# REPRESENTATIVENESS, BIAS AND PALAEODEMOGRAPHY

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TITLE Representativeness and Bias in Cemetery Samples: Implications for Palaeodemographic Reconstructions of Past Populations

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# ABSTRACT

This study examines the issue of representativeness with respect to palaeodemographic reconstructions from skeletal remains. Since determination of age and sex is fundamental to research in skeletal biology, it seemed warranted to examine the impact of representativeness and bias on interpretations based on these data. Mean age-at-death (MAD) is the primary statistic relied upon for interpretations of changing patterns of health and well being from palaeodemographic analyses. This study examines the issue of representativeness between skeletal samples and the cemetery population from which they are drawn. A series of sampling experiments conducted on three documented 19th century mortality sample distributions (St. Thomas' Anglican, Belleville; Union Cemetery, Waterdown; St. Luke's Anglican, Burlington) illustrates the danger in making interpretations based on mean age-at-death. It is proposed that whatever *process* mean age-at-death reflects in the health of past populations (fertility or mortality), it is irrelevant if the sample on which the statistic is calculated is not representative of the population. Given that most cemetery samples will be subject, differentially, to biases at a variety of levels, comparative studies based on palaeodemographic data cannot realistically be considered reliable ***without careful control for those biases***. Without careful consideration of what or who exactly is represented by skeletal samples, palaeodemographic analyses shed little light on the realities of past life. If representativeness is, as I would suggest, the primary theoretical obstacle for researchers to overcome, then it is necessary to shift our focus to rigorously exploring those factors that bias our samples. Without some direct quantification of the representativeness of a sample, palaeodemographic estimators such as mean age-at-death are meaningless and any subsequent interpretations regarding the past, dubious at best.

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# CHAPTER 1

## INTRODUCTION

The initial impetus for this thesis was a dissatisfaction with the theoretical foundations on which past lives are reconstructed from skeletal remains. In particular, issue is taken with demographic reconstructions which focus on estimating vital statistics such as birth and death rates, average life expectancy, fertility, fecundity and reproductive rates.

A basic premise of anthropological reconstructions of past populations is that information on mortality is sufficient to derive a reasonably accurate picture of health, disease and population structure. Built into this premise are two distinct, but related issues; first, the analysis of the data is accurate; second and somewhat more crucial, the data itself is free from bias, and is representative of population parameters (eg. average life expectancy, fertility rates, disease prevalence etc.).

Demographic analyses depend upon the accurate enumeration of sex and age-at-death distributions ***within a representative sample*** of the population under study. In fact, the question of what constitutes a population is paramount in both demography and skeletal biology, and will be discussed later in some detail (Chapter 3). Demographic analyses based on human skeletal remains (palaeodemography) can be broken down at three fundamental levels. First, it is presupposed that the dead, or more specifically the skeletons of the dead, are representative of the once living population from which they were drawn. Second, it is assumed that demographic theory can be utilized to derive population level parameters about the dead. And third, researchers contend that demographic statistics can be translated into tangible interpretations of health and well being within past populations.

Ignoring for the moment the familiar discomfort with the borrowing and subsequent modification of demographic theory for interpreting *past life*, it is of interest to consider the validity of the assumption of representativeness with respect to palaeodemographic studies. As has recently been noted, osteological studies make

> the implicit assumption that skeletons in a cemetery, at least on average, are reasonably representative of the living population that produced them and therefore that changes in skeletal assemblages reflect real changes in the health of once-living populations. This is an assumption made implicitly or explicitly, with varying degrees of caution, by most quantitatively oriented paleopathologists (Cohen 1994:629).

Virtually all investigators make reference to the assumption of representativeness as being a necessary first step in osteological reconstructions, but then acknowledge the difficulties in accepting the restrictions of that same assumption (eg. Armelagos et al. 1972; Buikstra and Cook 1980; Hummert 1983; Merchant and Ubelaker 1977). For the most part, osteologists have necessarily been forced to ignore the issue of representativeness as too large a problem to deal with (Saunders and Hoppa 1993). Moreover, osteology is a sample-driven science, in that by the sheer rarity and scientific potential of any single new sample, interpretations based on the analysis are made at the broadest level possible. For example, while a family cemetery of several dozen individuals may allow for a calculation of infant mortality to be made, the context and size of the sample may have little bearing on the actual level of infant mortality experienced by the community Investigators often cannot help but make such broadly sweeping interpretations even on the smallest and most irregular of skeletal series which they themselves recognize as unlikely to be representative of a single tangible population cohort. This is not to say that such interpretations should be omitted, but simply, as most do, they should be framed within the constraints of theory.

The primary objective of this study is to examine the issue of representativeness with respect to palaeodemography — the demographic analysis of past populations from their material remains. An exploration of this issue is conducted through a series of sampling and re-sampling simulations conducted on three sets of 19th century mortality data from Southern Ontario. These data are derived from two Anglican parish burial records (St Thomas', Belleville and St. Luke's, Burlington), and one rural cemetery (Union Cemetery, Waterdown) A critical assessment of the impact of bias is undertaken by generating a series of hypothetical skeletal samples with varying levels of representativeness (with respect to the age and sex structure), as compared to the overall cemetery populations Unlike stochastic simulations which have been conducted controlling for specific biases (eg. Weiss 1975 used simulations to examine the impact of irregular population growth on the subsequent mortality sample), it was felt that the use of real cemetery populations would reflect any subtle nuances in the development of the cemetery that may be missed or overlooked in such models. In doing so, this work provides a comprehensive assessment of whether palaeodemographic analyses provide valid data from which to base more general interpretations of health in the past.

