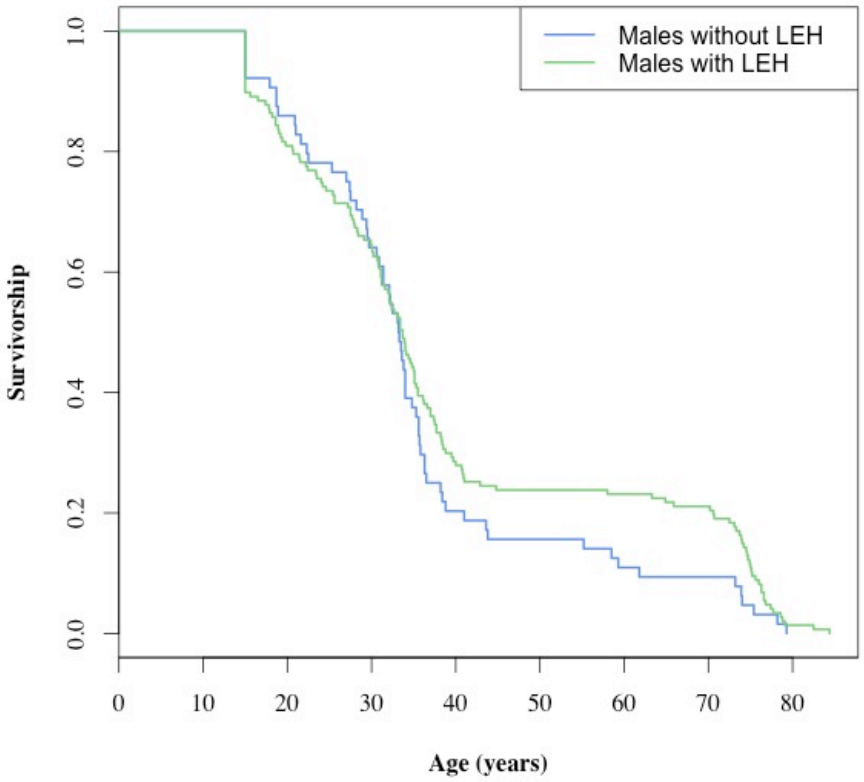


Figure 8.3 Kaplan-Meier survival plot for males with and without LEH

Table 8.4 presents the results of sex-specific survivorship for those with LEH. Significant differences were found between males and females, with females who experienced childhood stressors attributed to LEH dying approximately 7 years earlier than males with LEH (Figure 8.4). This suggests that LEH placed stronger selective pressures on females who were considerably frailer than males who also presented evidence of LEH.

When taking into account time period, no differences were found in survivorship among Early, Middle, and Late Mississippian adults with LEH (Table 8.5). This suggests that the childhood stress events that cause LEH had no impact on longevity during the Mississippian period (Figure 8.5).

Table 8.4 Relationship between LEH presence and sex

| | **Mean Age-at-Death** | **SE** | **95% CI** |
|---|---|---|---|
| **Females with LEH (n=93)** | 32.42 | 1.95 | 28.61 - 36.24 |
| **Males with LEH (n=147)** | 39.31 | 1.74 | 35.91 - 42.71 |
| | | | $\chi^2$=7.26 |
| | | | p=0.007 |

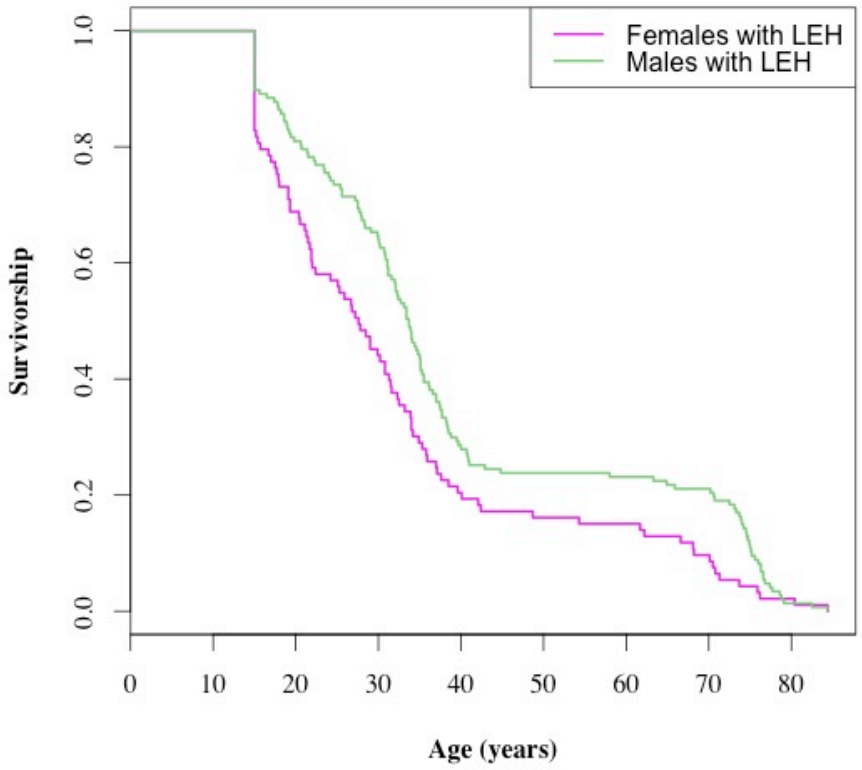


Figure 8.4 Kaplan-Meier survival plot for LEH presence by sex

Table 8.5 The effect of time period on survivorship for adults with LEH

| | **Mean Age-at-Death** | **SE** | **95% CI** |
|---|---|---|---|
| **Early Mississippian Adults with LEH (n=27)** | 41.47 | 4.94 | 31.79 - 51.15 |
| **Middle Mississippian Adults with LEH (n=26)** | 36.97 | 4.74 | 27.69 - 46.26 |
| **Late Mississippian Adults with LEH (n=246)** | 35.83 | 1.38 | 33.14 - 38.53 |
| | | | $\chi^2$=1.69 |
| | | | p=0.430 |

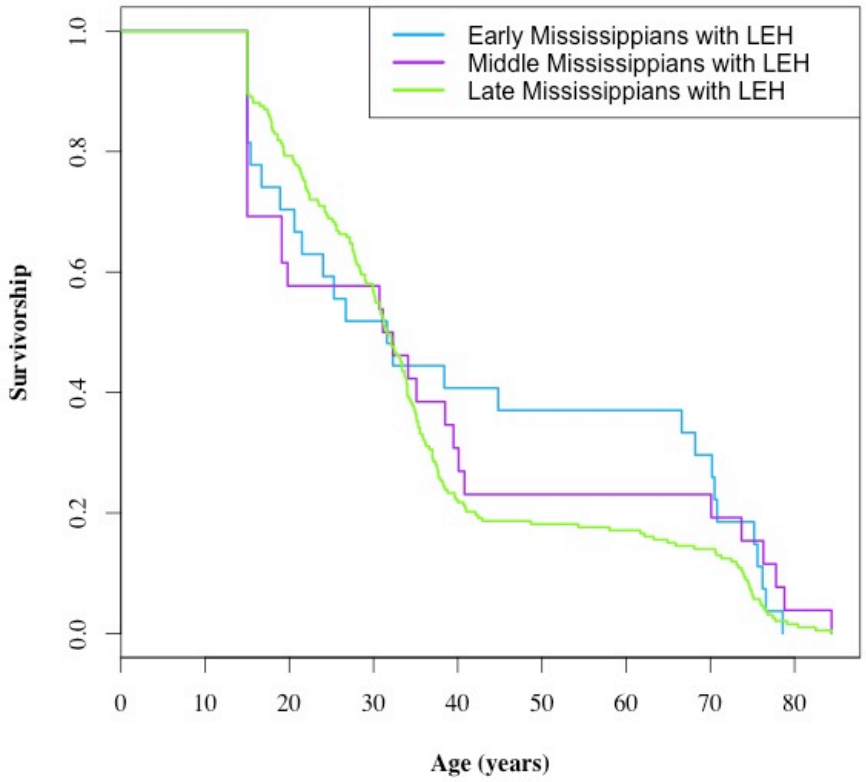


Figure 8.5 Kaplan-Meier survival plot for Early, Middle, and Late Mississippian adults with LEH

**Porotic Hyperostosis**

A total of 419 adults from the MCR sample were available to score for the presence or absence of porotic hyperostosis (PH). These include individuals that were scored using Transition Analysis and presented sufficient cranial elements (frontal, parietals, occipital) for the assessment of PH. As with the LEH analyses, these data were divided into smaller subsets in order for separate analyses to be run.

Table 8.6 presents the analyses of the pooled sex sample of 419 adults. The log-rank test reveals a significant difference in survivorship among adults with and without PH. Figure 8.6 demonstrates that individuals with PH had lower survivorship than individuals without PH. These results run counter to the findings for enamel hypoplasias. Individuals with PH died ten years earlier than those without PH, which suggest that early childhood stressors that produce PH lesions had a negative effect on survivorship.

Table 8.6 Relationship between PH presence and adult survivorship

| | **Mean Age-at-Death** | **SE** | **95% CI** |
|---|---|---|---|
| **Adults without PH (n=315)** | 41.17 | 1.21 | 38.75 - 43.55 |
| **Adults with PH (n=104)** | 31.07 | 1.81 | 27.53 - 34.61 |
| | | | $\chi^2$=18.94 |
| | | | p<0.005 |

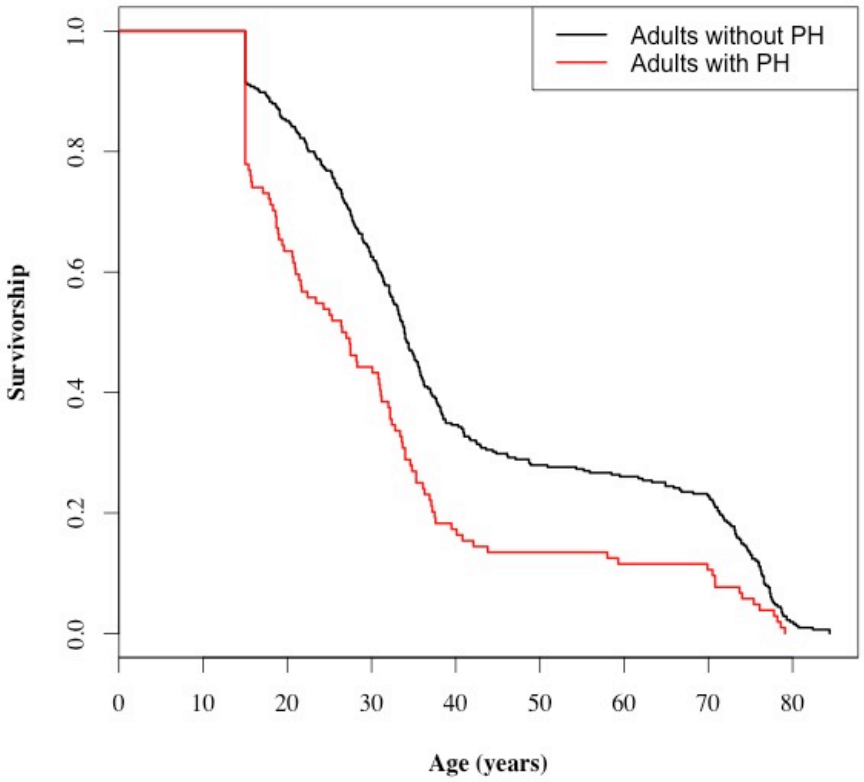


Figure 8.6 Kaplan-Meier survival plot for adults with and without PH

Statistical differences in survivorship were found among females with and without PH (Table 8.7) Females with PH had a mean age-at-death that was 9 years earlier than females without PH. Additionally, Figure 8.7 illustrates that survival curves of females with and without PH are markedly different from one another across all ages. Differences in survivorship were also found among males with and without PH (Figure 8.8). Table 8.8 indicates that males with PH had a mean age-at-death that was 11 years earlier than males without PH, illustrating the effect of selective mortality.

Table 8.9 presents the results of sex-specific survivorship for those with PH. Significant differences were found between males and females, with females who experienced childhood stressors attributed to PH dying approximately six years earlier than males with PH (Figure 8.9). This suggests that the etiology of PH, though non-specific in source, placed stronger selective pressures on females compared to males who also presented evidence of PH.

Table 8.7 Relationship between PH presence and female survivorship

| | **Mean Age-at-Death** | **SE** | **95% CI** |
|---|---|---|---|
| **Females without PH (n=120)** | 36.37 | 1.83 | 32.79 - 39.95 |
| **Females with PH (n=46)** | 27.03 | 2.43 | 22.27 - 31.79 |
| | | | $\chi^2$=8.43 |
| | | | p=0.004 |

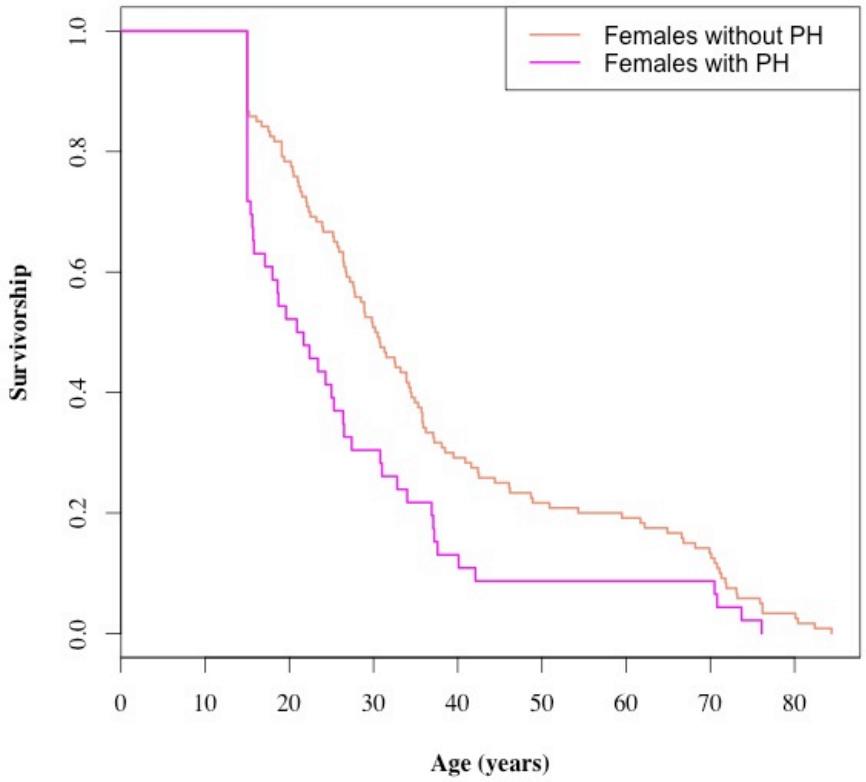


Figure 8.7 Kaplan-Meier survival plot for females with and without PH

Table 8.8 Relationship between PH presence and male survivorship

| | **Mean Age-at-Death** | **SE** | **95% CI** |
|---|---|---|---|
| **Males without PH (n=186)** | 44.27 | 1.61 | 41.11 - 47.43 |
| **Males with PH (n=55)** | 33.87 | 2.54 | 28.90 - 38.84 |
| | | | $\chi^2$=9.53 |
| | | | p=0.002 |

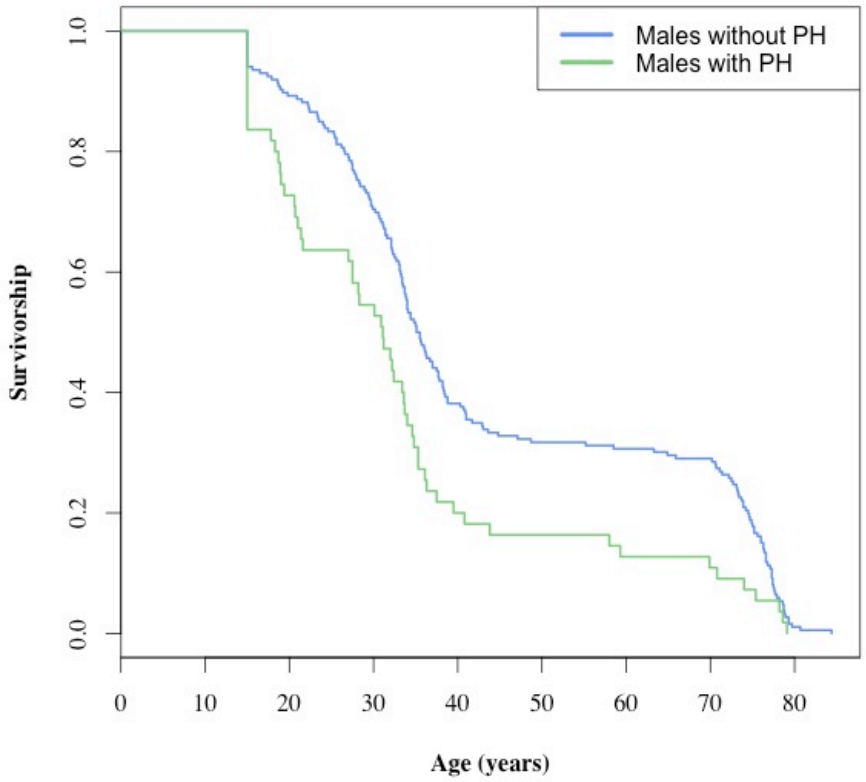


Figure 8.8 Kaplan-Meier survival plot for males with and without PH

Table 8.9 Relationship between PH presence and sex

| | **Mean Age-at-Death** | **SE** | **95% CI** |
|---|---|---|---|
| **Females with PH (n=46)** | 27.03 | 2.43 | 22.27 - 31.79 |
| **Males with PH (n=55)** | 33.87 | 2.54 | 28.90 - 38.83 |
| | | | $\chi^2$=4.29 |
| | | | p=0.038 |

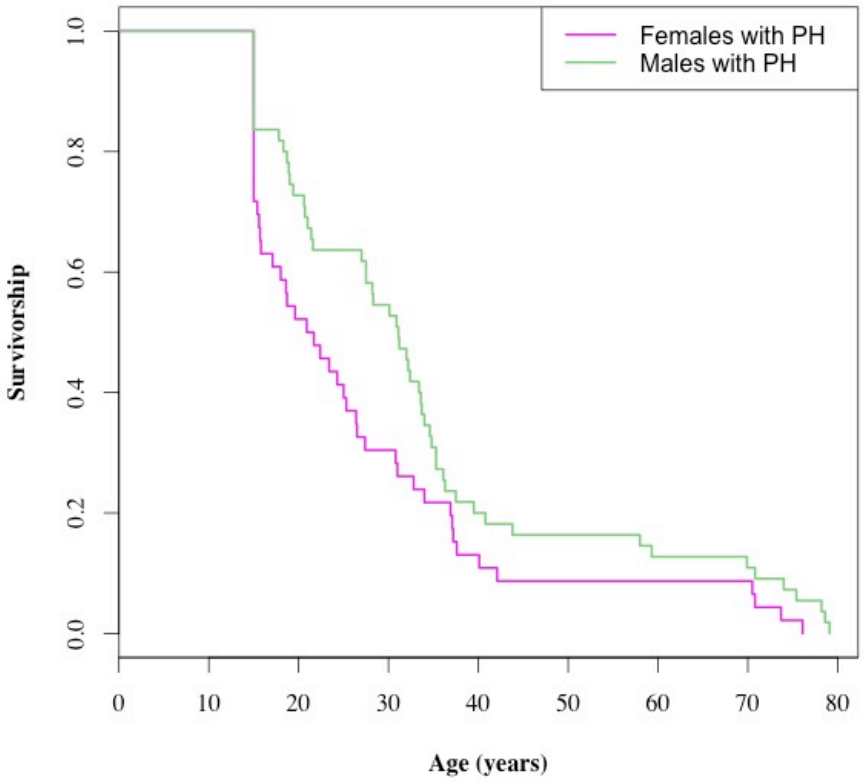


Figure 8.9 Kaplan-Meier survival plot for females and males with PH

When considering time period, there are no differences in survivorship among Early, Middle, and Late Mississippian adults with PH (Table 8.10). These findings suggest that PH has no impact on longevity during the Mississippian period (Figure 8.10). However, this could be a result of the small sample size, especially that of the Early Mississippian sample.