While the issue of representativeness in skeletal biology has broad implications for all types of analysis (eg. disease prevalence, nutrition, growth), this thesis will focus on palaeodemographic reconstructions, since the determination of age and sex distributions are a common foundation to almost all analyses The thesis begins by familiarizing the reader with palaeodemography. Chapter 2 reviews the literature in the field of palaeodemography, examining methodological and theoretical considerations and the past and current criticisms of both, and provides an overview of demographic considerations relevant to understanding the issue at hand Chapter 3 reviews the issue of representativeness within skeletal biology It begins with a review of the literature within the discipline and then provides a model for understanding the process of data loss for skeletal samples from various sources. Chapter 4 describes the materials and methods used in the analysis, the background of the sources of documentation, reasoning for their use and assessment of accuracy. The results obtained from the analyses are presented in Chapter 5. Comparisons between each of the cemetery 'populations' and simulated samples are presented A discussion of these results and their implications for palaeodemography are presented in Chapter 5. A summary of the conclusions drawn from the research is presented in Chapter 6.

The goal of this study is to demonstrate whether or not palaeodemographic studies can *ever* make interpretations regarding the past based on the analysis of skeletal samples, and if so, under what circumstances. A critical review of the palaeodemographic literature and the issue of representativeness within osteological studies is made. It is clear from the literature that until recently, there have been few attempts to quantitatively assess the potential impact of sampling bias, for either specific analyses or for studies in general. Using three 19th century mortality samples from southern Ontario (St. Thomas' parish burial records, Union Cemetery Burials, and St. Luke's parish burial records) this study demonstrates, through a series of sampling experiments, the serious impact of sampling bias on palaeodemographic interpretations made from skeletal samples. It is clear that without very large sample sizes, and some understanding or control over the processes that are known to influence the deposition and final recovery of skeletal samples, comparisons of palaeodemographic parameters such as mean age-at-death are unlikely to be accurate. Subsequent interpretations based on the observed differences of these parameters, specifically with regard to the broader issues within human prehistory, such as increasing life expectancy over time, must then be re-considered. Although this exploration is specific to demographic interpretations, the results are more broadly applicable to the problems of sampling in physical anthropology.

# CHAPTER 2

## PALAEODEMOGRAPHY

### *Introduction*

This chapter is devoted to reviewing, in some detail, the development and evolution of palaeodemography as a discipline within physical anthropology. Beyond familiarizing the reader with the development of the discipline, it also provides a framework and context in which to place specific studies that have been published within the literature. The numbers of studies and types of analysis presented over the last four decades have changed considerably. However, many of the broad questions regarding human prehistory that palaeodemography has contributed to, are based on earlier studies and have not been re-evaluated in light of current trends in method and theory. While it is not the intent of this thesis to undertake such a task, it is hoped that the implications of representativeness and sampling bias presented in this study, will force investigators to carefully re-evaluate the kinds of interpretations that can and have been made from palaeodemographic analyses of skeletal samples.

While by no means the first to write on the subject (eg. Fusté 1954; Goldstein 1953; MacDonnell 1913; Pearson 1902; Senyürek 1947; Vallois 1937; Weidenreich 1939; Willcox 1938) J. Lawrence Angel may be considered the founding father of palaeo-demography with his early publications on the subject of life expectancy in the ancient world (eg. Angel 1947, 1954). By the 1970's, palaeodemography seemed to be a primary focus in the osteological literature (Acsádi and Nemeskéri 1970, Angel 1968, 1972, 1975; Asch 1976, Bennet 1973, Blakely 1971, 1977; Brothwell 1971; Clarke 1977; Kobayashi 1967, Lovejoy 1971, Lovejoy et al. 1977, Owsley and Bass 1979; Piasecki 1975, Piontek 1979, Piontek and Henneberg 1981; Swedlund and Armelagos 1969, Ubelaker 1974; Vallois 1960, Welinder 1979). The early days of palaeodemography represented an exploration of demographic theory applied to ancient populations and the use of the life table as a tool to aid interpretations of age-at-death profiles from skeletal samples (Angel 1969a,b; Armelagos and Medina 1977; Bocquet-Appel 1977, 1978, 1979; Bocquet-Appel and Masset 1977; Hassan 1981; Henneberg 1977, Masset 1973; Moore, Swedlund and Armelagos 1975; Palkovich 1978; Pardini et al. 1983, Passarello 1977; Plog 1975; Sullivan and Katzenberg 1981; VanGerven et al 1981; Weiss 1973,1975).

In the 1980's, many researchers began to question the usefulness of palaeodemographic analyses. Criticisms regarding the reference samples used for ageing techniques sparked several years of debate within the literature (Bocquet-Appel, Tavares da Rocha and Xavier de Morais 1980; Bocquet-Appel and Masset 1982, 1985; Bocquet-Appel 1986; Buikstra and Konigsberg 1985; Greene et al. 1986; Horowitz et al. 1988; Masset and Parzysz 1985; Sattenspiel and Harpending 1983; VanGerven and Armelagos 1983). Following this period there was greater emphasis on the methodological issues related to palaeodemographic research. The late 1980's and early 1990's focused on testing the accuracy and bias of the ageing techniques used to generate age-at-death profiles (Bedford et al. 1993; Brooks and Suchey 1990; Fairgrieve and Oost 1995; Lovejoy et al. 1985; Lucy et al., 1995, Meindl et al 1983, 1985, 1995, Saunders et al 1992) and saw a revival of the application of model life tables Most recently, the biases inherent in mortality samples, considered primarily a result of the fact that they are composed of non-survivors, have been reiterated by researchers. With this has followed an exploration of more sophisticated mathematical approaches to try to compensate for these biases (Gage 1985; Jackes 1985; Konigsberg and Frankenberg 1992; Milner, Humpf and Harpending 1989; Paine 1989; Roth 1992; Siven 1991a,b, Skytthe and Boldsen 1993, Wood et al 1992). Still dissatisfied, many researchers have begun to express concern regarding sample representativeness, and the theoretical foundations for palaeodemography have been questioned once again (Hoppa 1993; Lamphear 1989; Saunders, Herring and Boyce 1995; Wood et al. 1992). With the more wide-spread availability of historically documented cemetery samples, researchers have only recently begun to explore this problem by directly comparing the demographic structure of a skeletal sample to the structure inferred from its associated documentary records (Grauer and McNamara 1995; Saunders et al. 1991, 1995; Saunders, Herring and Boyce 1995; Scheuer and Bowman 1995; Sirianni and Higgins 1995; Walker 1995; Walker, Johnson and Lambert 1988). Of course, researchers must be equally cautious of assuming that the historical records are without bias and can be used to represent the *expected* demographic structure of the skeletal sample.