**Carious Lesions**

A total of 448 adults from the MCR sample were available to score for the presence or absence of carious lesions. These include individuals that were scored using Transition Analysis and presented first and second permanent molars for the assessment of caries. As with the analyses for LEH and PH, this sample was divided into smaller data sets in order for separate analyses to be run.

Table 8.11 presents the analysis of the pooled sex sample of 448 adults. The log-rank test reveals a significant difference in survivorship among adults with and without carious lesions (p=0.002). Figure 8.11 demonstrates that individuals with carious lesions had reduced survivorship compared to individuals without carious lesions, suggesting their negative impact on survivorship.

Taking a closer look at the effect of an advanced caries state, differences are found in survivorship beyond the mere presence or absence of caries. There is a significant difference on survivorship when conducting an overall comparison of caries severity ($\chi^2$=11.32, p=0.003). Pairwise comparison log-rank tests reveal that there is a difference in survivorship between individuals with no caries and individuals with carious lesions that involve the enamel or dentine (p=0.001, Table 8.12). Individuals with

Table 8.10 The effect of time period on survivorship for adults with PH

| | **Mean Age-at-Death** | **SE** | **95% CI** |
|---|---|---|---|
| **Early Mississippian Adults with PH (n=13)** | 34.94 | 7.74 | 19.78 - 50.09 |
| **Middle Mississippian Adults with PH (n=23)** | 33.94 | 4.51 | 25.09 - 42.78 |
| **Late Mississippian Adults with PH (n=68)** | 29.36 | 1.80 | 25.84 - 32.89 |
| | | | $\chi^2$=3.14 |
| | | | p=0.208 |

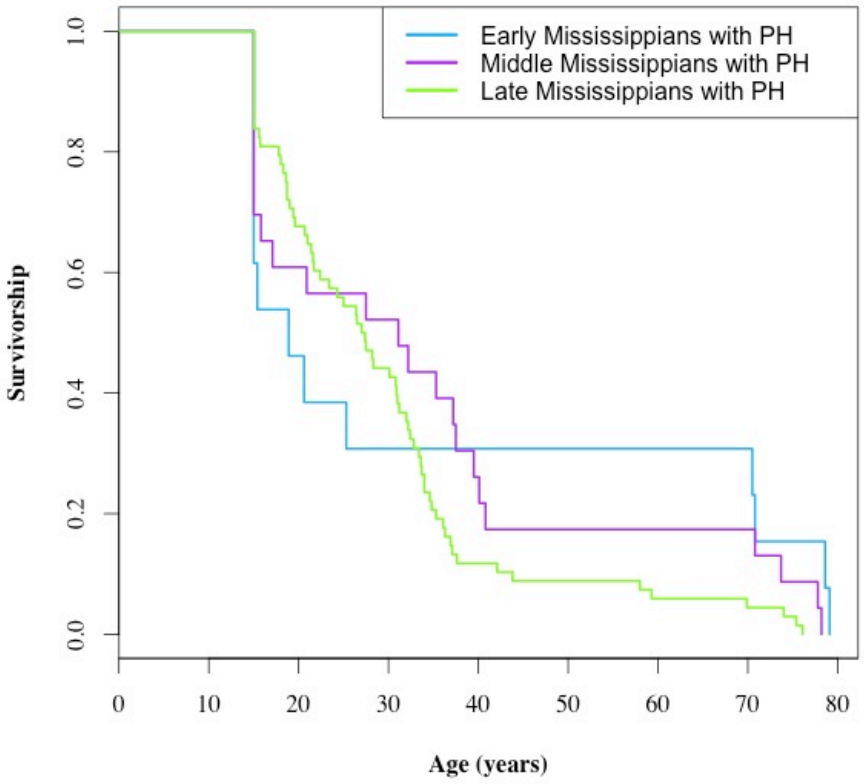


Figure 8.10 Kaplan-Meier survival plot for Early, Middle, and Late Mississippian adults with PH

Table 8.11 Relationship between carious lesion presence and adult survivorship

| | **Mean Age-at-Death** | **SE** | **95% CI** |
|---|---|---|---|
| **Adults with no carious lesions (n=67)** | 45.51 | 2.93 | 39.78 - 51.24 |
| **Adults with carious lesions (n=381)** | 36.42 | 1.04 | 34.38 - 38.46 |
| | | | $\chi^2$=9.19 |
| | | | p=0.002 |

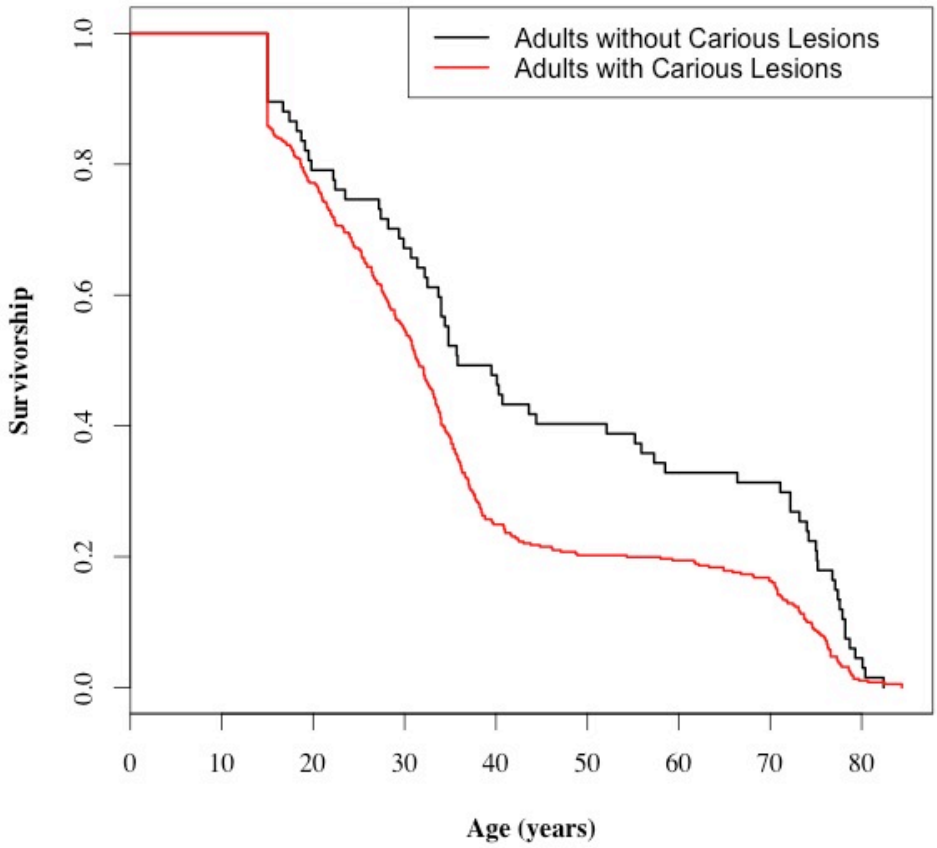


Figure 8.11 Kaplan-Meier survival plot for adults with and without carious lesions

Table 8.12 Log-rank tests on pairwise comparison of advanced caries state for MCR adults

| | **No carious lesions** | | **Carious lesions without pulp cavity involvement** | | **Carious lesions with pulp cavity involvement** | |
|---|---|---|---|---|---|---|
| | $\chi^2$ | **p-value** | $\chi^2$ | **p-value** | $\chi^2$ | **p-value** |
| **No carious lesions** | - | - | 11.08 | 0.001 | 3.72 | 0.054 |
| **Carious lesions without pulp cavity involvement** | 11.08 | 0.001 | - | - | 1.83 | 0.177 |
| **Carious lesions with pulp cavity involvement** | 3.72 | 0.054 | 1.83 | 0.177 | - | - |

no carious lesions have a mean age-at-death that is ten years later than individuals with caries involving the enamel or dentine (Figure 8.12). However, there is no difference in survivorship of individuals without carious lesions and individuals with caries that involve the pulp cavity (p=0.054). This finding is unexpected, since the unidirectional effect of more advanced caries is thought to have contributed to decreased survivorship (Lafranco and Eggers, 2012). Similarly, no statistical differences in survivorship are found in the progression of caries to a more advanced state (Table 8.13). Individuals with carious lesions that involved the pulp cavity did not experience increased mortality compared to individuals with caries that did not involve the pulp cavity (Figure 8.13).

The mean age-at-death of females with carious lesions was seven years earlier than females without carious lesions, but this finding was not statistically significant (Table 8.14; Figure 8.14). However, having more advanced carious lesions that involved the pulp cavity did have an effect on female survivorship in contrast to females without any carious lesions (p=0.041, Table 8.15); females with carious lesions that exposed the pulp cavity had a mean age-at-death that was eight years earlier than females without carious lesions (Figure 8.14). No differences in survivorship were found between females with no carious lesions and carious lesions that did not expose the pulp cavity (p=0.131, Table 8.15). No differences in survivorship were observed between females who presented carious lesions but differed in whether the pulp cavity was exposed (p=0.672, Table 8.15). This lack of difference is seen in Figure 8.14, with very similar survivorship curves for females who presented evidence of either state of carious lesions.

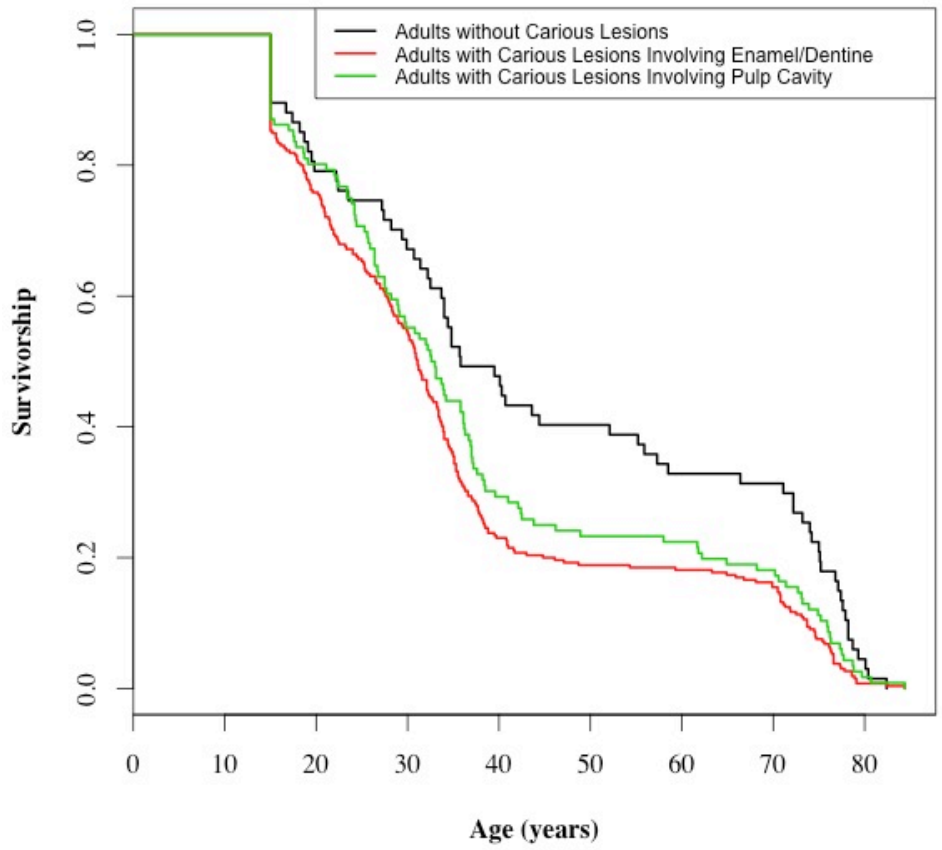


Figure 8.12 Kaplan-Meier survival plot for MCR adults by advanced carious state

Table 8.13 Descriptive statistics of advanced caries state for MCR adults

| | **Mean Age-at-Death** | **SE** | **95% CI** |
|---|---|---|---|
| **No carious lesions (n=67)** | 45.51 | 2.93 | 39.77 - 51.24 |
| **Carious lesions without pulp cavity involvement (n=265)** | 35.57 | 1.23 | 33.17 - 37.98 |
| **Carious lesions with pulp cavity involvement (n=116)** | 38.36 | 1.95 | 34.55 - 42.18 |

Table 8.14 Relationship between carious lesion presence and female survivorship

| | **Mean Age-at-Death** | **SE** | **95% CI** |
|---|---|---|---|
| **Females without caries (n=23)** | 39.90 | 4.78 | 30.53 - 49.27 |
| **Females with caries (n=158)** | 32.67 | 1.51 | 29.71 - 35.63 |
| | | | $\chi^2$=3.29 |
| | | | p=0.07 |

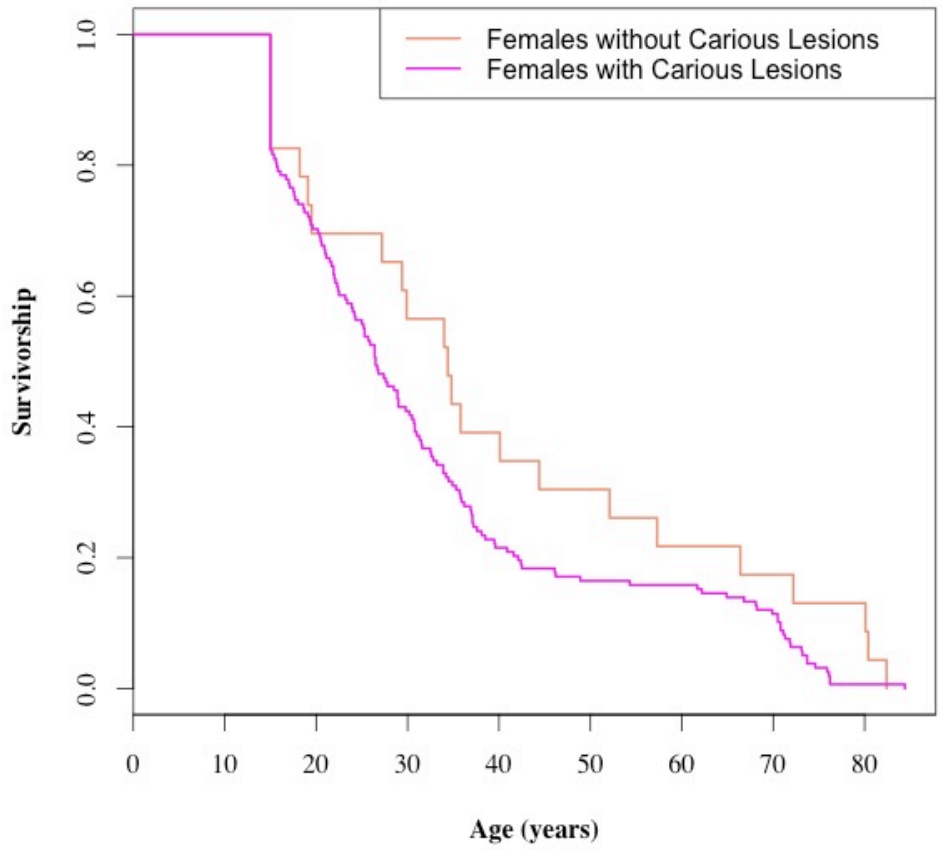


Figure 8.13 Kaplan-Meier survival plot for females with and without carious lesions

Table 8.15 Log-rank tests on pairwise comparison of advanced caries state for females

| | **Females without caries** | | **Female caries without pulp cavity involvement** | | **Female caries with pulp cavity involvement** | |
|---|---|---|---|---|---|---|
| | $\chi^2$ | **p-value** | $\chi^2$ | **p-value** | $\chi^2$ | **p-value** |
| **Females without caries** | - | - | 2.28 | 0.131 | 4.16 | 0.041 |
| **Female caries without pulp cavity involvement** | 2.28 | 0.131 | - | - | .179 | 0.672 |
| **Female caries with pulp cavity involvement** | 4.16 | 0.041 | .179 | 0.672 | - | - |

Table 8.16 Relationship between advanced caries state and female survivorship

| | Mean Age-at-Death | SE | 95% CI |
|---|---|---|---|
| **Females without caries (n=23)** | 39.90 | 4.78 | 30.53 - 49.27 |
| **Female caries without pulp cavity involvement (n=98)** | 33.29 | 2.07 | 29.24 - 37.34 |
| **Female caries with pulp cavity involvement (n=60)** | 31.66 | 2.12 | 27.50 - 35.81 |
| | | **Log-rank test on overall comparison:** | $\chi^2$=3.56 |
| | | | p=0.169 |

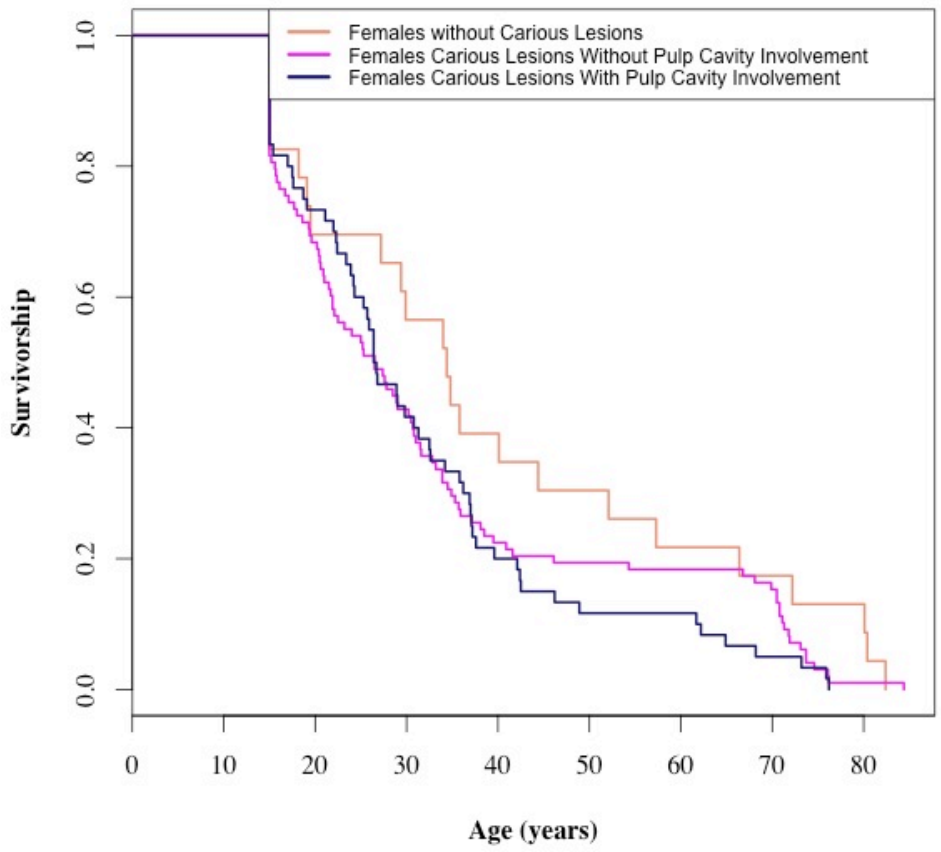


Figure 8.14 Kaplan-Meier survival plot for females without carious lesions, carious lesions without pulp cavity involvement, and carious lesions with pulp cavity involvement

Much like the findings for female survivorship and carious lesions, no differences in overall survivorship were found in males with and without carious lesions (Figure 8.15). Table 8.17 shows that males without carious lesions died an average of nine years later than males with carious lesions, though this difference was not statistically significant. However, a different pattern of male survivorship emerged when examining individual carious states (Table 8.18) Interestingly, having carious lesions that involved the pulp cavity actually *increased* male survivorship compared to males with carious lesions that did not involve the pulp cavity (p=0.006, Table 8.19). This differs from the female survivorship findings, which revealed no significant differences in individual carious states. Differences in male survivorship were also found between males without carious lesions and males with carious lesions that involved the enamel or dentine (p=0.009, Table 8.18). No differences in survivorship were found between males without carious lesions and carious lesions that exposed the pulp cavity (p=0.985, Table 8.19). Figure 8.16 illustrates this similarity, as the Kaplan-Meier survival curve for males with caries that involve the pulp cavity more closely resembles the curve of males with no carious lesions. This indicates that males with carious lesions that only effected the enamel or dentine had reduced survivorship compared to the other two carious states: males without any carious lesions and males with carious lesions that exposed the pulp cavity.