### *Birth of a Discipline: Life Expectancy in Ancient Peoples*

Palaeodemography examines three principal areas of population structure: i) changes through time, ii) changes in composition, most importantly age and sex distributions, and iii) changes in size. For reconstructions of past populations, the principle source of data comes from mortality statistics derived from skeletal remains, which may sometimes be augmented by associated documentary information from epigraphy, census and parish records, or primary, literary sources. When demographic parameters are known or can be estimated, it is argued that the resultant population structure is predictable and can be extended either forward or backward in time to examine the significance of sets of parameters (Howell 1986:219). Perhaps the simplest example of this process is that of a population observed to have a high mortality rate at a given period of time. It is not difficult to hypothesize that, prior to this period, the population was likely larger, and that following this period it will be smaller and at risk of extinction. It has been argued that anthropological demography can estimate the average size of the living population, the size and mortality of age cohorts, female fertility rates, and the presence of missing elements such as infant mortality (Melbye 1982). However, palaeodemographic theory relies upon several assumptions that cannot be readily validated by the researcher.

The primary assumption of palaeodemographic reconstructions is that the age and sex profiles seen within the sample of dead individuals provide a clear and accurate reflection of those parameters within the once living population — that is, the numbers, ages and sexes of the mortality sample accurately reflect the death rate of the population. Second, ***any bias that may affect the data can be recognized and taken into account*** (Ubelaker 1989).

Demographic analyses of past populations rely on the assumption of biological uniformitarianism (Howell 1976). This principle asserts that past and present regularities are crucial to future events and that under similar circumstances, similar phenomena will have behaved in the past as they do in the present, and will do so in the future (Watson et al.

1984:5) Application of this theory to biological processes, particularly those relevant to population structure, similarly assumes that humans have not changed over time with respect to their biological responses to the environment (Howell 1976). The most obvious concern is with patterns of maturation and the well-documented secular trends toward earlier sexual maturity in many recent populations (Eveleth and Tanner 1990; Tobias 1988; vanWieringen 1978).

The study of secular trends in populations is important to demographic studies for several reasons. First, there are known relationships between changes in growth and development and patterns of morbidity and mortality within a population (vanWieringen 1978). Further, changes in growth are likely to be reflected in human behaviour within a population. Factors such as the age of onset of menarche are important in the reconstruction of past population dynamics and important social information such as family patterns and marital practices may be inferred from such data (Acsádi and Nemeskéri 1970). For example, changes in marriage rules may follow secular trends in sexual maturity such as the age of menarche, with increases or decreases in the age of onset resulting in increases or decreases in population growth, respectively (Nelson 1985).

Presupposing the validity of biological uniformitarianism proposed by Howell (1976) the basic premise for demographic reconstructions is that the population from which the sample is drawn is *stationary*, a special type of *stable* population (Acsádi and Nemeskéri 1970). A stable population is defined as a "population which is closed to migration and has an unchanging age-sex structure that increases (or decreases) in size at a constant rate" (Wilson 1985:210). To be considered stationary, a population must meet certain further

**TABLE 2.1** Mean age-at-death (MAD) and life expectancy for males/females for Union Cemetery.

| | MAD | Birth | 20 years | 40 years | 60 years | 80 years |
|---|---|---|---|---|---|---|
| 1870-89 | 41 | 43.8/38.3 | 39.2/32.9 | 26.5/28.7 | 12.5/14.7 | 3.9/5.8 |
| 1910-29 | 61 | 58.6/62.7 | 46.2/48.2 | 31.4/32.4 | 15.2/16.5 | 4.5/4.7 |
| 1950-69 | 69 | 65.8/72 | 51.6/54.4 | 33.6/35.3 | 17.5/18.7 | 6.5/7.2 |

criteria. It too must be closed to both in-migration and out-migration with an unchanging age structure. However, to be stationary the number of births in the population must equal the number of deaths. Furthermore, it is assumed that each age cohort in the sample is fixed and representative of the population in absolute numbers and rate, and that the sex ratio represents the living sex ratio in the population. Fertility, mortality and size are assumed perpetual and unchangeable within the population. A stationary population maintains a constant age structure *and* size, while a stable population can experience changes in size so long as it is constant and the proportion of each age cohort is constant (Petersen 1975b). Unfortunately this fundamental assumption often precludes from analysis any of the variables that physical anthropologists are commonly interested in examining, such as differences in mortality at two different periods of time (Moore et al. 1975).

This problem is illustrated in the following traditional palaeodemographic analysis of burial data from Union Cemetery in southern Ontario (Hoppa 1989). Table 2.1 presents the calculated life-expectancy at various ages for three periods (1870-89; 1910-29; 1950-69). Figure 2.1 presents mortality curves for each of the three periods. A temporal trend in mortality can be observed with higher young adult and infant mortality in the earlier period (1870-89) and a higher mortality rate among older adults in the two later periods (1910-29