Figure 8.17 presents the results of sex-specific survivorship for those with carious lesions. Significant differences were found between males and females, with females who presented carious lesions dying seven years earlier than males who also had carious

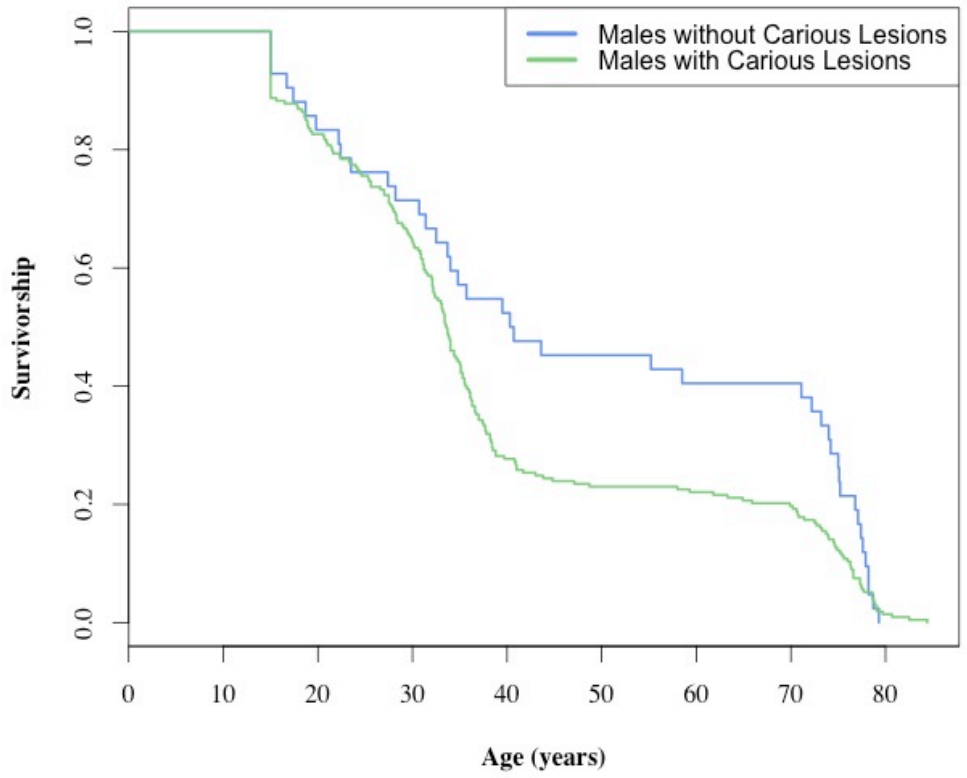


Figure 8.15 Kaplan-Meier survival plot for males with and without carious lesions

Table 8.17 Relationship between carious lesion presence and male survivorship

| | **Mean Age-at-Death** | **SE** | **95% CI** |
|---|---|---|---|
| **Males without carious lesions (n=42)** | 48.65 | 3.80 | 41.20 – 56.09 |
| **Males with carious lesions (n=213)** | 39.27 | 1.42 | 36.48 – 42.05 |
| | | | $\chi^2$=3.53 |
| | | | p=0.06 |

Table 8.18 Relationship between advanced caries states and male survivorship

| | **Mean Age-at-Death** | **SE** | **95% CI** |
|---|---|---|---|
| **Males without carious lesions (n=42)** | 48.65 | 3.80 | 41.20 – 56.09 |
| **Male carious lesions without pulp cavity involvement (n=159)** | 36.81 | 1.54 | 33.79 – 39.83 |
| **Male carious lesions with pulp cavity involvement (n=54)** | 46.50 | 3.11 | 40.41 – 52.60 |
| | | **Log-rank test on overall comparison:** | $\chi^2$=12.27 |
| | | | p=0.002 |

Table 8.19 Log-rank tests on the pairwise comparison of advanced caries states for MCR males

| | **Males without carious lesions** | | **Male carious lesions without pulp cavity involvement** | | **Male carious lesions with pulp cavity involvement** | |
|---|---|---|---|---|---|---|
| | **$\chi^2$** | **p-value** | **$\chi^2$** | **p-value** | **$\chi^2$** | **p-value** |
| **Males without carious lesions** | - | - | 6.87 | 0.009 | .000 | .985 |
| **Male carious lesions without pulp cavity involvement** | 6.87 | 0.009 | - | - | 7.57 | 0.006 |
| **Male carious lesions with pulp cavity involvement** | .000 | 0.985 | 7.57 | 0.006 | - | - |

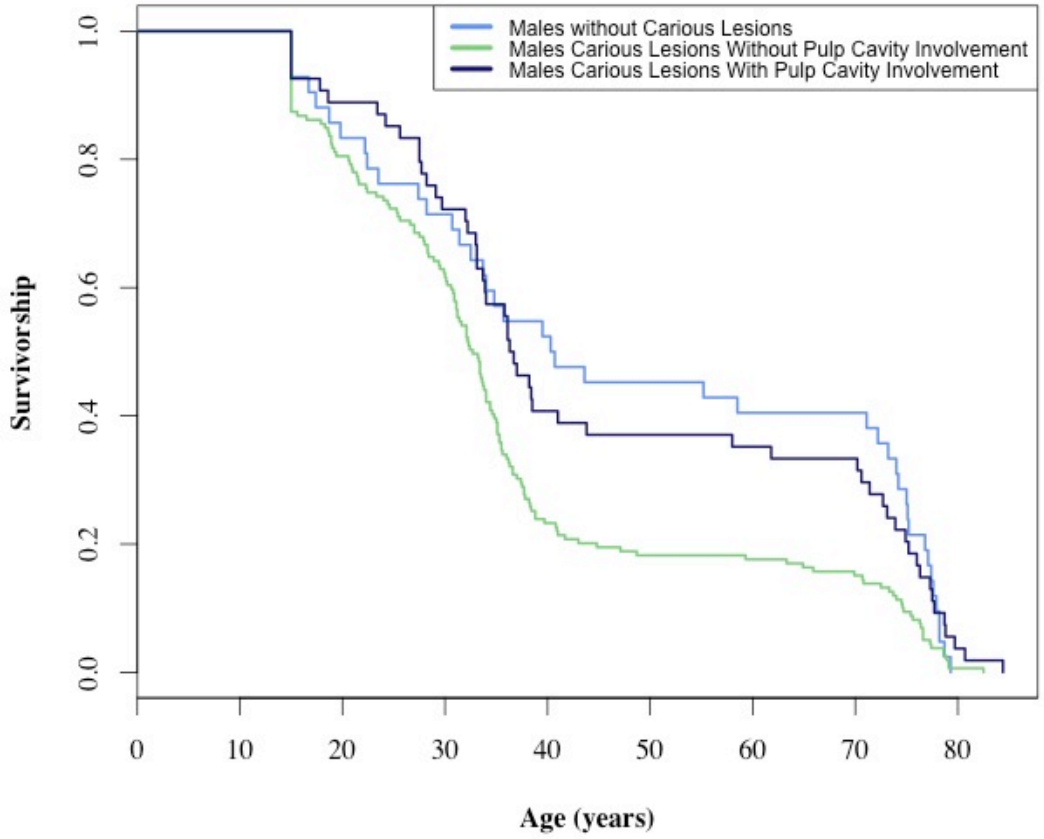


Figure 8.16 Kaplan-Meier survival plot for males without carious lesions, carious lesions without pulp cavity involvement, and carious lesions with pulp cavity involvement

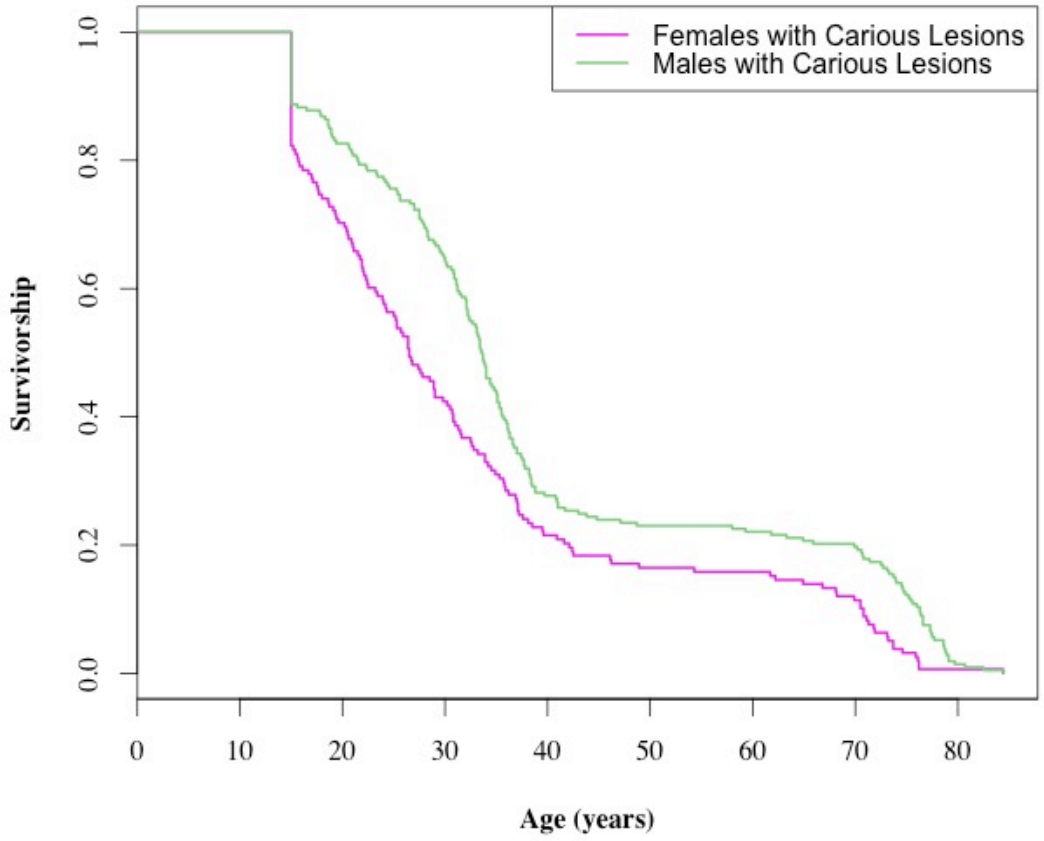


Figure 8.17 Kaplan-Meier survival plot for females with carious lesions and males with carious lesions

lesions (Table 8.20). This suggests that the presence of carious lesions placed stronger selective pressures on females compared to males who also presented evidence of caries.

When considering time period, differences in survivorship were detected among Early, Middle, and Late Mississippian adults with carious lesions (Table 8.21). No differences were found in survivorship between Early Mississippian and Middle Mississippian adults with carious lesions ($p=0.698$). There were also no differences in survivorship when comparing Middle Mississippian and Late Mississippian adults ($p=0.062$). However, differences were found in survivorship of Early and Late Mississippian adults with carious lesions, with Late Mississippian adults dying an average of seven years earlier than Early Mississippian adults ($p=0.005$). This indicates that the presence of carious lesions contributed to increased mortality from the Early to Late Mississippian period (Figure 8.18).

**Abscesses**

A total of 439 adults from the MCR sample were available to score for the presence or absence of abscesses. It was recorded whether one, two, or three or more abscesses were present, as well as the absence or inability to score for abscesses. These include individuals that were scored using Transition Analysis and presented at least half of the maxillary or mandibular alveolar bone for the assessment of abscesses. The log-rank test indicates that individuals with abscesses experienced increased survivorship compared to those without abscesses (Table 8.22). This finding runs counter to the expectation that abscesses would contribute to greater age-specific risk of death compared to individuals without abscesses. The Kaplan-Meier survival plot illustrates reduced survivorship of individuals without abscesses (Figure 8.19).

Table 8.20 Relationship between caries presence and sex

| | **Mean Age-at-Death** | **SE** | **95% CI** |
|---|---|---|---|
| **Females with carious lesions (n=158)** | 32.67 | 1.51 | 29.71 - 35.63 |
| **Males with carious lesions (n=213)** | 39.27 | 1.42 | 36.48 - 42.05 |
| | | | $\chi^2$=14.66 |
| | | | p<0.005 |

Table 8.21 The effect of time period on survivorship for adults with carious lesions

| | **Mean Age-at-Death** | **SE** | **95% CI** |
|---|---|---|---|
| **Early Mississippian Adults with carious lesions (n=51)** | 42.53 | 3.72 | 35.24 - 49.81 |
| **Middle Mississippian Adults with carious lesions (n=33)** | 38.89 | 4.58 | 29.91 - 47.86 |
| **Late Mississippian Adults with carious lesions (n=297)** | 35.10 | 1.05 | 33.38 - 38.46 |
| | | **Log-rank test on overall comparison:** | $\chi^2$=9.52 |
| | | | p=0.009 |

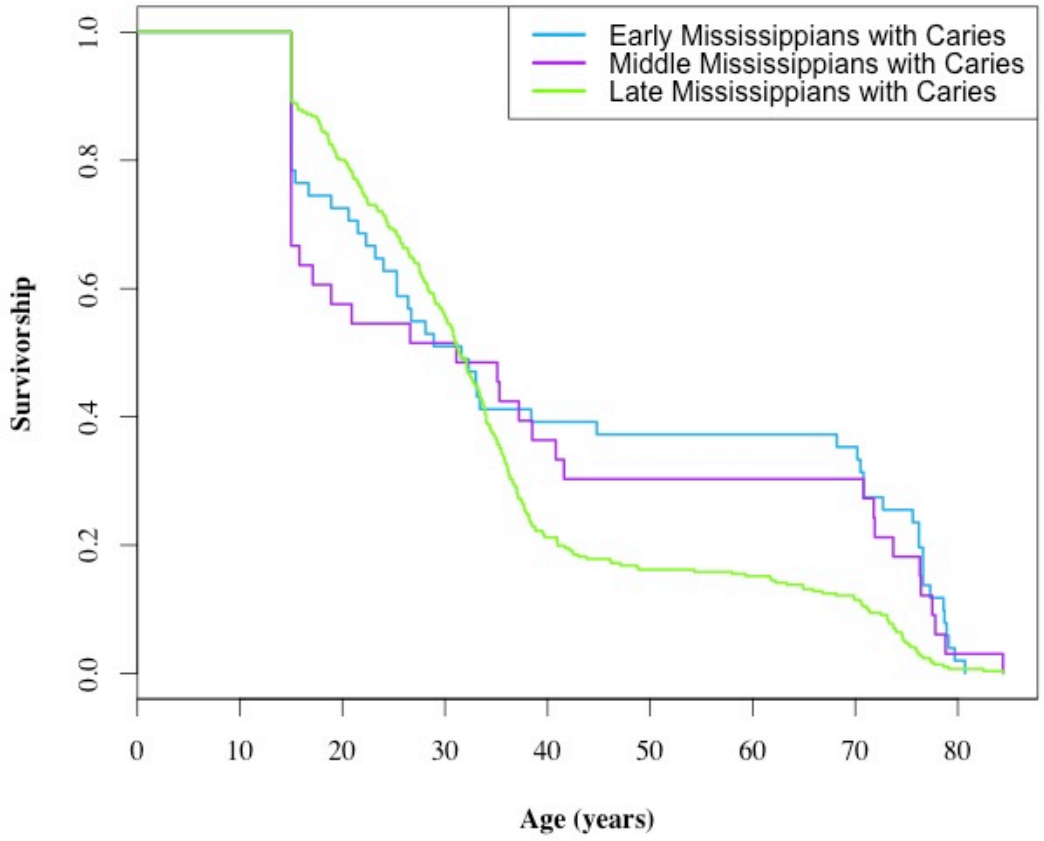


Figure 8.18 Kaplan-Meier survival plot for Early, Middle, and Late Mississippian adults with carious lesions

Table 8.22 Relationship between abscess presence and adult survivorship

| | **Mean Age-at-Death** | **SE** | **95% CI** |
|---|---|---|---|
| **Adults without abscesses (n=291)** | 35.45 | 1.21 | 33.08 - 37.82 |
| **Adults with abscesses (n=148)** | 43.47 | 1.77 | 40.01 - 46.93 |
| | | | $\chi^2$=11.95 |
| | | | p=0.001 |

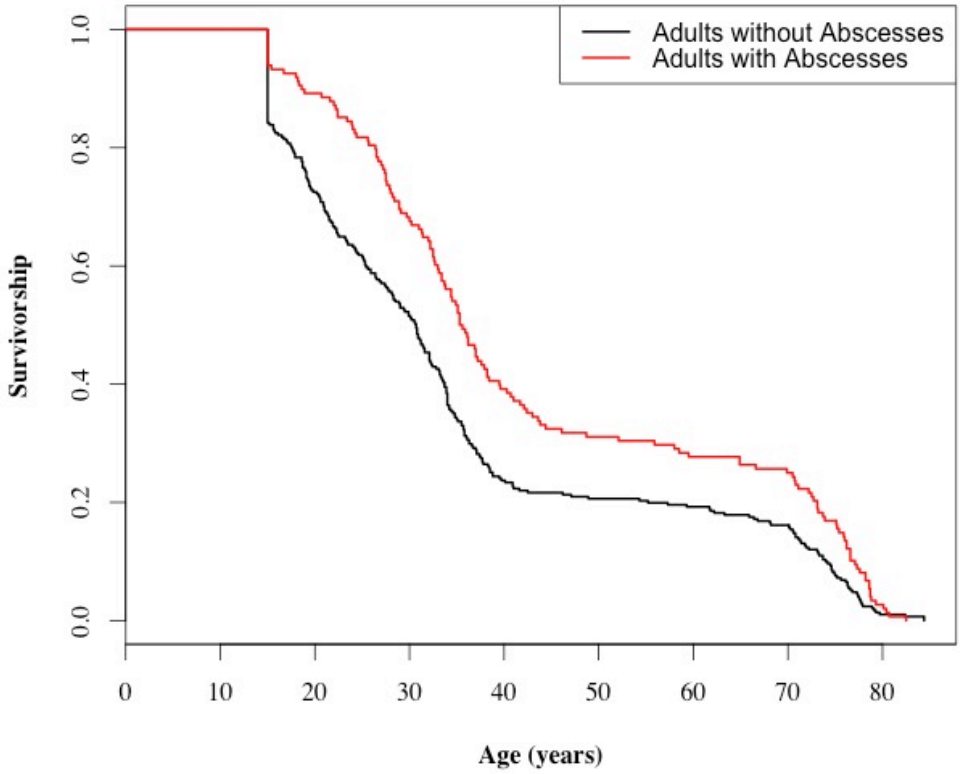


Figure 8.19 Kaplan-Meier survival plot for adults with and without abscesses

Differences are found in survivorship when conducting an overall comparison of the number of abscesses ($\chi^2$=12.66, p=0.005). Table 8.23 exhibits the increased survivorship of individuals as the number of abscesses increases. However, the pairwise comparison log-rank tests illustrate that there are no differences in survivorship of individuals who present evidence of abscesses but differ in count (Table 8.24, Figure 8.20). The log-rank test and survival plot suggest that differences in survivorship lie in the presence or absence of abscesses, and that individuals with abscesses live an average of six years longer than individuals without abscesses (Table 8.23).

An examination of sex-specific survivorship revealed that females without abscesses experienced reduced survivorship, dying an average of eight years earlier than females with abscesses (Table 8.25). This discovery is statistically significant and mirrors that of the pooled sex sample, which found individuals with abscesses to have increased longevity compared to those without abscesses (Figure 8.21). However, no differences were found in an overall comparison of female survivorship and the number of abscesses (p=0.109, Table 8.26). Pairwise comparisons of survivorship dependent on the number of abscesses likewise do not indicate differences given the presence of at least one abscess (Table 8.27). The only instance a difference in survivorship is apparent is between having one abscess and no abscesses (p=0.032). Females without abscesses exhibit the greatest age-specific risk of death, dying an average of eight years earlier than those with abscesses. Figure 8.22 illustrates this difference, as females without abscesses have a lower survival curve across all ages than all three of the female curves representing abscess presence. As such, this reduction in longevity remains constant when comparing the difference between having no abscesses and at least one abscess.

Table 8.23 Relationship between number of abscesses and adult survivorship

| | Mean Age-at-Death | SE | 95% CI |
|---|---|---|---|
| **No abscesses (n=291)** | 35.45 | 1.21 | 33.08 - 37.82 |
| **One abscesses (n=77)** | 41.47 | 2.43 | 36.70 - 46.23 |
| **Two abscesses (n=35)** | 44.27 | 3.92 | 36.58 - 51.95 |
| **Three or more abscesses (n=36)** | 46.99 | 3.37 | 40.38 - 53.59 |

Table 8.24 Log-rank tests on pairwise comparison of number of abscesses

| | 0 | | 1 | | 2 | | 3 | |
|---|---|---|---|---|---|---|---|---|
| **# of abscesses** | $\chi^2$ | **p-value** | $\chi^2$ | **p-value** | $\chi^2$ | **p-value** | $\chi^2$ | **p-value** |
| **0** | - | - | 5.32 | 0.021 | 2.96 | 0.085 | 6.80 | 0.009 |
| **1** | 5.32 | 0.021 | - | - | .001 | 0.972 | 1.64 | 0.200 |
| **2** | 2.96 | 0.085 | .001 | 0.972 | - | - | .448 | 0.503 |
| **3 or more** | 6.80 | 0.009 | 1.64 | 0.200 | .448 | 0.503 | - | - |

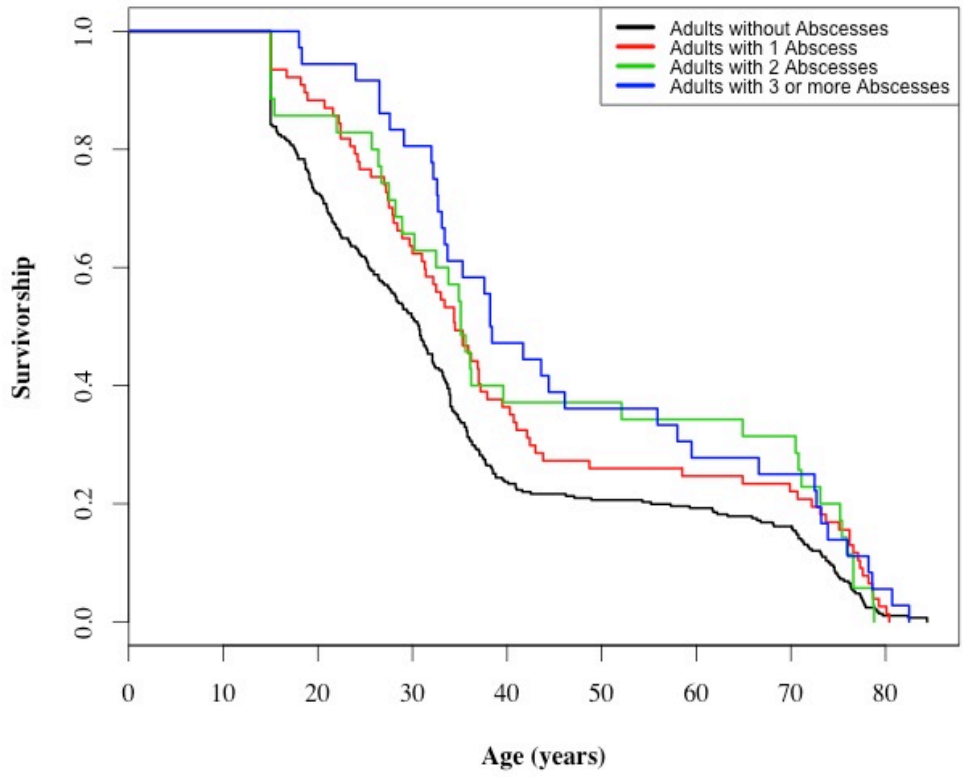


Figure 8.20 Kaplan-Meier survival plot for individuals with no abscesses, one abscess, two abscesses, and three or more abscesses

Table 8.25 Relationship between abscess presence and female survivorship

| | **Mean Age-at-Death** | **SE** | **95% CI** |
|---|---|---|---|
| **Females no abscesses (n=128)** | 31.52 | 1.72 | 28.15 – 34.89 |
| **Females with abscesses (n=53)** | 39.62 | 2.72 | 34.29 – 44.94 |
| | | | $\chi^2$=5.73 |
| | | | p=0.017 |

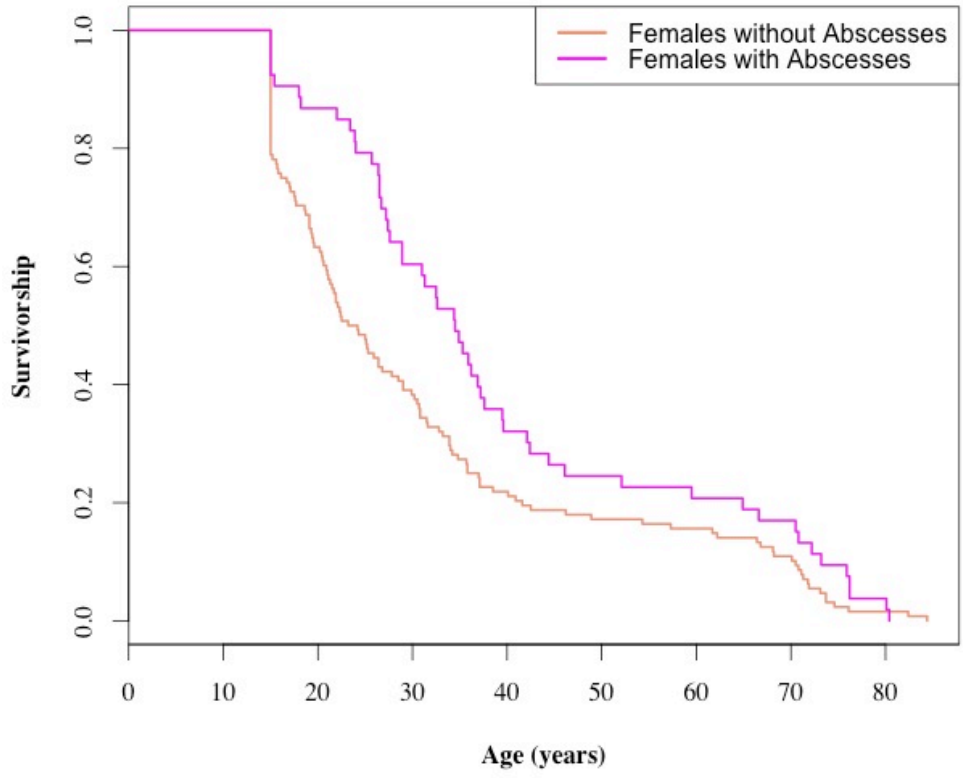


Figure 8.21 Kaplan-Meier survival plot for females with and without abscesses

Table 8.26 Relationship between abscess count and female survivorship

| | **Mean Age-at-Death** | **SE** | **95% CI** |
|---|---|---|---|
| **Females no abscesses (n=128)** | 31.52 | 1.72 | 28.15 – 34.89 |
| **Females one abscess (n=27)** | 39.89 | 3.99 | 32.06 – 47.71 |
| **Females two abscesses (n=14)** | 38.58 | 5.53 | 27.76 – 49.42 |
| **Females three or more abscesses (n=12)** | 40.22 | 5.20 | 30.03 – 50.40 |
| | | **Log-rank test on overall comparison:** | $\chi^2$=6.05 |
| | | | p=0.109 |

Table 8.27 Log-rank tests on the pairwise comparison of abscess count for MCR females

| # of abscesses | 0 | | 1 | | 2 | | 3 | |
|---|---|---|---|---|---|---|---|---|
| | $\chi^2$ | p-value | $\chi^2$ | p-value | $\chi^2$ | p-value | $\chi^2$ | p-value |
| **0** | - | - | 4.56 | 0.032 | 1.09 | 0.297 | 1.04 | 0.308 |
| **1** | 4.56 | 0.032 | - | - | .559 | 0.455 | .097 | 0.755 |
| **2** | 1.09 | 0.297 | .559 | 0.455 | - | - | .003 | 0.955 |
| **3 or more** | 1.04 | 0.308 | .097 | 0.755 | .003 | 0.955 | - | - |

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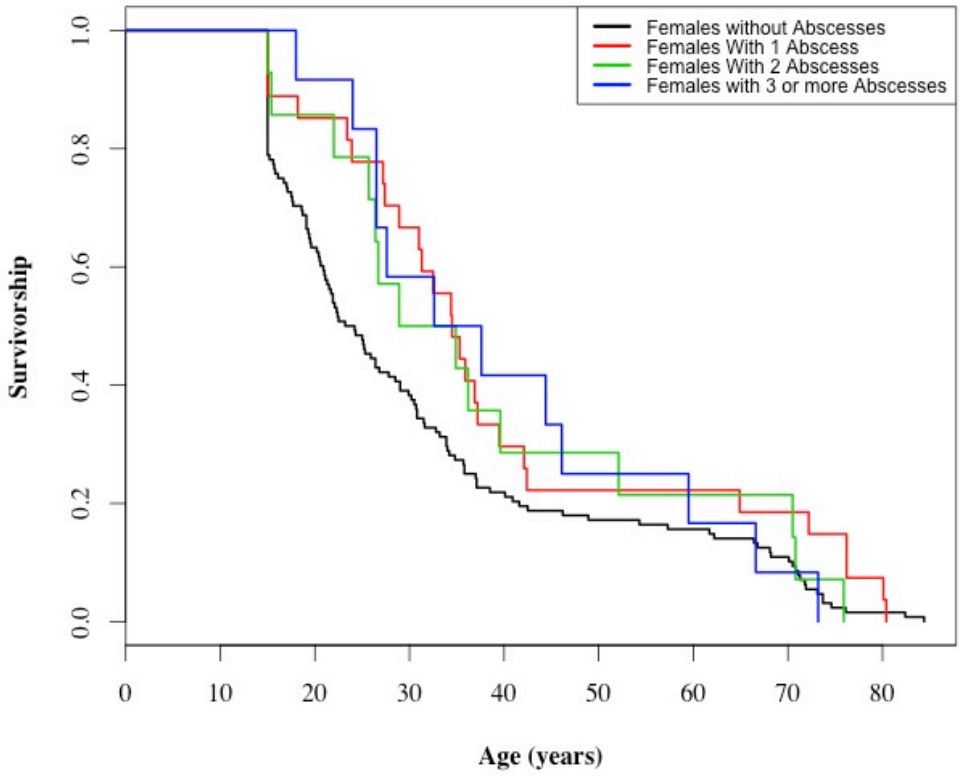


Figure 8.22 Kaplan-Meier survival plot for females with no abscesses, one abscess, two abscesses, and three or more abscesses

An analysis of male survivorship revealed that males without abscesses experienced reduced survivorship, dying an average of seven years earlier than males with abscesses (Table 8.28) This finding is statistically significant and mirrors that of both the female and pooled sex sample; males without abscesses experience reduced survivorship compared to those with abscesses (Figure 8.23).

As with the results for female survivorship, no differences were found in an overall comparison of male survivorship and the number of abscesses observed (p=0.083, Table 8.29). However, a different pattern than that of females emerged when considering the pairwise comparisons. A significant difference in survivorship was only detected in males having no abscesses and males having three or more abscesses (p=0.019, Table 8.30). Males with three or more abscesses lived an average of twelve years longer than males without abscesses (Table 8.29). Figure 8.24 demonstrates this difference, as males without abscesses have a lower survival curve across all ages than all three of the male curves representing abscess presence.

While females with abscesses lived an average of six years less than males who also presented abscesses, this difference was not significant ($\chi^2$=3.02, p=0.082, Figure 8.25). This indicates that abscesses did not predispose females to earlier mortality or have

Table 8.28 Relationship between abscess presence and male survivorship

| | **Mean Age-at-Death** | **SE** | **95% CI** |
|---|---|---|---|
| **Males no abscesses (n=156)** | 38.85 | 1.68 | 35.55 – 42.15 |
| **Males with abscesses (n=91)** | 45.40 | 2.34 | 40.81 – 50.01 |
| | | | $\chi^2$=4.64 |
| | | | p=0.031 |

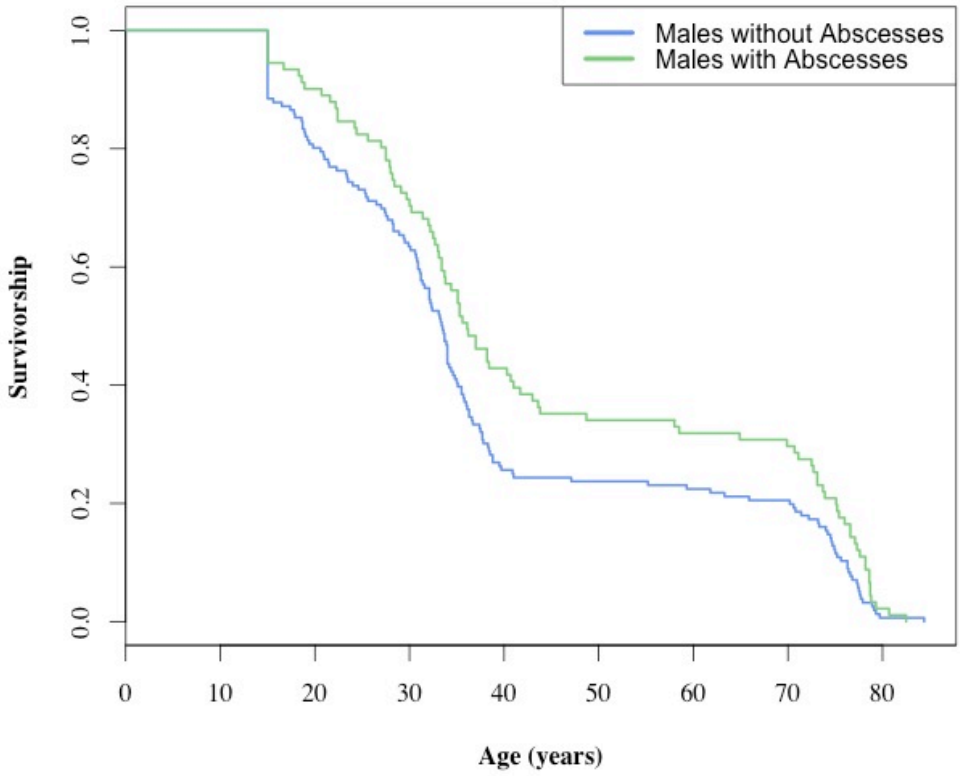


Figure 8.23 Kaplan-Meier survival plot for males with and without abscesses

Table 8.29 Relationship between abscess count and male survivorship

| | Mean Age-at-Death | SE | 95% CI |
|---|---|---|---|
| **Males no abscesses (n=156)** | 38.85 | 1.68 | 35.55 - 42.15 |
| **Males one abscess (n=49)** | 42.41 | 3.15 | 36.24 - 48.58 |
| **Males two abscesses (n=20)** | 46.65 | 5.40 | 36.06 - 57.23 |
| **Males three or more abscesses (n=22)** | 50.95 | 4.55 | 42.03 - 59.86 |
| | | **Log-rank test on overall comparison:** | $\chi^2$=6.67 |
| | | | p=0.083 |

Table 8.30 Log-rank tests on the pairwise comparison of abscess count for MCR males

| | 0 | | 1 | | 2 | | 3 | |
|---|---|---|---|---|---|---|---|---|
| **# of abscesses** | $\chi^2$ | **p-value** | $\chi^2$ | **p-value** | $\chi^2$ | **p-value** | $\chi^2$ | **p-value** |
| **0** | - | - | .904 | 0.342 | 1.06 | 0.302 | 5.51 | 0.019 |
| **1** | .904 | 0.342 | - | - | .266 | 0.606 | 2.88 | 0.090 |
| **2** | 1.06 | 0.302 | .266 | 0.606 | - | - | .763 | 0.382 |
| **3 or more** | 5.51 | 0.019 | 2.88 | 0.090 | .763 | 0.382 | - | - |

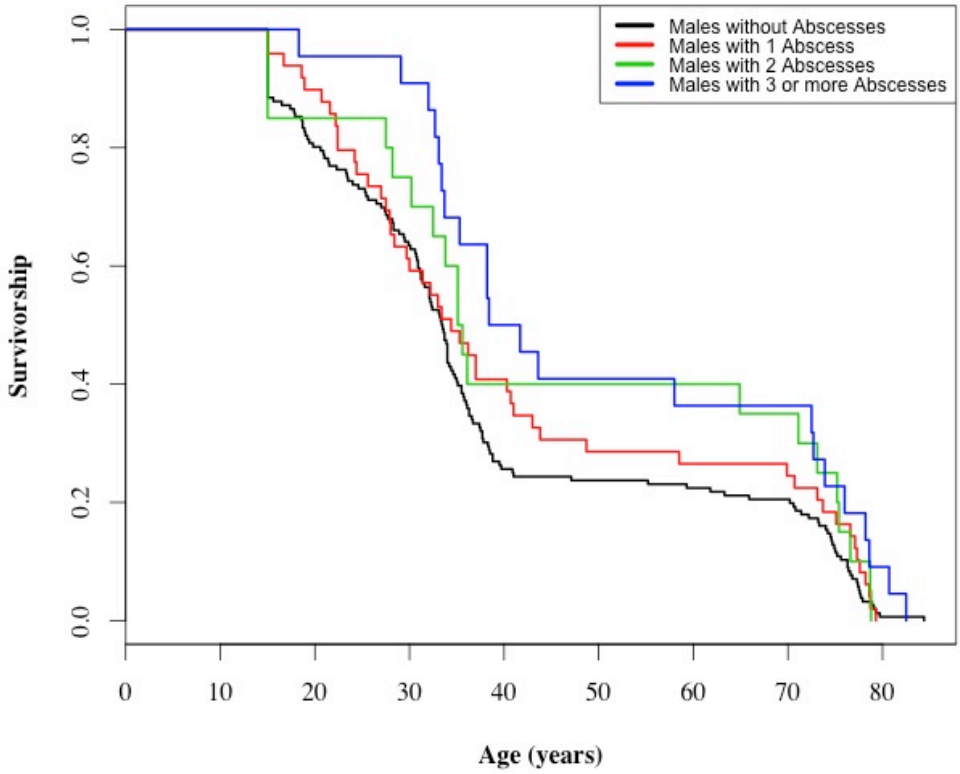


Figure 8.24 Kaplan-Meier survival plot for males with no abscesses, one abscess, two abscesses, and three or more abscesses

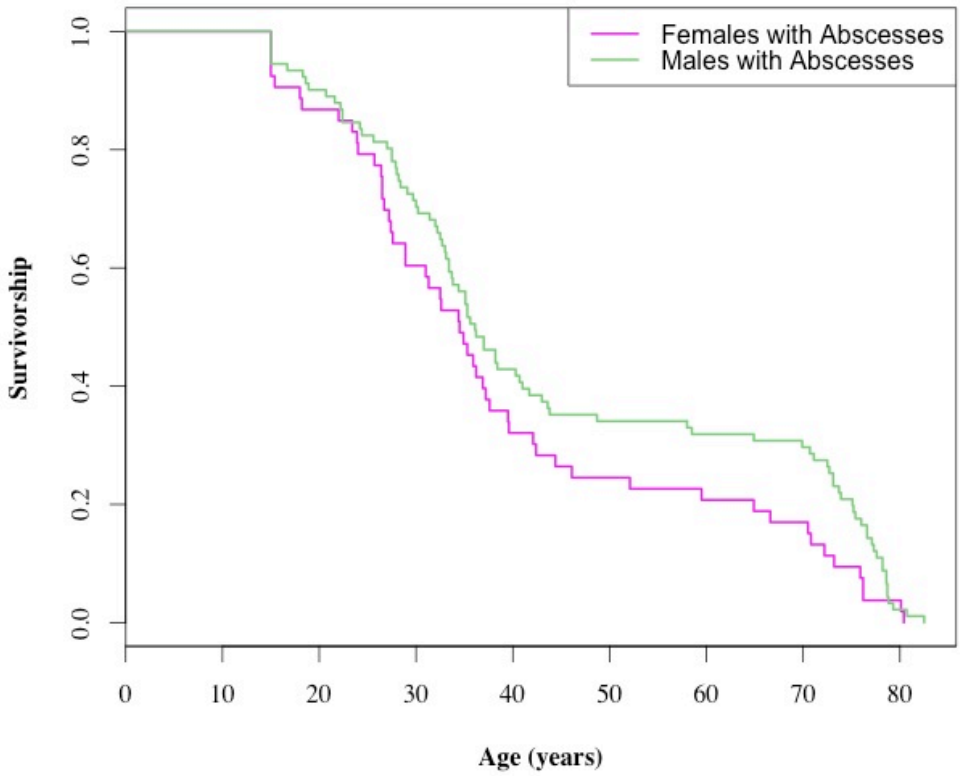


Figure 8.25 Kaplan-Meier survival plot for females and males with abscesses

a significant impact on survivorship. This analysis corresponds with the sex-specific results which find that an increase in the number of abscesses actually increased longevity for both sexes.