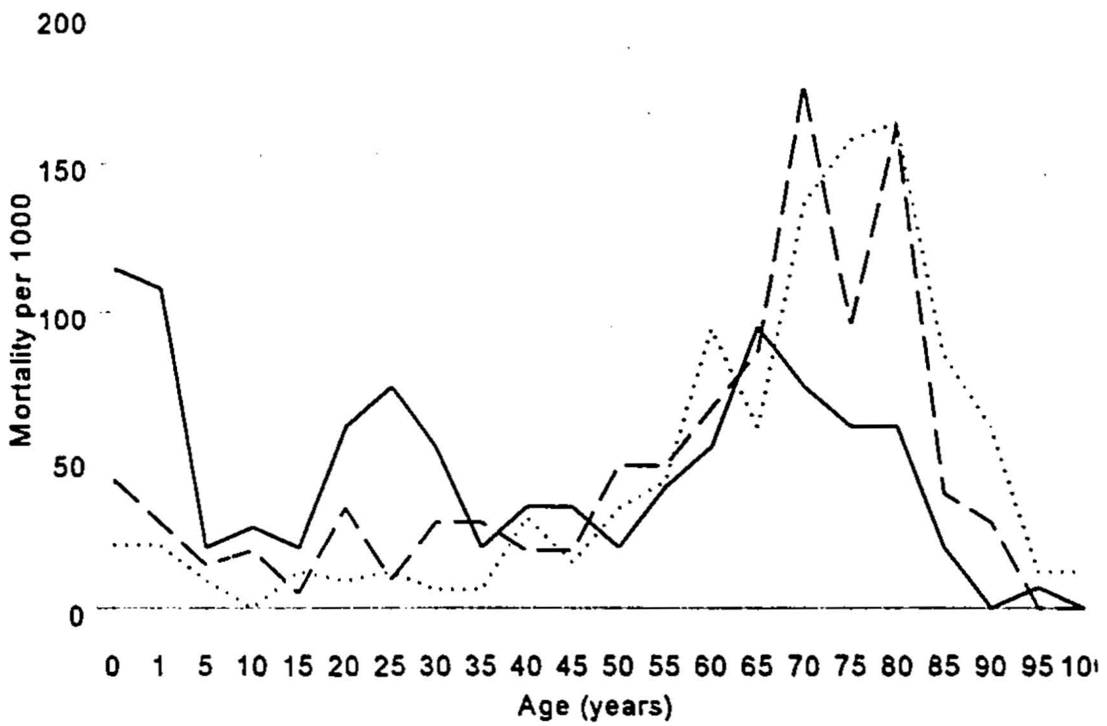

**Figure 2.1**: Mortality curves for Union Cemetery illustrating the changes between the three periods: 1870-89 (———), 1910-29 (- - - -) and 1950-69 (·····) from Hoppa (1989).

and 1950-69). The latter is in fact, a result of a differential increase in the relative size of the old adult cohort with a larger proportion of the population living to, and thus dying, in the 1910-29 and 1950-69 cohorts. Such a trend could be interpreted to represent changes in lifestyle including a better standard of living and improved nutrition and health after the turn of the century. Unfortunately, these interpretations are suspect given that the population under study is undergoing growth, thus violating the assumption of a stationary population. The level of growth can be estimated from both the palaeodemographic life table itself or from other historical sources such as census statistics[1].

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[1] In this case the intrinsic growth rate, r= 3.6% between 1870-89 and 1910-29 and 2.6% between 1910-29 and 1950-69 from the palaeodemographic life table and an r of 3.5% to 5.3% is estimated for the mid 20th-century from the population sizes recorded for the county of Wentworth and the village of Waterdown (Hoppa 1989).

### *A Tool for Interpretations: The Life Table and Mean Age-at-Death*

Traditionally, the statistical tool used by palaeodemographers has been the abridged life table. The life table is simply a mathematical model which allows for the estimation of biological life processes from a given age-at-death distribution (Moore et al. 1975). Estimates of vital statistics such as mortality rates ($M_x$), probability of death ($q_x$), and life expectancy ($e_x$) can be calculated from the life table. Under the assumption of a stationary population, palaeodemography uses mean skeletal age-at-death to estimate expectation of life at birth. Generally, mean age-at-death (MAD) is considered approximately equivalent to the inverse of the *birth rate* in a population, but is independent of both life expectancy and the death rate (Horowitz and Armelagos 1988, Sattenspiel and Harpending 1983). Mean age-at-death reflects life expectancy only if birth and death rates are equal. However, the conditions of a stationary population are unlikely to exist in real populations and thus we should not assume that these two rates are identical in past populations (Gage 1985; Sattenspiel and Harpending 1983). When the conditions of a stationary population are not met, this calculation simply represents mean age-at-death (Coale 1972). To calculate life expectancy at birth under non-stationary conditions, one must have information on the total size of each living cohort, that is, the total population at risk. Obviously, however, this is not possible for past populations and therefore the assumption of a stationary population is made by all researchers. Horowitz and Armelagos (1988) have criticized Sattenspiel and Harpending's (1983) claim that the inverse of the birth rate is equivalent to mean age-at-death. They demonstrate that the precise relationship between the two variables can be derived from stable population theory and that the two variables are considered equivalent only in special circumstances. As a result, Horowitz and Armelagos (1988) are cautious of demographic assessments that do not consider related socio-cultural factors. Nevertheless, mean age-at-death is regularly used to estimate life expectancy and when MAD increases we infer that there is an associated decrease in death rate. While this is true for modern populations where cohort sizes are known, this may not be so for past populations. Sattenspiel and Harpending (1983) demonstrated that for populations that were undergoing moderate growth or decline, the effects of changes in mortality are negligible while the effects of birth rate and therefore fertility, are significant for mortality profiles. As a result, these authors argue that conclusions derived from mean age-at-death regarding the general level of mortality observed within a skeletal sample are meaningless and unreliable (Sattenspiel and Harpending 1983:495). In their application of model life tables to several archaeologically derived samples, Milner and co-workers (1989; Wood et al. 1992) similarly concluded that the age distribution of skeletal samples provides less information about mortality than it does about fertility, a position supported very early on in the demography literature by Coale (1957). In fact, the same fertility and mortality schedules can produce different birth and death rates in populations with differential age structures (Coale 1972).