There are differences in survivorship among Early, Middle, and Late adults with abscesses ($p<0.005$, Table 8.31) Pairwise comparison log-rank tests reveal no differences between Early and Middle Mississippians ($\chi^2=2.11$, $p=0.147$) or Middle and Late Mississippians ($\chi^2=1.39$, $p=0.238$) with regard to abscesses. However, differences in survivorship were detected between Early and Late Mississippian adults with abscesses ($\chi^2=15.99$, $p=0.00064$). Early Mississippian adults with abscesses lived an average of 20 years longer than Late Mississippian adults with abscesses (Figure 8.26).

**Antemortem Tooth Loss**

A total of 434 adults from the MCR sample were available to score for antemortem tooth loss (AMTL). These were individuals that presented 50% complete alveolar bone for the examination of AMTL. The log-rank test denotes that individuals with AMTL lived an average of ten years longer than individuals without AMTL ($p<0.005$, Table 8.32). Figure 8.27 displays the reduced survivorship of adults without AMTL. Additionally, differences in survivorship were found in the presence and absence of AMTL in sex-specific examinations of females ($p<0.005$, Table 8.33) and males ($p<0.005$, Table 8.34). The survival curves for females (Figure 8.28) and males (Figure 8.29) demonstrate a similar reduction in survivorship for those without AMTL compared to individuals with AMTL. Investigating the effect of sex-specific survivorship, females

Table 8.31 The effect of time period on survivorship for adults with abscesses

| | **Mean Age-at-Death** | **SE** | **95% CI** |
|---|---|---|---|
| **Early Mississippian Adults with Abscesses (n=26)** | 59.55 | 4.77 | 50.21 - 68.89 |
| **Middle Mississippian Adults with Abscesses (n=10)** | 45.98 | 7.25 | 31.70 - 60.17 |
| **Late Mississippian Adults with Abscesses (n=112)** | 39.52 | 1.79 | 36.01 - 43.04 |
| | | **Log-rank test on overall comparison:** | $\chi^2$=16.34 |
| | | | p<0.005 |

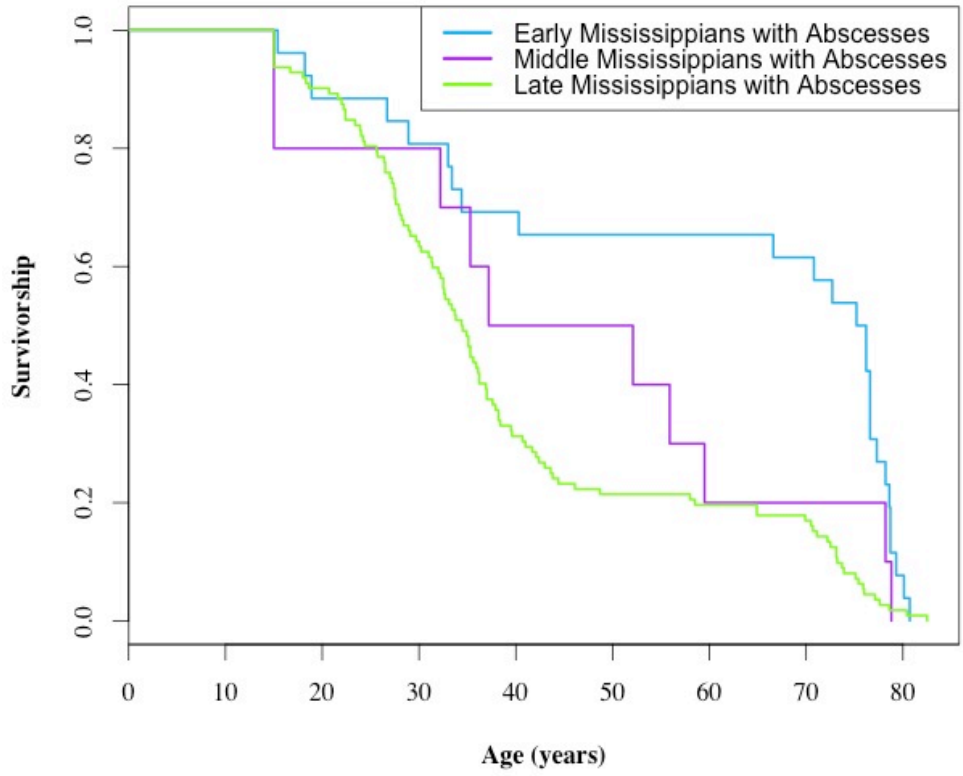


Figure 8.26 Kaplan-Meier survival plot for Early, Middle, and Late Mississippian adults with abscesses

Table 8.32 Relationship between AMTL and adult survivorship

| | Mean Age-at-Death | SE | 95% CI |
|---|---|---|---|
| **Adults without AMTL (n=246)** | 33.40 | 1.25 | 30.94 - 35.85 |
| **Adults with AMTL (n=188)** | 43.98 | 1.58 | 40.88 - 47.08 |
| | | | $\chi^2$=28.77 |
| | | | p<0.005 |

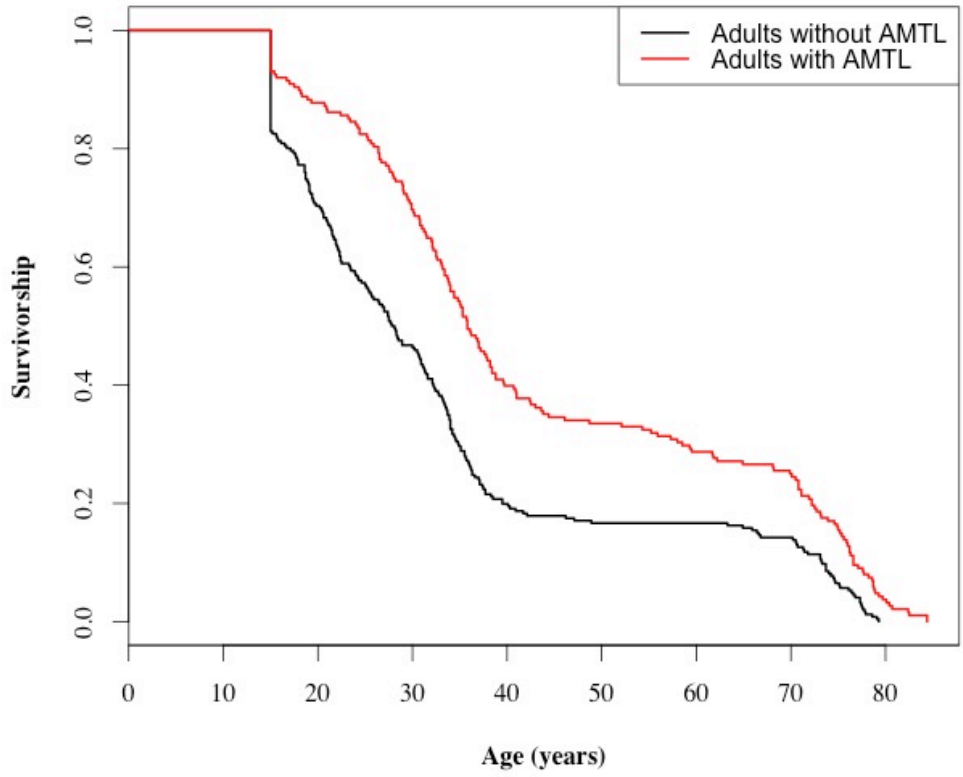


Figure 8.27 Kaplan-Meier survival plot for adults with and without AMTL

Table 8.33 Relationship between AMTL and female survivorship

| | **Mean Age-at-Death** | **SE** | **95% CI** |
|---|---|---|---|
| **Females without AMTL (n=102)** | 28.98 | 1.72 | 25.60 - 32.67 |
| **Females with AMTL (n=78)** | 40.21 | 2.40 | 35.51 - 44.91 |
| | | | $\chi^2$=14.91 |
| | | | p<0.005 |

Table 8.34 Relationship between AMTL and male survivorship

| | **Mean Age-at-Death** | **SE** | **95% CI** |
|---|---|---|---|
| **Males without AMTL (n=138)** | 36.69 | 1.75 | 33.26 - 40.12 |
| **Males with AMTL (n=106)** | 46.57 | 2.12 | 42.42 - 50.72 |
| | | | $\chi^2$=14.80 |
| | | | p<0.005 |

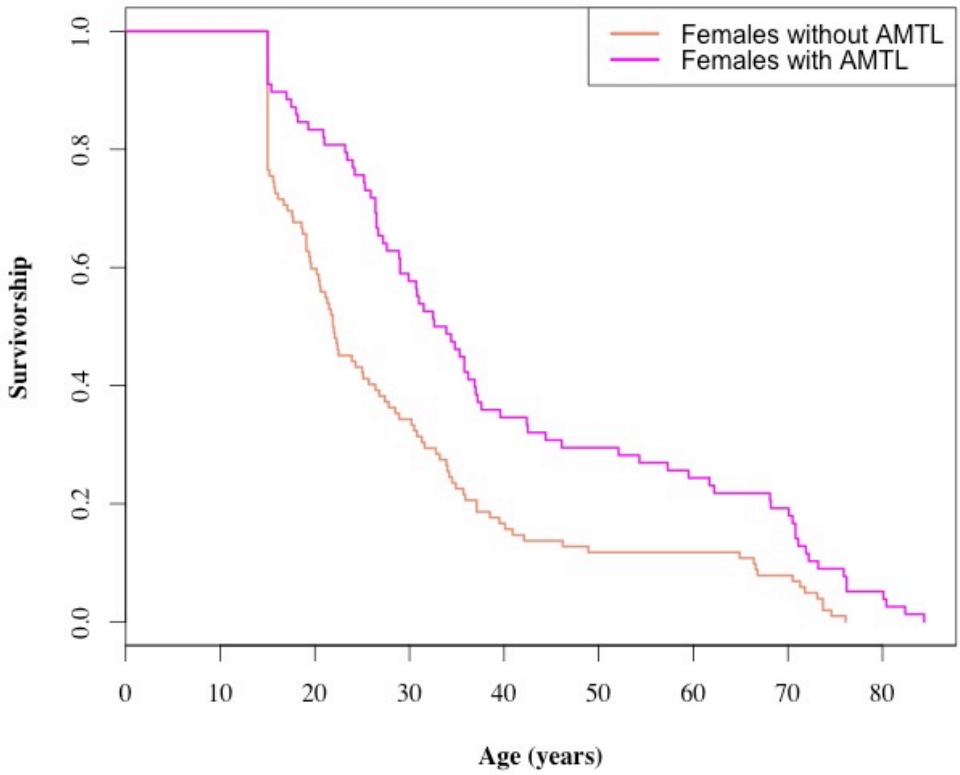


Figure 8.28 Kaplan-Meier survival plot for females with and without AMTL

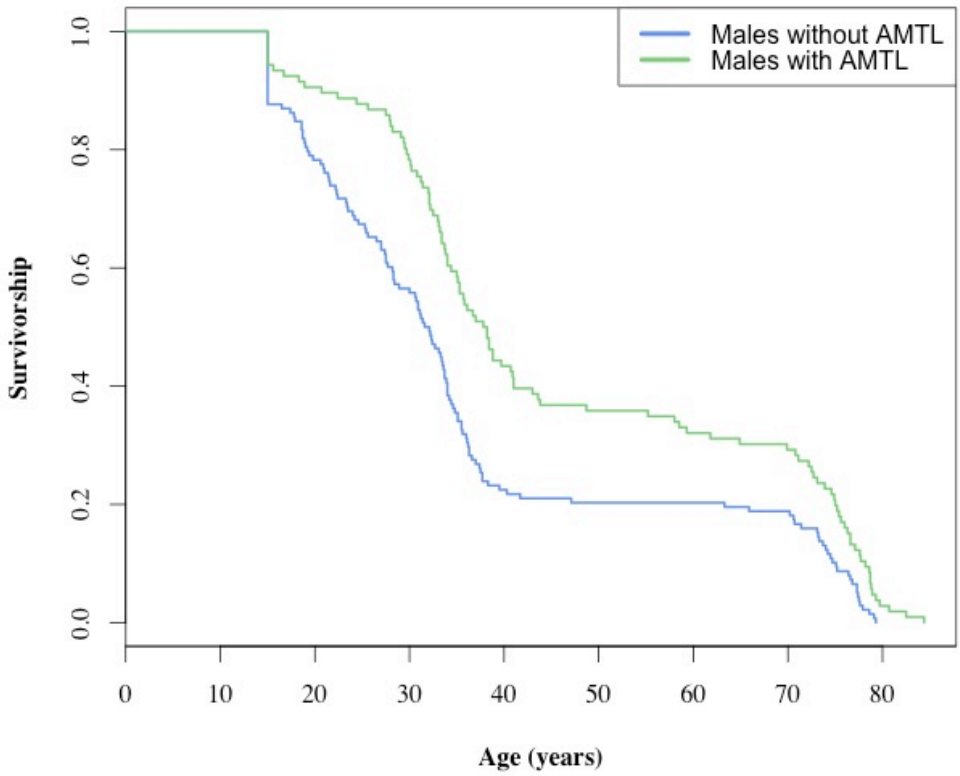


Figure 8.29 Kaplan-Meier survival plot for males with and without AMTL

with AMTL lived an average of six years less than males who also presented AMTL (Figure 8.30). However, this result was only nearly significant (p=0.049, Table 8.35).

There are differences in survivorship among Early, Middle, and Late Mississippian adults with AMTL (p<0.005, Table 8.36). Pairwise comparison log-rank tests reveal that there were no statistical differences between Early and Middle Mississippians with AMTL ($\chi^2$=.325, p=0.569) or Middle and Late Mississippians with AMTL ($\chi^2$=2.88, p=0.09). However, a significant difference was observed in survivorship of Early and Late Mississippian adults with AMTL ($\chi^2$=10.83, p=0.001). Early Mississippian adults with AMTL had a mean age-at-death that was 16 years later than Late Mississippian adults with AMTL. Figure 8.31 presents the reduced survivorship of Late Mississippian adults with AMTL.

**Skeletal Trauma**

A total of 422 adults from the MCR sample were available for skeletal trauma analysis. These included individuals with age-at-death estimated using Transition Analysis and those examined by Worne (2011) for evidence of interpersonal violence. The log-rank test does not find a difference in survivorship for adults with and without evidence of trauma (p=0.077, Table 8.37). The Kaplan-Meier plot illustrates that no one past the age of 43 years old presented evidence of skeletal trauma (Figure 8.32).

No differences in survivorship were detected in the presence or absence of skeletal trauma among females (p=0.344, Table 8.38). This may be a result of the small sample size (n=6), or a reality that females were not involved in violent acts (Figure 8.33). Compared to females, more males presented evidence of skeletal trauma. A slight

Table 8.35 Relationship between AMTL presence and sex

| | Mean Age-at-Death | SE | 95% CI |
|---|---|---|---|
| **Females with AMTL (n=78)** | 40.21 | 2.40 | 35.51 - 44.91 |
| **Males with AMTL (n=106)** | 46.57 | 2.12 | 42.42 - 50.72 |
| | | | $\chi^2$=3.88 |
| | | | p=0.049 |

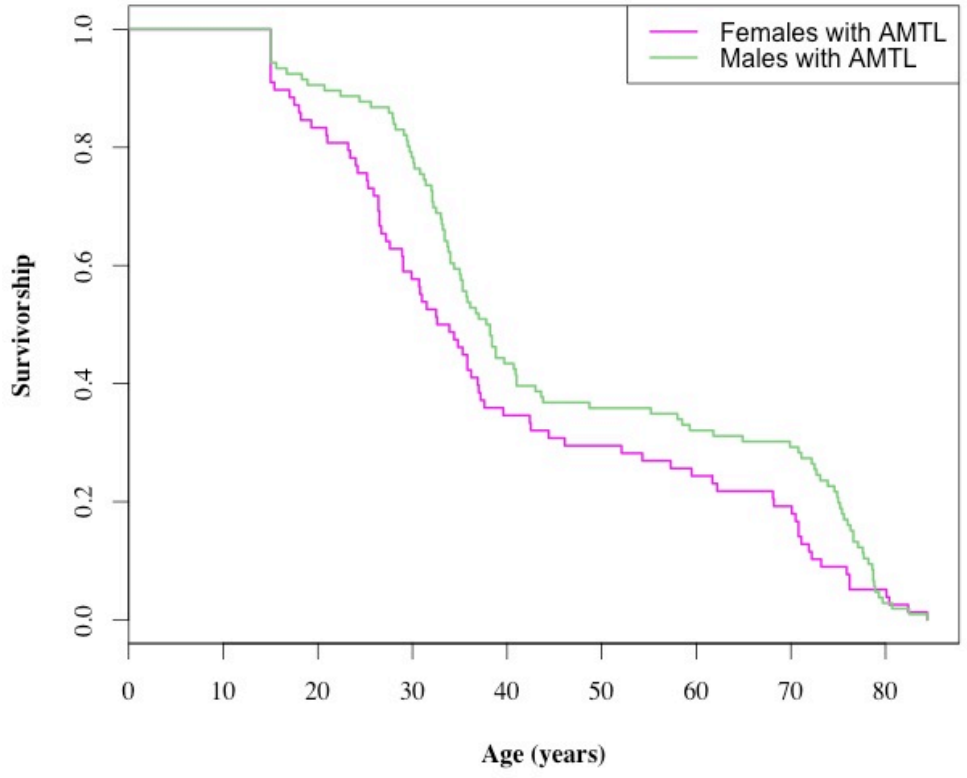


Figure 8.30 Kaplan-Meier survival plot for AMTL by sex

Table 8.36 The effect of time period on survivorship for adults with AMTL

| | Mean Age-at-Death | SE | 95% CI |
|---|---|---|---|
| **Early Mississippian Adults with AMTL (n=31)** | 56.25 | 4.69 | 47.06 - 65.44 |
| **Middle Mississippian Adults with AMTL (n=13)** | 51.30 | 6.75 | 38.07 - 64.56 |
| **Late Mississippian Adults with AMTL (n=144)** | 40.67 | 1.61 | 37.51 - 43.83 |
| | | **Log-rank test on overall comparison:** | $\chi^2$=16.34 |
| | | | p<0.005 |