Conventionally, life tables are used to estimate general mortality patterns and fertility is "derived as a residual of the estimation of mortality" (Johansson and Horowitz 1986:235). Johansson and Horowitz (1986) suggest that in comparative analyses of two palaeodemographic samples, observed differences in mean age-at-death should be interpreted as the result of differences in fertility rather than mortality. This is not surprising given the interrelationship between the two, and it is argued that mortality, not reproductive rates *per* *se*, governs fertility rates in populations (Wood 1990). The implications for such a radical shift in interpretations of differences in MAD's are quite striking. If, in fact, fluctuations are a result of differential fertility rather than mortality rates, then investigators must re-consider the types of factors that may be important for understanding these differences. Rather than examining disease prevalence and their proximate determinants, researchers may find that cultural factors such as marriage customs may have a more direct role in observed differences in MAD between samples. For example, two samples may be subject to the same risks of mortality, but one represents a culture where marriage occurs late. Conversely the second might represent a culture where men marry early and take several wives. While both are experiencing the same mortality rates, the latter will have a much higher fertility rate which will be the cause for the observed differences in sample MAD's.

While independent estimates of growth rate may be difficult to derive for archaeological populations (Moore et al. 1975; Milner et al. 1989), Johansson and Horowitz (1986) argue that measures of fertility levels can be obtained directly from skeletal samples. Reproductive rates are estimated by the gross reproductive rate or number of female births per number of fertile females[2], and the net reproductive rate which measures the replacement of females within a population. If the net reproductive rate is greater than one, then population growth is occurring. If this value is less than one, the replacement of females is incomplete and the population may become extinct.

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[2] For palaeodemographic studies, it is assumed the all females between the ages of first menstruation and menopause represent the possible number of fertile females. Corrections for female sterility, fetal deaths or other biological or cultural process that affect fertility can be made, using the rates observed in modern and historic populations.

Growth and migration are perhaps the two most prominent factors that inhibit the assumption of stationarity in populations Petersen defines migration as "the permanent movement of persons or groups over a significant distance" (1975b:41). The immediate effects of migration into or out of a population are obvious. Increases or reductions in numbers differentially by age and sex with associated shifts in fertility and mortality rates, and potential changes in the gene pool that can affect risks of disease are all potential sources of variation that can result from migration. The movement of campaigning military forces, for example, between communities in medieval Europe provided a constant renewal of new hosts for any diseases that they may have been subject to in their previous location. The extent and degree of such changes are dependant upon the source of migration and the cultural forces that are propelling the migration. Beyond war or invasion, persecution, plague, and socio-economic factors such as supplies of food and resources and political policy, can alter the demographic parameters of a population over both the short and long term. Perhaps the most popular example is the considerable impact of European contact on the demography and health of the indigenous populations of the New World (e.g. Dobyns 1993; Verano and Ubelaker 1992). Failure to recognize the possible effects of migration on the age structure of past populations is undesirable, especially in populations for which there is good reason to suppose such movements (Johansson and Horowitz 1986).

The basis for the use of stable population theory in demographic analyses is that it provides the relationship between a population's age structure, its age-specific mortality rates and the intrinsic growth rate, birth rates and death rates, thus allowing the use of age structure to make statements regarding birth and death rates (Gage 1985). Palaeodemography necessarily makes the assumption of a stationary population for the study of past peoples because "independently derived archaeological information on the rate of growth is rarely available" (Milner et al. 1989:49). Johansson and Horowitz (1986) suggest that whenever possible population growth rates should be assessed independently from archaeological sources, so that the artificial constraint of stationarity need not be imposed on samples to estimate mortality. Estimates of population size and thus growth have been attempted from settlement data by examining features such the size and area of the living site, number of dwellings and the density and distribution of artifacts and food remains, as well as from ethnohistoric estimates of population size (cf. Hassan 1981; Howells 1960; Schacht 1981). Even when data are available, estimates of population size must often be made through ethnographic analogy, whereby the relationship between population size and material remains observed in modern or historic groups is imposed on the archaeological site. Further, such estimates result in a single point estimate (usually with some bounds of confidence) of population size. Actual growth or decline in population size requires at least two well defined points in time from which estimates can be calculated independently; an often difficult task when archaeological layers fall one atop another.

Population growth is measured by the intrinsic growth rate (*r*) where zero indicates no growth and positive and negative values indicate growth and decline, respectively. Population growth can be considered a discrete, self-contained process, with for example, a high fertility rate resulting in a subsequent age structure with a high proportion of potential parents (Petersen 1975). However, such a process in human populations is ultimately controlled by other factors such as natural resources, socio-economic stability, or kinship and family structure to name a few. Further, growth can be considered an independent variable capable itself of influencing such factors within a population. Malthus contended that continuous population growth continuously exceeded the subsistence limits or carrying capacities of populations. Boserup (1965) extended this hypothesis, arguing that population increase could act as a cause as well as a consequence of changing cultural systems.

This dichotomy is clearly illustrated by the debate regarding the relationship between increase in population size and density, and the shift to an agricultural subsistence base. On the one hand, the advent of agriculture would allow for the support of larger, sedentary groups and thus its adoption may have promoted population growth. On the other hand, a sudden increase in population growth would necessitate the development of a more stable mode of subsistence. Cohen (1977a,b, 1989) for example, following Boserup (1965) applied the concept of population pressure for the development of agricultural practices, a stance supported by other investigators. Cohen's hypothesis unites population growth with Flannery's (1973) "Broad Spectrum revolution", arguing that increasing population growth placed excess pressure on the available food resources, and in response human populations expanded their subsistence base to include less favoured but more widely available foods. This question was the central focus of the edited volume *Palaeopathology at the Origins of Agriculture* (Cohen and Armelagos 1984b) in which osteological evidence for demographic patterns and so-called indicators of stress are presented for several regions of the world. The general conclusions drawn from this volume are that the shift to an agricultural subsistence and economy can be associated with increases in mortality rates and the prevalence of infectious diseases, although these results are by no means consistent (Cohen and Armelagos 1984b; Roosevelt 1984). That reduced mean age of death inferred from various early agricultural populations has been used to support the hypothesis of increased mortality associated with the shift to agriculture (Cohen 1989; Cohen and Armelagos 1984a) is questionable given the preceding discussion As remarked above (pp. 14), for non-stationary populations the effects of changes in mortality are negligible, whereas changes in fertility significantly affect mortality profiles (Johansson and Horowitz 1986; Milner et al. 1989, Moore et al. 1975; Sattenspiel and Harpending 1983). In a recent review of the impact of agriculture Larsen (1995) makes reference to a variety of studies (e.g. Cohen and Armelagos 1984) which have observed lower mean ages-at-death for agricultural populations as compared to earlier hunter-gatherer samples This he notes has been interpreted as a reflection of increased mortality and decreased life expectancy associated with the shift to agriculture. However, given the more recent arguments that mean age-at-death is a reflection of fertility rather than mortality, the observed decline in MAD among agricultural populations is more likely a reflection of their rapid population growth (Larsen 1995). The extent to which fertility and mortality increased or decreased with a shift to agriculture is a key question, which as yet remains unsolved (Howell 1986). However, given the wide range of ecological conditions in which various populations adopted agricultural practices, there may have been a similarly broad spectrum of demographic responses to this shift with respect to mortality and fertility (Johansson and Horowitz 1986).