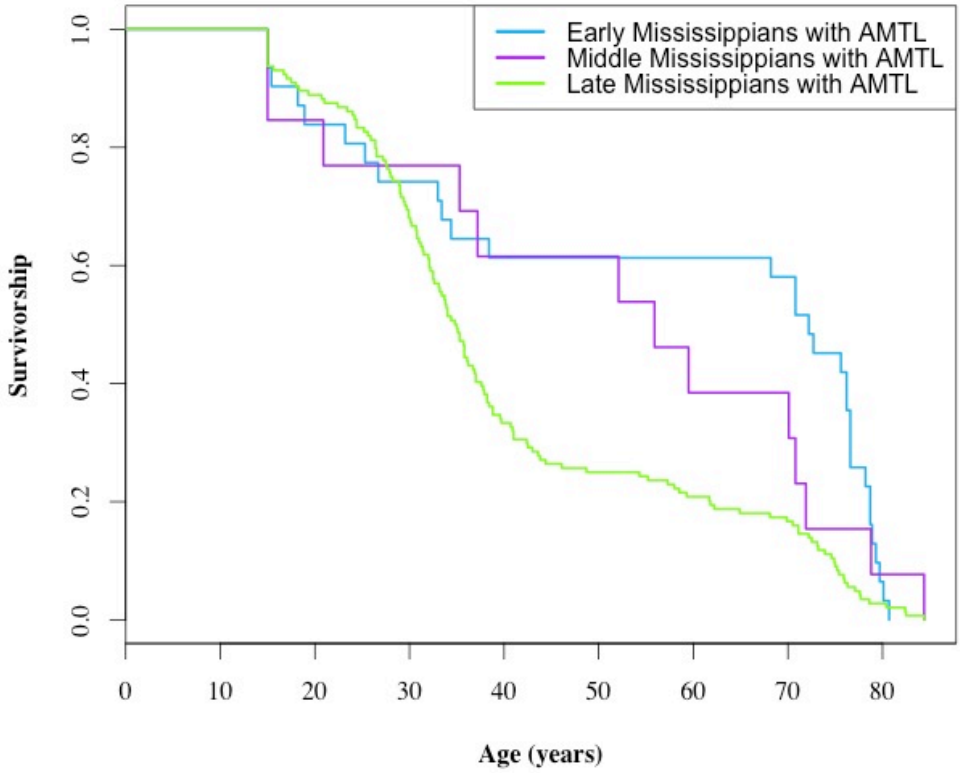


Figure 8.31 Kaplan-Meier survival plot for Early, Middle, and Late Mississippian adults with AMTL

Table 8.37 Relationship between trauma presence and adult survivorship

| | Mean Age-at-Death | SE | 95% CI |
|---|---|---|---|
| **Adults without trauma (n=396)** | 38.71 | 1.09 | 36.58 - 40.85 |
| **Adults with trauma (n=26)** | 31.05 | 1.49 | 28.13-33.97 |
| | | | $\chi^2$=3.133 |
| | | | p=0.077 |

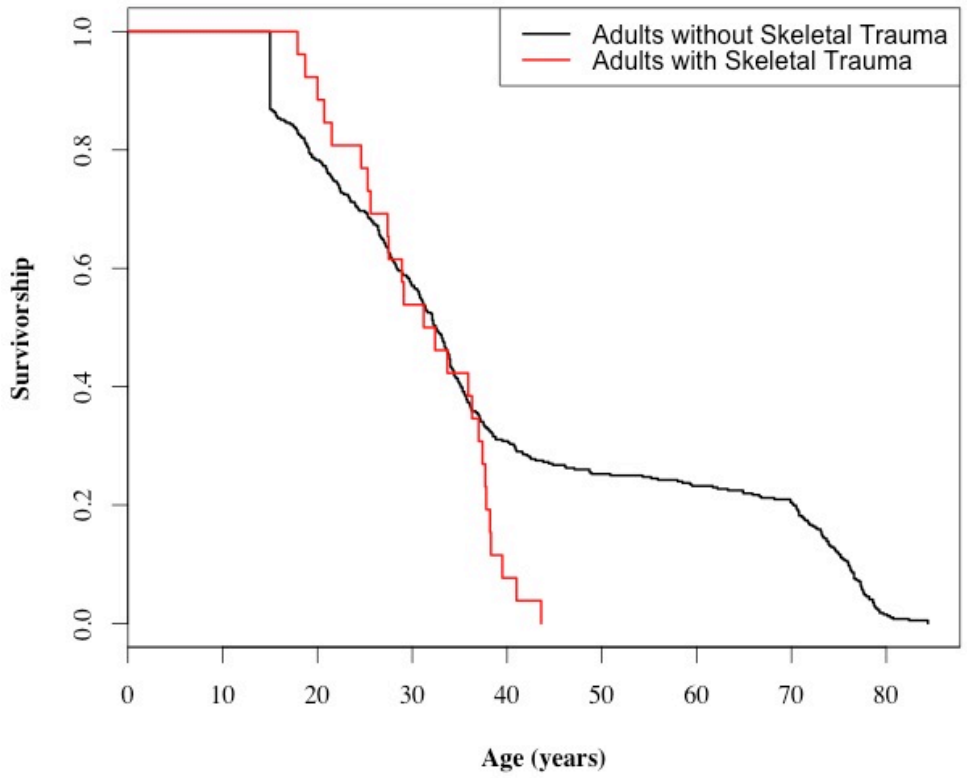


Figure 8.32 Kaplan-Meier survival plot of adults with and without evidence of skeletal trauma

Table 8.38 Relationship between skeletal trauma and female survivorship

| | Mean Age-at-Death | SE | 95% CI |
|---|---|---|---|
| **Females without trauma (n=161)** | 33.95 | 1.54 | 30.99 - 36.99 |
| **Females with trauma (n=6)** | 26.82 | 3.73 | 19.51 - 34.18 |
| | | | $\chi^2$=0.896 |
| | | | p=0.344 |

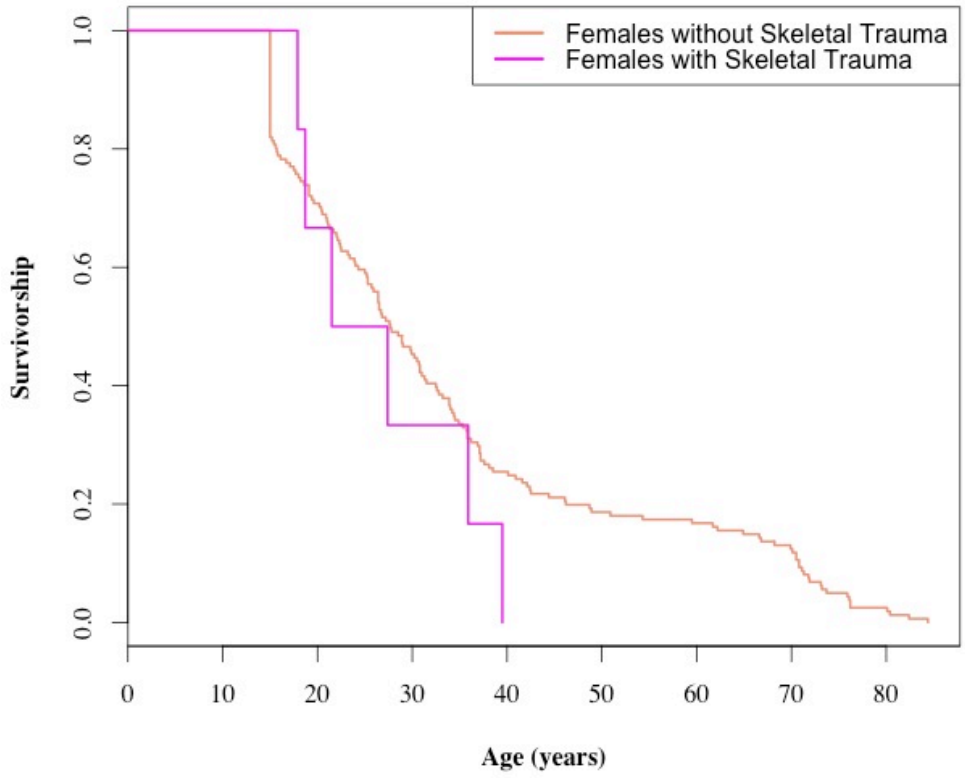


Figure 8.33 Kaplan-Meier survival plot for females with and without evidence of skeletal trauma

difference was found in survivorship of males with and without evidence of trauma (p=0.047, Table 8.39). Males without trauma survived an average of 10 years longer than males with evidence of trauma. Figure 8.34 illustrates the finding that males without evidence of skeletal trauma exhibited greater longevity compared to males with trauma.

An examination of survivorship by sex does not reveal a significant difference between males and females with evidence of trauma (p=0.859, Table 8.40). While no differences were found, perhaps more revealing are the visuals captured in Figure 8.35. No individuals, regardless of sex, presented evidence of skeletal trauma past age 40. This implies that interpersonal violence may have exclusively afflicted young to middle age individuals in the MCR. It is important to note that I am limited to observations documented on bone and that traumatic lesions may have occurred but may not be discernible in the skeletal record.

The small sample size for skeletal trauma prohibits a Kaplan-Meier analysis of the effect of time period. One individual from the Early Mississippian, one individual from the Middle Mississippian, and 24 individuals from Late Mississippian presented evidence

Table 8.39 Relationship between skeletal trauma and male survivorship

| | **Mean Age-at-Death** | **SE** | **95% CI** |
|---|---|---|---|
| **Males without trauma (n=223)** | 42.30 | 1.50 | 39.36 – 45.24 |
| **Males with trauma (n=20)** | 32.32 | 1.53 | 29.43 – 35.31 |
| | | | $\chi^2$=3.95 |
| | | | p=0.047 |

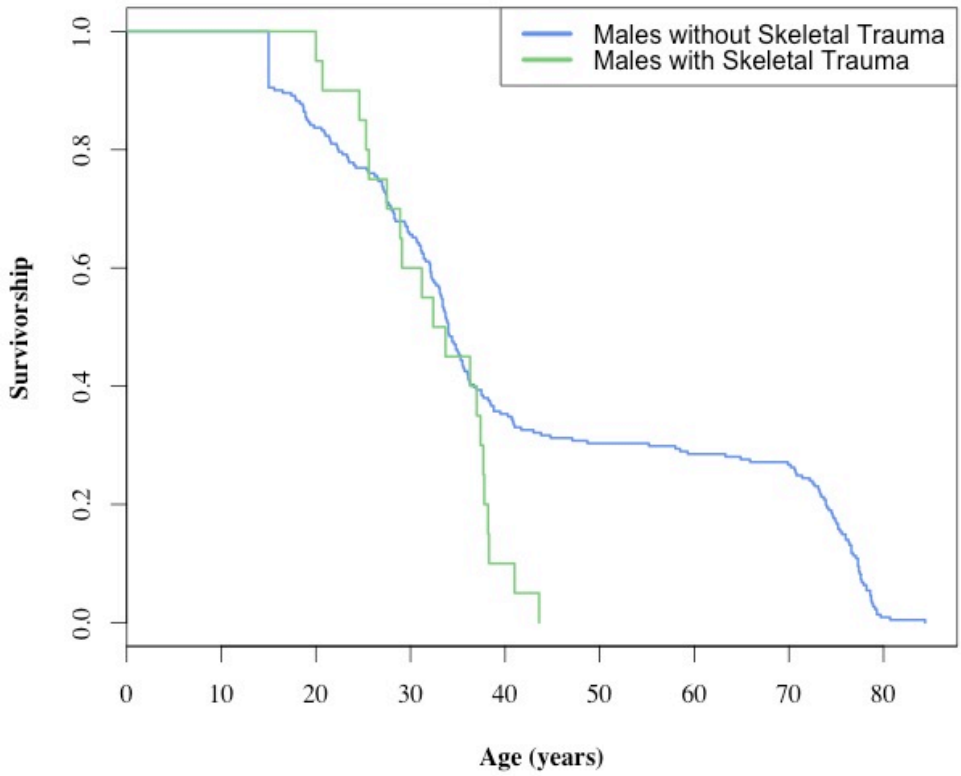


Figure 8.34 Kaplan-Meier survival plot for males with and without evidence of skeletal trauma

Table 8.40 Relationship between skeletal trauma and sex

| | Mean Age-at-Death | SE | 95% CI |
|---|---|---|---|
| **Females with trauma (n=6)** | 26.82 | 3.73 | 19.51 - 34.18 |
| **Males with trauma (n=20)** | 32.32 | 1.53 | 29.43 - 35.31 |
| | | | $\chi^2$=.031 |
| | | | p=0.859 |

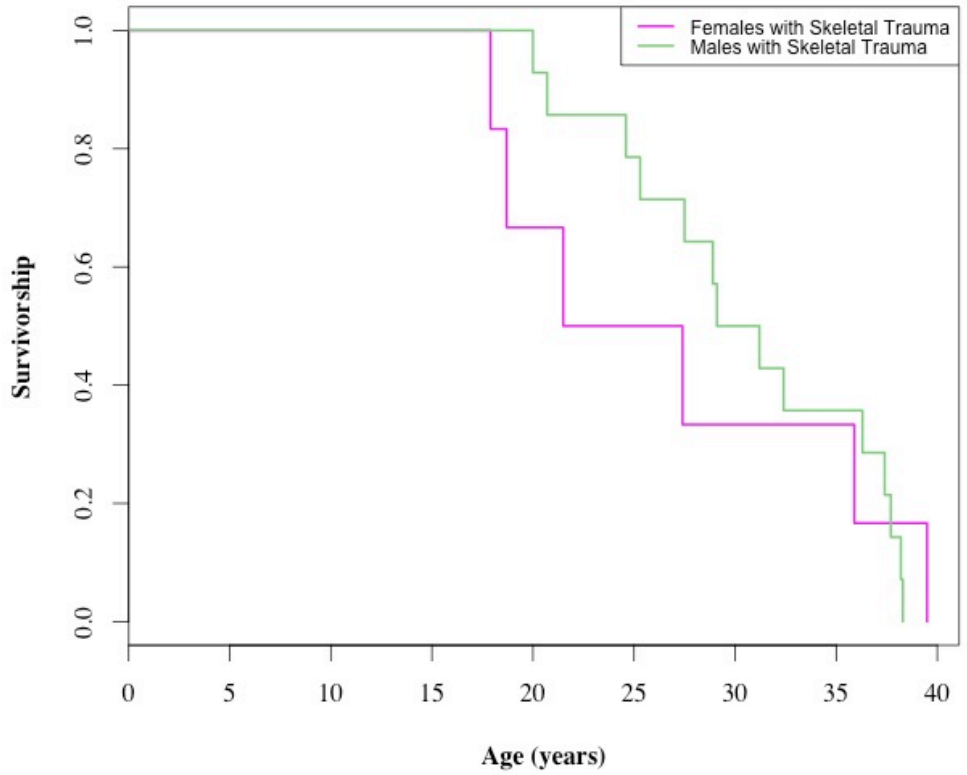


Figure 8.35 Kaplan-Meier survival plot for females and males with evidence of skeletal trauma

of skeletal trauma and refined age-at-death estimates from Transition Analysis. It is possible that this distribution represents reality, with violence increasing from the Early to Late Mississippian period in the MCR. But as with the analysis of skeletal trauma by sex, it is important to bear in mind that not all cases of trauma are able to be recorded skeletally. Additionally, I am limited by the sample that generated age estimates from Transition Analysis. Worne's (2011) examination of trauma was not limited to skeletons aged using TA and thus generated a larger sample (n=47), with her findings consistent with small-scale intergroup conflict.

**Paleoclimate**

Subtle climatic changes during the Mississippian period were unable to be detected using the Palmer Drought Severity Index (PDSI). Table 8.41 presents the mean, median, and standard deviations of PDSI values for the average of grid points 219 and 220 that bracket the MCR. The values for both Early and Late Mississippian periods were negative, which indicate dry conditions. However, none of the values deviate from normal soil moisture and temperature. The values for both time periods fall within the "near normal" range (-.49 to -0.49) for precipitation and temperature. This places Early and Late Mississippian periods into the "normal harvest" agricultural productivity category, indicative of normal annual consumption plus one year's surplus for the maintenance of a chiefdom's status. No statistical differences were found in the mean PDSI values of Early and Late time periods (p=0.648), and the standard deviations indicate that climate variability was similar. This precludes an exploration into whether

Table 8.41 Mean, median, and standard deviation PDSI values for Early, Middle, and Late Mississippian MCR sites

| | Mean PDSI value | Median PDSI value | Standard deviation |
|---|---|---|---|
| **Early Mississippian MCR (1000-1325 A.D.)** | -0.1495245 | -0.323 | 1.680 |
| **Late Mississippian MCR (1325-1500 A.D.)** | -0.2206229 | -0.141 | 1.618 |

extreme climatic conditions impacted risk of death, since the PDSI values suggest similar soil moisture and precipitation levels throughout the Mississippian period in the MCR.

Given the temporal categories into which MCR sites are divided, more nuanced patterns of climate change, if any, cannot be gleaned at this time. However, Meeks and Anderson (2013) were able to document two periods of drought in the Vacant Quarter during the 14$^{th}$ and 15$^{th}$ centuries using the Palmer Drought Severity Index. The authors utilized 50 grid points to encompass not only the MCR but four other regions in the Vacant Quarter: the American Bottom, Ohio-Mississippi confluence, Tennessee-Cumberland-Ohio confluence, and Ohio-Green confluence. Using the two gridpoints (219 and 220) of closest proximity to Middle Cumberland Region sites may account for my deviations from the more specific patterns revealed by Meeks and Anderson (2013), who, should be noted, examined the PDSI data year by year rather than cumulatively, as done in the current research. While, the Palmer Drought Severity Index has proven most effective in determining long-term, multi-year to decadal scale drought events (e.g., Anderson et al., 1995; Benson et al., 2009). As such, the use of PDSI values in the current study does not sufficiently capture extreme conditions on the order of years or decades that may have drastically altered subsistence and food reserves central to

Mississippian groups in the MCR. Despite the inability to discern the effect of climate on risk of death, the current research presents a big picture approach to depopulation, substantiating broader regional and temporal trends in the late prehistoric period. A more nuanced approach, and one that uses PSDI values to analyze annual or decadal droughts in the MCR, will be explored in the future.

## Chapter Summary

Paleoepidemiological results demonstrate the effects of heterogeneous frailty and selective mortality in the Mississippian MCR. While some findings support traditional interpretations that the presence of pathological conditions had a negative impact on survivorship (PH, carious lesions, trauma), results for LEH, abscesses, and AMTL offer support for the osteological paradox. Furthermore, by accounting for differences in severity and number (in the case of caries and abscesses, respectively), as well as sex and time period, a more comprehensive picture of population dynamics can emerge. Although the paleoclimate analysis did not yield significant results, the overall findings suggest that changes in environmental conditions through time may have altered social dynamics, and thus had physiological manifestations that altered survivorship of Mississippian groups in the Middle Cumberland Region.

# Chapter 9: Discussion

This research aims to explore two issues addressed in bioarchaeology: the mortality profile of a prehistoric sample and the risk of death given pathological lesions associated with childhood stress and poor dental health. Using skeletal samples from the Middle Cumberland Region, my research applied updated statistical models to investigate two hypotheses. This chapter will first address the implications of the paleodemographic findings reported in Chapter 7, and then reflect on the implications of the paleoepidemiological results presented in Chapter 8. Finally, this chapter will conclude with the study's implications for regional depopulation during the Late Mississippian period.

## Paleodemography Implications

I hypothesized that, given purported social and environmental changes during the Mississippian period, mortality would be elevated in the Late Mississippian period compared to the Early Mississippian period. **This hypothesis was supported**. Using the Gompertz hazard model, the mean age-at-death for the Early Mississippian group was seven years higher than the mean age-at-death for both Gompertz-Makeham hazard models for the Middle and Late Mississippians. Given that this hypothesis was supported, it is worthwhile to explore the possible reasons for the population dynamics observed. Additionally, it is necessary to evaluate the methods used (Transition Analysis and

hazards models) and the implications of these results with regard to the mortality profile of the MCR.

### *Refinement of Adult Age Estimates Using Transition Analysis*

My dissertation research rests on the assumption that the age estimates derived from the Transition Analysis (TA) method are accurate and represent the age-at-death distribution of the Middle Cumberland Region. The component-scoring method of TA seeks to resolve many of the functional and statistical limitations of traditional phase-aging methods and is applicable to paleodemography contexts such as the present study. A validation study by Milner and Boldsen (2012) calls into question whether the method they developed truly has ability to provide accurate maximum-likelihood age estimates and confidence intervals for older individuals. The authors included skeletal samples (n=252) from the University of Tennessee Bass Donated Skeletal Collection and forensic cases from Mercyhurst University. The authors concluded that the auricular surface was not particularly informative for individuals aged 60+, and the cranial sutures are not good age indicators for those aged 40+. For both of these age indicators, age is underestimated after age 60 for the auricular surface and after age 40 for cranial sutures. Such implications severely hamper the use of these indicators for older individuals in the population, systematically underestimating age when including them in the analysis. The pubic symphysis was the most accurate and continues to have utility, though only if it is present. When scoring traits for TA, I did not discriminate with regard to the aging traits that I used; if one or all three skeletal indicators were available, it was used in my analysis. When the skeletal information for all three age indicators are available and

combined, Milner and Boldsen (2012) found that the age estimates better approximate the documented ages.

One interesting finding in Milner and Boldsen's (2012) validation study is that, from approximately 40-70 years old, the confidence intervals are very large around the maximum-likelihood estimate. However, after 70 years of age, the variability in morphological changes appears to decrease. This may be an artifact of selective mortality, as those who survive to old age share similar senescent characteristics that allowed them to survive to those ages. Such a finding runs counter to the assumptions relied upon in life table analysis, namely that risk of death is equal across all ages categories. Death is selective and acts upon individuals of varying frailty, thereby placing them into a mortality sample at a given age. For this reason, paleodemographic research that continues to use life tables, and thereby does not appropriately address selective mortality will be inaccurate.

Another assumption I am making when using Transition Analysis concerns the applicability of the informed prior probability. I am postulating that the 17$^{th}$ century Danish age distribution built into the TA ADBOU software is similar to my target 9$^{th}$-15$^{th}$ century Middle Cumberland Region sample. To refine the age estimates of the MCR sample, my original plan was to manually code a different informative prior in R (or similar statistical environment) instead of using the Danish prior in ADBOU. My intent was to use the age distribution generated by Wilson (2010), a Mississippian period sample from the central Illinois valley, as the temporal and geographic context was closer to my MCR sample. Although Transition Analysis is over a decade old (Boldsen et al., 2002), the method's developers have not made available a key series of data. This dataset

contains the phase parameters from the Terry reference collection for each of the five pubic symphysis components, nine auricular surface components, and five cranial sutures scored in the ADBOU program. The mean and standard deviation for each transition of each component scored in the reference sample is required to recode the data to create more appropriate age estimates. Without these data, it is impossible to tailor the method to use a different informative prior. The unavailability of this dataset is unfortunate, as my research and that of many others could benefit from modifying the Transition Analysis data (Konigsberg, 2015). In 2014, Milner received a National Institute of Justice grant to improve upon the current TA method by incorporating novel skeletal traits that score for the binary presence or absence of a skeletal trait. The updated TA method may hold potential to better capture the variability in adult age-at-death, and generate more accurate and precise age estimates for individual skeletal samples. The revised method is slated for release in approximately two years (Milner personal communication, 2016).

Despite TA's expectation to deliver more appropriate age estimates, it does not conform to recommendations outlined by Hoppa and Vaupel (2002), with regard to having some knowledge about the target population's age-at-death structure before the age of individual skeletons can be estimated. Although I have identified an age distribution (Wilson, 2010) that would be more representative of my target MCR sample, the present version of TA does not allow me to incorporate an informative prior other than the 17$^{th}$ century Danish prior. Since the TA method built into the ADBOU software represents the best—though flawed—approach to derive individual age estimates for prehistoric samples, I will discuss the implications of the MCR age estimates generated from the method. Similar to Milner and Boldsen (2012) observations in their validation

study, MCR individuals with age estimates of 40+ exhibit very large confidence intervals; some of confidence intervals range from 40 to 50 years around the MLE age estimate. Milner and Boldsen (2012) discerned that very few skeletal traits are exceptionally characteristic of individuals in middle age, i.e., approximately 40 to 70 years old. A goal of Milner's revised TA method is to identify age-related changes that correspond with this middle age category.

Given that a large portion of the skeletal sample consisted solely of either scoreable cranial sutures or auricular surface, it is likely that the MCR age estimates generated by TA are underestimates, particularly those from 40 onward. The situation improves when all three components are used; however, as I remarked, I was not selective when I scored for age and used as many available traits, even if they were limited. If we are to trust that the majority of age estimates beyond 40 are underestimates for age, this would indicate that the actual MCR population lived to be much older than documented in this research. As a point of comparison, Berryman's (1981) original demographic analysis of Averbuch skeletal samples from all three cemeteries did not find any individuals surviving past age 40. Using Transition Analysis, the mean age-at-death for the entire sample is 43 years, with many estimates into the 70s.

***Hazard Models***

Gompertz and Gompertz-Makeham hazard models were used to fit the MCR adult age distributions. A 6-7 year decrease in mean age-at-death was observed when comparing the Early and Late Mississippian pooled sex groups. For MCR females, the mean age-at-death is held constant, though always lower, than MCR males, across all time periods. The mean age-at-death of MCR females hovers around 41 years old for

approximately five centuries. In the Early Mississippian period, males have a mean age-at-death of 57.99—nearly two decades of increased survival over females. This sizeable discrepancy in sex-specific survivorship suggests either that different life experiences place more selective pressures on females, or males are better able to buffer against stressors to survive longer.

In the Middle Mississippian period, the mean age-at-death of males is significantly reduced to 45.41 years while female mean age-at-death remains unchanged at 41.33. During the Middle Mississippian, sex-specific differences in survivorship are not as pronounced. In the Late Mississippian, female mean age-at-death is 41.39, while male mean age-at-death is 44.45. Comparing the survivorship patterns of the Middle and Late Mississippian periods reveals that the differences are not significant. This is somewhat expected, considering that the "Middle Mississippian" time period is more of a Middle-Late grouping since these sites had an overlap of dates into Regional Periods IV and V, as described in Chapter 3.

The optimal hazard models chosen for each time period need to be underscored. For all female time periods, the Gompertz model best fits the data. This indicates that the third parameter (mortality unrelated to senescence) in the Gompertz-Makeham model does not contribute any meaningful information to the overall level of female adult mortality. In contrast, the Early Mississippian males are best fit by the Gompertz model, but the Gompertz-Makeham models fit the Middle and Late Mississippian males optimally. Inclusion of the additional parameter of age-independent mortality for later period males better captures age-independent adult mortality that is not observed in females. Increased mortality of males may be attributed to risky behavior, accidents,

and/or warfare-related death during the Late Mississippian period. It is likely that a consequence of this increased conflict in the Late Mississippian period clarifies why the mean age-at-death for MCR males falls so dramatically from the Early to Middle-Late Mississippian periods. By the Late Mississippian period, social and environmental changes in the MCR are so pronounced that it affects males and females equally and sex differences become obscured. By using hazard models to fit the mortality profiles, the hidden heterogeneity in frailty that is so commonly overlooked in paleodemographic analyses can be illuminated.

**Paleoepidemiology Implications**

I hypothesized that, given the concepts of heterogeneous frailty and selective mortality, individuals without markers of childhood stress and poor oral health will have a greater age-specific risk of death than similarly-aged individuals with these markers. **Some analyses support this hypothesis, while other results reject it.** Overall results for linear enamel hypoplasias, dental abscesses, and antemortem tooth loss supported this hypothesis, thereby maintaining the interpretation of health put forth by the osteological paradox (Wood et al., 1992). Individuals without these conditions experienced greater age-specific risk of death compared to similarly-aged individuals with these conditions. Though the results were only slightly different ($p=0.045$), individuals with LEH survived four years longer than individuals without LEH. Individuals with abscesses lived eight years longer than those without abscesses ($p=0.001$). Individuals with antemortem tooth loss survived an additional 10 years, on average, than individuals without antemortem tooth loss ($p<0.005$).

On the other hand, the overall results for porotic hyperostosis, carious lesions, and skeletal trauma do not support the paleoepidemiology hypothesis. Individuals without these three conditions experienced lower age-specific risk of death compared to similarly-aged individuals with these conditions. These results support the traditional interpretation of lesions, being that those with evidence of skeletal and dental markers suffer from poor health and are at greater age-specific risk of death. Individuals without porotic hyperostosis live ten years longer than individuals with porotic hyperostosis ($p<0.005$). Individuals without carious lesions survive eight years longer than individuals with carious lesions ($p=0.002$). Males without skeletal trauma lived ten years longer than males with evidence of warfare-related trauma ($p=0.047$). This section attempts to elucidate the coexistence of results that both support and refute the paleoepidemiological hypothesis as well as take a closer look at the findings by sex and time period.

### *Childhood Stress Indicators*

Using the pooled sex and time period sample, results indicate that the presence of linear enamel hypoplasias (LEH) contributes to increased longevity in the MCR, though this effect is only marginally significant ($p=0.045$). These results run counter to a series of studies that correlate the presence of LEH with a negative effect on survivorship (Goodman, 1989; Duray, 1996; Boldsen, 1997; DeWitte and Wood, 2008; Wilson, 2014). In the MCR sample, it is the individuals without LEH that suffer from reduced survivorship. Evidence of LEH on permanent dentition signifies survival, as individuals who were physiologically stressed during infancy or childhood recovered from a biological insult (e.g., acute illness, nutritional deficiency) and survived.

Hillson and Bond (1997:96) report that macroscopic observations of LEH represent stress events that lasted between eight to 160 days. Therefore, it is possible that the evidence of LEH recorded in the MCR sample represents short periods of stress that did not have lasting effects on health. For these individuals, the body's ability to evade death in childhood may have created a heighted immune response that followed them into adulthood. During brief episodes of stress, anti-inflammatory hormones such as cortisol are released into the bloodstream. Cortisol is a vital hormone, produced in response to physiological and psychosocial stressors. Cortisol helps regulate a range of bodily functions by breaking down glucose and protein reserves to provide energy for immune responses (Seyle, 1976; Korte et al., 2005; Flinn, 2006). This permits the body to react to changing environmental perturbations by preparing for, and successfully recovering from, short-term demands. This represents a positive adaptive response (survival) to short bouts of stress, by promoting immune functioning and allowing the body to restore homeostasis promptly. In some circumstances, temporary increases in cortisol may provide heightened mental alertness and protect against inflammatory response (Flinn, 2006). Therefore, MCR adults without LEH represent those who did not experience biological insults during infancy and early childhood, and may not have been afforded the same immunological stamina to circumvent insults later in adulthood. While cortisol production is effective to combat short-term stress events, chronically stressed infants and children are subjected to long-term complications. These complications include pathological immunosuppression and depletion of energy reserves, at the expense of development and building immunity (Sapolsky, 1992). It is possible that cases that reveal an association between LEH presence and early mortality represent individuals who were

chronically stressed in early childhood, manifesting in slower and less effective responses to stressors later in life, resulting in early mortality (Webster Marketon and Glaser, 2008). This could be clarified by including MCR juveniles and examining the age-specific risk of death given the presence or absence of LEH.

Additionally, Reid and Dean (2006) report differential timing of LEH formation on the permanent dentition that governs the chronology of hypoplasias. Earlier-developing tooth crowns are subjected to earlier distribution of hypoplasias, with the maxillary central incisor being the most at risk among the permanent incisors for developing LEH between one to four years of age (Goodman and Armelagos, 1985). At later ages in childhood, the mandibular canine appears to be more susceptible to LEH, with a peak frequency of defects formed between four and five years of age. In the current research, LEH presence was pooled on anterior teeth; as such, differences in risk of death for individuals with LEH on individual teeth (canines, incisors) may be obscured. Future research may consider whether there are any differences in survivorship given LEH and tooth type.

Watts (2015a) did not find an association between LEH presence and early adult mortality. This suggests that disruptions to amelogenesis during infancy and early childhood do not cause long-term damage to health, or that the causative stress events that lead to LEH did not have lasting effects on survival. Additionally, a failure to discover a strong association of gross observations of LEH with either increased or decreased survivorship may suggest that the macroscopic presence of LEH is a poor proxy for early childhood stress in the MCR sample. Microscopic research has reported a strong relationship of LEH and reduced survivorship, by identifying enamel surface

depressions and accentuated perikymata spacing (King et al., 2005; Guatelli-Steinberg, 2008; Hassett, 2014; Temple, 2014). Future research may consider the use of microscopic methods for more precise LEH assessment, including age-at-defect formation. While the majority of bioarchaeological literature cites a relationship between childhood stress events and early mortality, some studies mirror the results of the MCR sample finding increased survivorship given the presence of LEH (Bennike et al., 2005; Geber, 2014).

Using the pooled sex and time period sample, the results indicate that the absence of porotic hyperostosis (PH) had a significant impact on increased longevity; these findings oppose the LEH results which found the opposite effect. Individuals without PH lived ten year longer than individuals with PH lesions. Holland and O'Brien (1997) report that maize contains phytic acid, and reliance on the iron-poor cereal grain during the Mississippian period likely had deleterious effects on the ability of the gastrointestinal tract to absorb dietary iron. Walker et al. (2009) posit that deficiencies in vitamin $B_{12}$ contribute to the porotic hyperostosis lesions presented in the bioarchaeological record. Maize intensification in the Middle Cumberland Region was quicker and more extreme compared to temporally similar groups in the Midwest (Buikstra,1992; Buikstra et al., 1988). Increased sedentism associated with agricultural subsistence would have formed different settlement patterns in the MCR from the preceding Late Woodland period. Rose et al. (1984:418) note that it is not diet in itself that has a negative effect on health but that “cultural change and population nucleation [associated with subsistence] are the prime stimuli for increased stress and morbidity.” Walker and colleagues (2009:119) underscore that the body’s response to anemic insult is complex, rooted in “the synergistic effects of nutritionally inadequate diets, poor sanitation, infectious disease and

cultural practices related to pregnancy and breast feeding." The difference in living conditions may have instigated the prevalence of porotic hyperostosis lesions, and in the MCR, contributed to a decrease in survivorship among both sexes. This may have taken the form of issues related to weanling diarrhea or periods of famine due to drought conditions. Reproductive-age females subsisting on iron and vitamin $B_{12}$-poor maize may have passed on a chronic state of iron-deprivation to the fetus as well as postnatally during breast feeding (Holland and O'Brien, 1997).

***Dental Health Markers from Adulthood***

Analyses of carious lesions, dental abscesses, and antemortem tooth loss (AMTL) reveal conflicting results. When considering the pooled sex sample, individuals without caries lived 10 years longer than individuals with caries of the enamel or dentine. However, individuals with caries that involved the pulp cavity did not experience significantly greater risk of death than individuals with caries of the enamel or dentine. In fact, individuals with caries that involved the pulp cavity lived three years longer than individuals with caries that did not involve the pulp cavity. This was surprising, given that exposure of the pulp cavity is believed to create easier access for systemic infections to enter the bloodstream.

Differences in survivorship by sex uncover a multifaceted pattern for carious lesions. The mean age-at-death of those with carious lesions that do not involve the pulp cavity are similar: 33.29 for females and 36.81 for males. However, the absence of caries and carious exposure of the pulp cavity generate dissimilar results. Females without carious lesions have a mean age-at-death of 39.9 years, while males without carious lesions have higher mean age-at-death of 48.65 years. Exposure of the pulp cavity in

caries resulted in reduced survivorship in females, with a mean age-at-death of 31.66, while carious exposure of the pulp cavity did not significantly reduce survivorship for males (mean age-at-death of 46.5). Some studies have investigated the natural history of caries in living populations without access to dental care. A sequence is observed that reflects a caries-prone group of individuals, such as the MCR sample at hand. Evidence supports the age-progressive nature of carious lesions, beginning with occlusal caries that affect the enamel or dentine, then gradually being replaced by caries that exposes the pulp cavity with advanced age (Manji et al., 1989 ; Hillson, 2008; Zandoná et al., 2012). This is another paradoxical interpretation of health, wherein survival of a systemic infection may have produced an advantageous immune response for males with exposed pulp cavity caries. Concomitantly, exposure of the pulp cavity decreased age-at-death by eight years for females. These results demonstrate that females without any carious lesions still had a mean age-at-death that was lower than males with caries that exposed the pulp cavity.

Sex differences in caries prevalence may be attributed to diet and behavioral factors (Lukacs and Largaespada, 2006). The higher caries prevalence among females is often ascribed to one of three explanations: 1) precarious eruption of permanent teeth in females, and thus, a longer exposure to a carious oral environment, 2) sexual division of labor, with females responsible for planting, harvesting, and food preparation, and 3) pregnancy and hormonal differences. Clinical studies do not find a causal link between the association of sex differences in caries and the earlier eruption of permanent dentition in females (Mansbridge, 1959). Larsen (1998) uses prehistoric samples of foragers and farmers in the Georgia Blight to document increases in caries prevalence among females.

He cites sex-based differences in preparation and consumption that resulted in greater caries prevalence among females. Larsen (1998) suggests differential food consumption, with males consuming more meat than females and a greater consumption of plants by females compared to males. Walker and Hewlett (1990) use ethnographic data to examine the health of foragers and farmers in Central Africa and arrive at an analogous behavioral interpretation for the higher caries rates seen in pygmy and Bantu women.

While most research attributes the dramatic decline in women's oral health to changes in diet and sexual division of labor, Lukacs and colleagues (Lukacs and Thompson, 2008; Lukacs, 2010) challenge this paradigm. Larsen (1997, 1998) trivializes physiological reasons for sex differences in caries prevalence, citing the variation to be "behaviorally mediated" (Larsen, 1997:76). Though agriculture may play a role in dental caries rates, Lukacs cautions that relying exclusively on a dietary explanation is "short-sighted and incomplete" (Lukacs and Thompson, 2008:910).

Sex differences in caries prevalence increase with age, particularly during women's reproductive years, and ultimately, physiological differences underlie sex-specific survivorship. The patterns observed in MCR female samples with caries may be explained by underlying sex-specific biological variation. Clinical research reveals that the chemical composition of saliva is modified by hormones associated with women's reproductive biology (Salvolini et al., 1998; Dowd, 1999; Lukacs and Largaespada, 2006). Saliva has an indirect role on oral health, as it prevents pathogens from colonizing the oral cavity (Walter and DeWitte, 2016). The smaller salivary glands of females, coupled with higher estrogen levels, results in females having a lower salivary flow rate; androgens do not effect caries rates (Lukacs and Largaespada, 2006). Moreover,

processes such as puberty, menstruation, and pregnancy contribute to a cariogenic oral environment experienced by females. Pregnancy, in particular, reduces the buffer capacity of saliva and produces xerostomy, or the condition of dry mouth; insufficient saliva production facilitates bacterial growth, thereby increasing the risk of caries (Salvolini et al., 1998; Dowd, 1999; Lanfranco and Eggers, 2012). Given that bioarchaeologists examine skeletal material, the role of saliva on oral health has been underappreciated until recently. Boldsen (1997) found an increased risk of death among reproductive-age females with active caries (caries with pulp cavity exposed) in medieval Denmark. He attributes their increased mortality to chronic calcium deficiency associated with long periods of breast-feeding and insufficient nutrition based on unfermented cereal grains such as maize. On the other hand, males were equally likely to develop and die from active caries at any age. It is evident that caries has a complex etiology, further complicated by its association with abscesses and antemortem tooth loss.