The two primary concerns with population growth are first, the assumption of a stationary population and second, the lack of objective methods for measuring rates of growth within past populations (Coale 1972; Milner et al. 1989; Moore et al. 1975; Sattenspiel and Harpending 1983; Weiss 1973,1975). In order for a population to conform to the stationary assumption necessary for demographic inferences the growth rate must be zero. Palaeodemographic analyses do not really expect this assumption to be true, especially since changes in composition over time are a central focus; temporal analyses would be meaningless if we truly assumed the intrinsic growth rate was zero over time. Errors introduced by failure of the population to meet stationary conditions will depend on the extent to which the population deviates from the assumed conditions (Gage 1985).

> In nonstationary populations, age-at-death distributions are extremely sensitive to changes in fertility but not to changes in mortality.... Thus, if a population is not stationary — and changing populations never are — small variations in fertility have large effects on its age-at-death distribution, while even quite large modifications of mortality have virtually none (Wood et al. 1992:344).

Acsádi and Nemeskéri (1970) once argued that the long term rate of growth within populations has been very close to zero. Weiss (1975) similarly notes that most animal populations, including humans tend toward an approximate zero-growth equilibrium, with significant deviations often being corrected for through natural ecological processes. Even with the apparent rapid growth in the world population over the last 10,000 years, Hassan (1981) argues that it is likely that intervals of rapid growth in human prehistory were infrequent and easily defined against a general trend of very slow growth. Whether this claim is applicable in the short term with respect to various local populations, which are for the most part the primary focus of analysis for palaeodemography, is difficult to assess (Johansson and Horowitz 1986). Moore and colleagues (1975) attempted to assess the effects of stochastic fluctuations within small populations. Using computer simulations, these authors suggested that since an individual cemetery represents only one of many possible outcomes within a dynamic system, interpretations based on such samples are questionable

Very early on, Weiss (1975) attempted to simulate the effects of various demographic disturbances on mortality samples, noting that the most disruptive event was an excess of births. His premise was much the same as is for this study, noting that in order to make demographic interpretations from a single set of population data, "we need to know the effects... of sampling variation and of major sporadic demographic disturbances..." (Weiss 1975:47). Using the vital rates documented for the Yanomama Indians (Neel and Weiss 1975), a hypothetical population of known demographic rates is subjected to a number of simulated fluctuations and disturbances, by differentially weighting specific age categories. While the approach is simplistic, it nevertheless provided a general overview of the relative influence of various types of disturbances on the demographic structure of the population and the accumulated dead. From his simulations, Weiss (1975) concluded that demographic reconstructions from burial data are not precluded by the occurrence of intermittent fluctuations, and that large cemetery samples can be used with some confidence to represent the general mortality parameters of the living population from which they are derived. In contrast, however, he notes that "a small cemetery always shows more 'noise'" (1975:56).

As observed by Weiss, a population that is undergoing significant demographic shifts should not be assumed to create cemetery samples representing the underlying average death rate (Weiss 1975). A major problem associated with cemetery samples is that they represent an amalgamation of all such demographic fluctuations within the population, over the period for which the cemetery was in use. As a result, "a cemetery may contain the permanent residues of all demographic upsets, as well as its 'normal' deposits, and, it may not reflect the underlying demographic patterns" (Weiss 1975: 54). Thus, the cross-sectional nature of skeletal samples (individuals cannot be divided by date of death) imposes an average or smoothed mortality structure, in which specific peaks or dips in mortality cannot be identified, but which, nevertheless, will be influencing the pattern observed. This concept is illustrated in Figure 2.2 which shows the frequency of deaths per year in a burial population. For this cemetery population an increasing trend over time is interrupted by three distinct peaks in mortality. However, without the benefit of a temporal framework, only the mean number of burials per year can be calculated; a value which does not reflect the changing trend over time, nor the later peaks in mortality. Sattenspiel and Harpending state that for fluctuating birth and death rates (ie non-stationarity) life expectancy and mean age-at-death are not related to one another over periods of a generation or longer. Anthropological studies of small, contemporary populations have supported this. Howell (1979) for example, did not find short-term stationarity in her demographic study of the Dobe !Kung. Weiss and Smouse (1976) on the other hand, argue that skeletal series spanning a duration of a few centuries can likely be considered to have been derived from a living population aggregate that very closely approximates stationarity. This has led several researchers to argue that cemeteries of relatively long duration can be used to assess past demographic patterns.