While the presence of carious lesions reduced survivorship in the overall MCR sample, individuals with abscesses or AMTL experienced increased longevity. The pulp cavity may serve as doorways for infectious agents to enter the bloodstream wherein an inflammatory response is necessary. The body's inflammatory response is to relieve pressure by draining through an abscess in the maxilla or mandible. This may result in eventual necrosis of the periodontal ligament, destruction of a tooth's supportive alveolar bone, and complete antemortem loss of the tooth. Given the relationship between an advanced carious state, abscesses, and AMTL, how can the contradictory survivorship patterns be resolved?

One way the abscess results can be interpreted is in light of the age-progressive nature of dental wear. Using a medieval Danish sample, Boldsen (1998:348) found that the risk of having at least one abscess rose with increasing age. He found the increase in risk to be steep among young adults. This risk plateaued from the mid-30s into the 50s, then the risk increased again after age 55. Boldsen (1998) determined that, once a person exhibited one abscess, the risk of having multiple abscesses increased. When Boldsen (1998) investigated the effect of attrition (tooth wear) on permanent molars, the relationship was clarified even further. Given the cumulative effects of daily tooth-to-tooth contact during masticatory processes, attrition is expected to increase with age. Boldsen (1998) calculated odds ratios for the effects of attrition and caries on the risk of having an abscess. Scores that are positively associated with the risk of having abscesses were ten times more common for attrition than for caries. Boldsen's (1998) results elucidate that, although caries is more closely associated with abscesses than dental attrition, attrition is the sole factor that explains the variance in the number of abscesses.

A similar association may be present in the MCR sample with regard to the presence and number of abscesses. Dental attrition was not observed or scored in the current study. However, if the pathogenesis put forth by Boldsen (1998) holds true in my research, differences in survivorship between MCR individuals with and without abscesses would be illuminated. It is presumed that an individual must survive well into adulthood in order for permanent molars to wear down to the extent of pulp exposure. These individuals are considered to be in good health. Differences in occlusal surface morphology as well as the severity of wear produce distinctive wear patterns in individuals, which manifest as a variation in the number of abscesses formed once the

pulp is exposed. Thus, the etiology of pulp exposure in these circumstances is attributed to attrition rather than the severity of carious lesions, though both can result in dental abscesses (Clarke and Hirsch, 1991; Dias and Tayles, 1997).

Though the presence of multiple dental abscesses indicates an inflammatory response to infectious agents in the blood stream, the fact that an individual was healthy enough to withstand its effects to form an abscess is a testament to its function as a marker of survival, and not necessarily poor health. This idea parallels the survivorship findings in the MCR, as individuals without any abscesses present the lowest mean age-at-death in both the pooled sample and by sex; these individuals may have succumbed to disease processes that failed to leave a skeletal signature.

Differences in attritional patterns may explain the perplexing abscess results in the MCR sample by sex, when running pairwise comparisons on the presence of one, two, or three abscesses. A difference in survivorship was apparent in females without abscesses and with one abscess ($p=0.032$, Table 8.29). Once a female presented one abscess, she was nearly at equal risk of death had she had two or three abscesses. The mere presence of one abscess was predicated on her survival to a later age-at-death, in contrast to females who lacked abscesses and died an average of eight years earlier. Among males, a significant difference in survivorship was only detected in males without any abscesses and males with three or more abscesses ($p=0.019$; Table 8.32). This suggests that, unlike females who had a similar risk of death whether they had one, two, or three abscesses, males had a greater ability to buffer against higher pathogen loads associated with the presence of three or more abscesses. Males with three or more abscesses had a mean age-at-death of 50.95 years compared to that of males without

abscesses (38.85 years). Again, these findings support a paradoxical interpretation of health championed by Wood and colleagues (1992). The optimal buffering capabilities afforded to males may be related to the physiological disparities of women's biology mentioned earlier, especially during their reproductive years.

Given the interpretation that dental attrition may best explain the abscess results, it is intuitive to suspect that antemortem tooth loss would also be related to attrition-induced abscesses. The fact that the AMTL results in the MCR echo the patterns seen for dental abscesses provide additional grounds to use this logic. While carious lesions that penetrate the pulp cavity are cited as a route for bacteria to enter the circulatory system, occlusal wear that exposes the pulpal chamber achieves the same result. Therefore, the AMTL results can be interpreted in light of the age-progressive nature of dental attrition. Adults with AMTL survive an additional 10 years compared to individuals without AMTL. Females with AMTL experience increased survivorship, living 11 years longer than females without AMTL. Males with AMTL live 10 years longer than those without AMTL. Much like with the results for abscesses, the implications of the AMTL results suggest that, in order for teeth to be shed during one's lifetime, an individual must survive to advanced age so that occlusal wear eventually exposes the pulp cavity. It is feasible that carious lesions exposed the pulp cavity to infectious agents, thus contributing to AMTL.

### *Skeletal Trauma and Paleoclimate*

Differences in survivorship were not detected for adults with and without skeletal trauma. This is undoubtedly a consequence of the small sample size of those with evidence of skeletal trauma (n=26) compared to those without trauma (n=396). Despite

the scant evidence of trauma, three deductions can be made: 1) Males with evidence of skeletal trauma did experience reduced survivorship compared to males without trauma. Males with trauma died at an average of 10 years earlier than males without trauma ($p=0.047$). 2) No individuals after the age of 40 presented evidence of warfare-related trauma. The mere presence of decapitation and dismemberment, cut marks associated with scalping, and cranial blunt force trauma in the Middle Cumberland Region sample indicates that groups were participating in small-scale intergroup conflict. It is important to remember that many cases of trauma may have only injured soft tissue and would not be represented skeletally. As such, any observations made with regard to the presence of skeletal trauma are likely underestimates. 3) Because not all ages and sexes were represented equally in the trauma sample, this finding corroborates Worne's (2011) conclusion that large scale massacres were not a feature of the Mississippian MCR. Young males were predominantly affected by skeletal trauma, which parallels iconographic representations of warrior imagery in the archaeological record (Dye, 2004; Brown and Dye, 2007).

While significant conjectures cannot be made with regard to trauma and risk of death in the MCR sample, it is worth considering the overall role that violence has on well-being. Conflict, or a constant threat of violence—whether stemming from armed conflict during times of ware or domestic abuse—have the potential to bring about profound physiological stress. The World Health Organization categorized violence as a public health issue (Krug et al., 2002). Apart from the dysfunction that violence imparts on adults, risky behavior and disease in adulthood can be traced to childhood abuse in living populations. The Adverse Childhood Experiences (ACE) Study reports that a series

of childhood exposures (psychological, physical, or sexual abuse; substance abuse; criminal behavior) have a strong relationship to multiple risk factors for several of the leading causes of death in adults, e.g., cancer, chronic lung disease, liver disease, and obesity (Feletti et al., 1998). Past experiences and memories of violence can have lasting psychosocial effects, thereby affirming the role of violence as a co-variate of health.

Human conflict can also be mediated by the influence of climate. Although use of the Palmer Drought Severity Index did not reveal significant differences in the mean PDSI values for the Early and Late Mississippian periods, it is important to consider the role of the environment on conflict. Research by Meeks and Anderson (2013) illustrate that four periods of drought-induced stress after the Mississippian period, two of which would have affected the MCR. Drawing upon many disciplines including archaeology, criminology, psychology, and geography, Hsiang et al. (2013) quantify the extent that past climatic events were responsible for causing conflict, violence, or political instability. While an overly deterministic environmental model is not suggested to be a primary driving force of conflict, Hsiang and colleagues (2013) demonstrate that the median effect of a one standard deviation change in climate variables generated a 14% change in intergroup conflict. If the changes taking place during the Mississippian MCR are viewed through a climate-violence approach, the temperature and precipitation changes marshaled by the Little Ice Age may have created a tumultuous terrain on which neighboring Mississippian groups operated. A possible decrease in crop yields may have intensified hostility in the region, as nucleated settlements attempted to move to arable land on which to subsist. Working within such a framework returns us to Goodman and Armelagos' (1989) generalized stress model described in Chapter 5. Doing so requires a

concern for environmental constraints, the cultural system, and physiological disruption in order to understand the cumulative effects that stress can impart on a population.

### *Temporal Changes*

No significant differences were found between time period and skeletal and dental markers of childhood stress, i.e., linear enamel hypoplasias and porotic hyperostosis. There were no differences in survivorship of individuals with LEH in the Early, Middle, and Late Mississippian time periods. Similarly, no differences in survivorship of individuals with PH were found in the Early, Middle, and Late Mississippian time periods. These findings suggest that neither of these skeletal indicators contributed to significant changes in health of the populations in the MCR during the Mississippian period; frequencies of the expression of these conditions remained constant over time, in as much as no changes in survivorship were detected given their presence in the sample.

On the other hand, significant differences were found between time period and indicators of poor dental health, i.e., carious lesions, dental abscesses, and antemortem tooth loss. For all three of these dental health markers, Early Mississippians with these dental markers lived longer than Late Mississippian with these dental markers. Early Mississippian MCR individuals with carious lesions lived seven years longer than Late Mississippian MCR individuals with carious lesions. Early Mississippian MCR individuals with dental abscesses lived 20 years longer than Late Mississippian MCR individuals with dental abscesses. Early Mississippian MCR individuals with antemortem tooth loss lived 16 years longer than Late Mississippian MCR individuals with antemortem tooth loss. If we revisit the temporal paleodemographic results (Figure 7.22), we are reminded that Middle and Late Mississippian individuals experienced decreased

survivorship compared to the Early Mississippian sample. Consideration of the Mississippian mortality profiles with the paleoepidemiology results suggests that the expression of dental health markers indicative of more recent health conditions had a significant impact on heterogeneous frailty. In other words, it is possible that dental health indicators mediate the mortality patterns that we see in the Early and Late Mississippian MCR samples, more so than indicators of childhood stress (LEH and PH). Differential exposure to cultural and environmental stressors throughout the Late Mississippian period may have be more critical in determining differences in survivorship than childhood stress episodes.

Clinical, epidemiological, and experimental research have established an association with malnutrition and changes in the oral cavity that promote cariogenesis (Johansson et al., 1984; Enwonwu, 1995; Proster et al., 2005; Lukacs, 2011). Starvation and limited food intake reduces salivary flow rate, which corresponds to an increase in plaque formation and the development of carious lesions. Most of the influences on oral health (gingiva, saliva) are not available to the bioarchaeologist but their impact can be extrapolated. If Late Mississippian groups had limited food resources due to crop shortages or failures as a result of changing climatic conditions, this may clarify the reduced survivorship seen in the Late Mississippian compared to the Early Mississippian period. Possible famines in the Late Mississippian period may have exacerbated physiological differences between the sexes, contributing to an increase in carious lesions.

Some studies have employed food crises documented in recent history to examine the physiological impact of resource stress. Zhou and Corruccini (1998) examined LEH

among living Chinese individuals born before, during, and after the Great Leap Forward. Also known as the Great Chinese Famine (1959-1961), the famine was caused by political factors of the socialist wealth distribution system, and affected tens of millions of the population. The authors found a 14% higher prevalence of LEH in individuals whose teeth developed during the famine than those whose teeth developed before the famine. Additionally, LEH prevalence was 23% higher in the group whose teeth developed during the famine compared to whose teeth developed after the famine.

Geber (2014) examined childhood stress markers among children affected by the Great Irish Famine (1845-1852). His assessment of Harris lines and subadult stature revealed differences in famine-induced growth patterns. Similar to my results for the LEH analysis of the MCR, Geber (2014) did not find a negative impact on survivorship among individuals with LEH. He found that individuals without LEH had a greater risk of death than those with LEH. Geber (2014) alludes to the osteological paradox to explain his results, theorizing that the childhood stresses that were severe enough to cause enamel hypoplasias may have provided a heightened ability to survive the stresses related to the Irish famine.

## Chapter Summary

An amalgamation of the paleodemographic and paleoepidemiological results of the Middle Cumberland Region does not support catastrophic mortality events or widespread epidemics. These data demonstrate that population levels were sufficiently supported by an adequate number of females surviving to reproductive age, as the mean age-at-death remained constant throughout the Mississippian Period (Table 7.16; Figure 7.23). Survivorship of males decreased sharply from the Early Mississippian to Late

Mississippian period, possibly due to elevated rates of conflict. On the whole, mortality was elevated in the Late Mississippian period compared to the Early Mississippian period. This supports my paleodemography hypothesis. A closer investigation into differences in survivorship by sex and time period establish that some paleopathological findings expound otherwise hidden heterogeneity in frailty, thereby maintaining my paleoepidemiological hypothesis. Results for carious lesions, porotic hyperostosis, and skeletal trauma support the normative interpretation that these lesions have a negative impact on survivorship. Since an abrupt exodus away from the Middle Cumberland Region is not documented in the archaeological record, what precipitated the eventual abandonment of the area? The last chapter will provide concluding remarks with regard to this phenomenon, as well as propose future research endeavors.

# Chapter 10: Conclusion

My research uses prehistoric skeletal remains to reconstruct the demographic profile of the Mississippian Middle Cumberland Region and assess risks of death associated with physiological, cultural, and environmental processes. In doing so, I sought to determine whether a signature of depopulation could be detected in the skeletal record. Temporal differences in survivorship among MCR males suggest that sociopolitical and ecological changes brought about increased mortality in the Late Mississippian period. The construction of palisades in the Late Mississippian period attests to the presence of intergroup conflict or presumed threat of violence. Females had lower survivorship compared to males, with a mean age-at-death of 41 years old throughout the entirety of the Mississippian MCR occupation. Underlying physiological differences substantiate findings of increased mortality among females, largely ascribed to women's reproductive biology. Examination of the pooled sex sample reveals an overall reduction in survivorship from the Early to Late Mississippian period, likely driven by the dramatic mortality rise among MCR males.

While the Vacant Quarter hypothesis is an intellectually stimulating subject in and of itself, the main objective of my research was neither to resolve why Mississippian groups abandoned the MCR, nor to where they migrated. However, I would be remiss not to discuss the presumed movement of MCR groups out of the Nashville Basin. Although differences in mean PDSI values of the Early and Late Mississippian periods were not identified in the current research, drought events ushered in by the Little Ice Age may

have altered numerous facets of the Mississippian experience. These differences include changes in subsistence, settlement patterns, and the chiefdom redistribution system. Sociopolitical strife and unfavorable climatic conditions in the Late Mississippian period may have offered little incentive for Middle Cumberland groups to remain in the area. East Tennessee is one proposed location to which MCR groups may have migrated. While archaeological evidence does not support wholesale movement to the region (Boyd and Boyd, 1991; Schroedl, 1998), MCR groups could have made contact with groups living in the region. Evidence of burning at Dallas, an East Tennessee site contemporaneous with the Mississippian MCR, may indicate a localized conflict coming from MCR groups when conditions in Middle Tennessee were increasingly uninhabitable (Sullivan, 2007). Accidental burning or ceremonial intentional burning of the Dallas site are also possibilities that would exclude MCR involvement. During the Late Mississippian period in the MCR, social shifts and the appearance of different artifacts in East Tennessee valley sites may suggest that MCR groups migrated to the area (Sullivan, 1995).

The population decline of the MCR should not be contained within an environmentally-deterministic paradigm. It is necessary to move beyond a simplistic assumption that a reliance on agricultural production precipitated a decline among MCR communities. Mississippian groups were not passive agents, and we must consider their ability to make decisions in order to shape their surroundings. This is evident given the palisade construction at the Averbuch site in the early-to-mid-1400s. Averbuch inhabitants attempted to preserve despite deteriorating cultural and environmental conditions (Cobb et al., 2015). A sufficient portion of the population accrued resources to

bury their dead and build defensive walls in response to perceived threats. It is feasible that MCR groups remained in the region as long as they could, but settled in smaller farmsteads or hamlets that are currently untraceable archaeologically.

Twenty years after the seminal osteological paradox publication, bioarchaeologists continue to debate what constitutes good or bad health (DeWitte and Stojanowski, 2015). A more productive exercise would be to see beyond this binary categorization of health. Wright and Yoder (2003:56) comment that normative interpretations of skeletal lesions may co-exist with paradoxical interpretations, which are equally important to consider in order for a "sensitive interpretation of frailty and its change through time and space." The current research highlights the benefit of using multiple lines of evidence to assess health, as well as a full consideration of the archaeological context. The results of my research demonstrate that both interpretations of health can operate in tandem. The effects of heterogeneous frailty and selective mortality are addressed using hazard models and survival analysis. This approach sheds light on the utility of addressing age- and sex-specific risks of death when examining population dynamics.

Future research using MCR skeletal samples fall instinctively into paleodemographic and paleoepidemiological categories. With regard to paleodemographic research, I hope to attain the Terry reference parameters of the Transition Analysis method and incorporate a different informative prior than the Danish age distribution built into ADBOU. I will compare these new survival curves and maximum likelihood estimates with those generated in the current research to determine whether there are any changes in the age distribution of the pooled sex sample, by sex,

and by time period. If there are differences, results of the Kaplan-Meier analyses would also need to be altered.

With respect to paleoepidemiological research, there are two avenues I am interested in examining further. The first is the relationship between dental attrition, caries, abscesses, and antemortem tooth loss. A complex etiology of pulp cavity exposure and dental attrition was proposed, but not tested, to explain the paradoxical interpretations of increased survivorship among individuals with abscesses and those with AMTL. By controlling for attrition, and in turn, age, I can test the notion that survival into old age ran tandem with dental attrition for those with abscesses and AMTL. The second idea revisits climatic conditions as a co-variate of health. I would like to refine the way I employ the Palmer Drought Severity Index to detect informative changes in paleoclimate. In the current research, I was unable to find differences in mean PDSI values from the Early and Late Mississippian periods. But by investigating the effect of decadal drought events, I may be better able to elucidate the ecological consequences of decreased maize yields and surplus that would have destabilized both subsistence and the economic redistribution system of Mississippian chiefdoms. In order to do this, it is will be necessary to place MCR sites into more explicit time frames that correspond to these climatic changes.

While this project examines a Mississippian period population, bioarchaeologists and medical anthropologists in other geographic and temporal contexts can apply this framework to model health questions pertinent to other social and ecological factors of interest. In this way, we can better understand and predict how life ways past, present, and future are influenced by a series of multifaceted processes.

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# Vita

Christina Laiz Fojas received a B.A. in Anthropology from New York University in 2006. She interned at the American Museum of Natural History, worked on a sifting operation to identify victims from September 11, 2001, and conducted bioarchaeological fieldwork in Sudan. She continued to pursue her interests in human skeletal biology and graduated with an M.S. in Biological Anthropology from Mercyhurst University in 2010. Following one year of doctoral coursework at Binghamton University, she transferred to the University of Tennessee in 2011. At the University of Tennessee, she was a Graduate Assistant for the Forensic Anthropology Center, Graduate Research Assistant to Dr. Dawnie Steadman, Graduate Teaching Associate in the Department of Anthropology, and Lab Coordinator for anatomy courses in the Departments of Ecology and Evolutionary Biology and Anthropology. From 2015-2016, she was a Visiting Lecturer in the Department of Biomedical Sciences at the West Virginia School of Osteopathic Medicine. She received her doctorate in August 2016 and is currently employed as an Assistant Professor in the Physician Assistant Studies Program at Marist College in Poughkeepsie, NY.