## *The Great Debate: Palaeodemography on Trial*

The 1980's marked a pivotal point for palaeodemography as a sub-discipline of osteology. While there had been the occasional critique prior to the 1980's (eg. Howell 1976; Petersen 1975a) it was not until 1982 that the great debate over the merits of

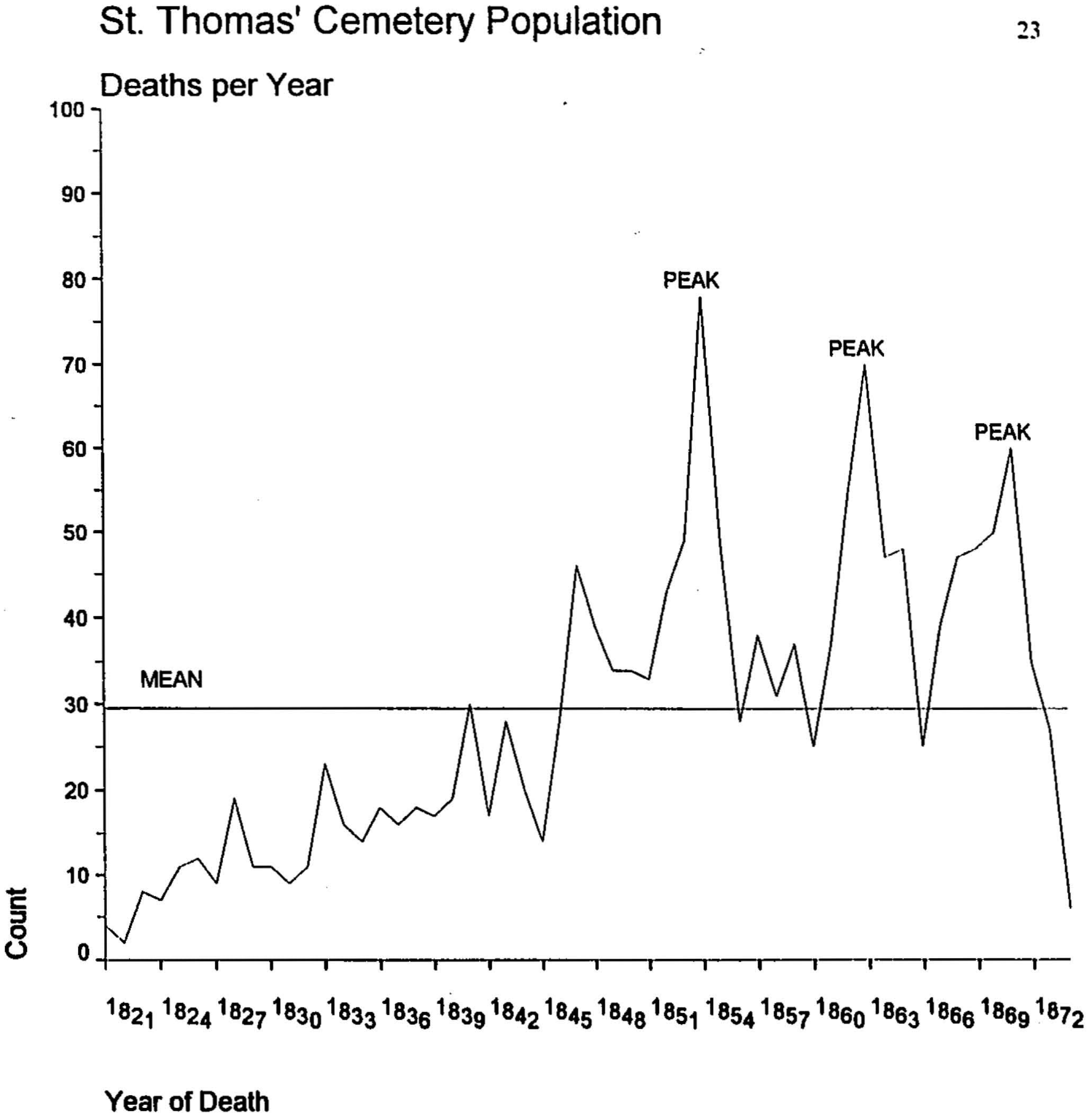

FIGURE 2.2 Frequency of deaths per year in a burial population showing the changes in mortality over time. For this cemetery population an increasing trend over time can be observed with three distinct peaks in mortality. However, without the benefit of a temporal framework, these features are essentially smoothed out, and only a mean number of burials per year can be calculated.

palaeodemography began. Bocquet-Appel and Masset (1982) attacked palaeodemography on two fronts: 1) that age-at-death profiles obtained from prehistoric skeletal samples are artifacts of the age distributions of the reference samples employed for estimating chronological age from human skeletal remains, and 2) there is inherent inaccuracy and unreliability of *all* age estimation techniques because of the low correlation between skeletal age and chronological age. These authors noted that the mean ages for various skeletal stages are a product of both the biological process of ageing and the age structure of the reference population. They further suggested that palaeodemographers assume that age-related changes in the human skeleton are constant through time. A number of researchers (Buikstra and Konigsberg 1985; Greene et al. 1986; VanGerven and Armelagos 1983) replied to this accusation by demonstrating that their skeletal age distribution did not, in fact, mimic the reference population from which the age-estimation technique was developed.

Recognizing that age estimation techniques in skeletal biology are less than 100 percent accurate, palaeodemographic reconstructions of age structures have had to compensate for the possible error, or range of confidence that is attributable to individual assessments. The development of techniques to minimize such error initially followed the simple relationship between the estimate of age attained from a specific skeletal indicator such as the pubic symphysis (Katz and Suchey 1986) or auricular surface of the ilium (Lovejoy et al. 1985b) and the mean age and standard deviation within the reference sample for that indicator. Jackes (1985,1992) has suggested that probability distributions derived using this concept are preferable to previously used methods of smoothing. Such a technique involves recasting an individual into a range of age cohorts based on the probability of the indicator used assigning the individual into each cohort. These probabilities are calculated from the mean and standard deviation of the indicator in the reference sample based on normal distribution theory, and then the skeletal specimen is recast into a 95 percent or 99 percent probability range. However, such techniques necessarily result in some inter-dependency between the mortality sample and reference sample; refinements to the ageing technique associated with improved reference samples would clearly alter the Bayesian distribution of skeletal assessments when recast using the refined indicator- mean age and standard deviation. Jackes recognized this difficulty and remarked that this method "could give us no assurance of accuracy, merely a reduction of inaccuracy" (1992:198).

Konigsberg and Frankenberg (1992) have recently re-opened the wound left by Bocquet-Appel and Masset, demonstrating through mathematical modelling and computer simulations that in fact, Bayesian-like techniques typically used to recast skeletal age distributions do produce biases. When the Bayesian approach is applied to palaeodemographic data it results in "an estimated age distribution which is neither a complete 'mimic' of the reference sample nor completely independent of the reference" (Konigsberg and Frankenberg (1992:239). Further, they demonstrate that when skeletal indicators used to estimate age-at-death in the skeletal sample are completely unrelated to true chronological age then the target and reference sample distributions are identical. At the other end of the spectrum, when an age indicator is completely accurate then for any age class there is *only one* probability equal to one, while those for all other age cohorts is zero. Thus, target and reference samples are completely independent (Konigsberg and Frankenberg 1992). Under these conditions the target sample is estimated with complete certainty. The latter example is theoretical only and is not applicable to skeletal biology since perfect age indicators are unlikely to be available to osteologists and if they were, recasting individuals would be redundant. Using Bayesian techniques in demographic reconstructions results in biased estimates of real age structure, particularly in older individuals, for two reasons: 1) the fact that ageing techniques are less than 100 percent accurate, 2) reference samples do not have a uniform age distribution, and 3) the target and reference samples differ in their age distributions (Konigsberg and Frankenberg 1992). Bocquet-Appel (1986) had previously argued that reference samples should be uniform in their age distribution, although Konigsberg and Frankenberg (1992) note that given the limited availability of reference data for ageing techniques, any method that omits data is not practical.

As a consequence of the bias introduced by Bayesian-like techniques, Konigsberg and Frankenberg (1992) have presented a new method called *iterated age length key* that compensates for the biases associated with Bayesian methods, without the need for a uniform reference sample age distribution. This method, taken from the fisheries literature for estimating the age structure of fish populations from measures of length, uses maximum likelihood estimation techniques to obtain a target sample age distribution most likely (ie having the highest probability) to have been produced by the observed distribution of the age indicator stages used to assess skeletal age (Konigsberg and Frankenberg 1992). Making the assumption of biological uniformitarianism (Howell 1976) the probability of obtaining an individual with a particular developmental stage or indicator state is then obtained from the unknown age distribution of the target sample and the conditional probabilities of indicator states in the reference sample (Konigsberg and Frankenberg 1992). Beginning with an initial estimate of the age distribution of the target sample. the estimated probability of being a specific age conditional of being in a certain indicator state is calculated. This estimation is then applied to the observed distribution of indicator states within the skeletal sample to obtain a new estimate of the target sample age distribution and the process begins again. Re-iteration of this process continues until the estimated age distribution converges[3] (Konigsberg and Frankenberg 1992). Applying this technique to simulated target samples using McKern and Stewart's (1957) pubic symphysis method of ageing, these authors demonstrated that the iterated age length key method provided a much better fit between the estimated and "true" age[4] distribution in the target sample than did simple Bayesian techniques that tended to emulate the reference sample distribution at older ages. Konigsberg and Frankenberg (1992) suggest that, given the influence of the reference sample age structure on skeletal age structure when Bayesian techniques are employed, many past comparative analyses of palaeodemographic reconstructions were likely observing differences resulting from morphometric ageing criteria based on distinct reference samples and not from true population differences. O'Connor and Holman (1995) have recently examined this conclusion for toothwear age-at-death distributions and similarly noted that the maximum likelihood estimation technique did not mimic the reference sample. However, these authors could not test the accuracy of this technique as their target sample was undocumented. The two fundamental problems with employing this technique are 1) the paucity of reference samples

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[3] For a more precise understanding of the mathematics of the process, the reader is referred to Konigsberg and Frankenberg 1992, pp. 239-240.

[4] Observed age distributions were created for the hypothetical target sample by assigning the most probable age indicator stage (pubic symphysis stage) for known age, and then estimating the age-at-death structure for the skeletal sample based on the assigned indicator stages.

with published age-at-death distributions, and perhaps more significantly ii) the lack of a variety of skeletal ageing methods (eg. pubic symphysis *and* auricular surface) which have been derived from a *single* reference population.

The continued debate regarding this issue raises further concern regarding the validity of mortality profiles published by many of the earlier palaeodemographic studies. Konigsberg and Frankenberg (1992) seem to effectively invalidate previously published studies, (many of which would have presented mortality age structures constructed using Bayesian-like techniques) without consideration of the implications. As noted earlier, many of these studies (e.g. Acsádi and Nemeskéri 1970, Angel 1947, 1968; Vallois 1960) have formed the basis for more broad-reaching interpretations of human prehistory such as changes in life expectancy. Ironically, the same authors later suggest (Konigsberg and Frankenberg 1994) that it is these broader questions that palaeodemography is perhaps better suited to answer.

### *A Return to Basics: Methodological (re)-Considerations*

Following these earlier debates, many studies turned to focus on the second issue raised by Bocquet-Appel and Masset (1982): the accuracy and reliability of age estimation methods. Initial studies examined this problem utilizing cadaver samples to test the relationship between estimated age and known chronological age. Later, with the increased availability of archaeological skeletal samples with documented individuals, researchers were able to examine the reliability of these methods.

The accuracy and reliability of age estimation techniques in particular, has been a central criticism of palaeodemography, particularly with respect to the under-estimation of the ages of older adults. While it is not the aim of this thesis to summarize and describe the various morphometric methods employed for age and sex determination from skeletal remains, it is of value to consider briefly the most recent studies of accuracy and bias for such methods. Lovejoy and colleagues (1985) define inaccuracy as the amount of error or difference between the known age and estimated age. Bias signifies the direction or relative under- or over- estimation of the true value (Lovejoy et al. 1985). Specific examinations of the accuracy and reliability of ageing methodologies will not be detailed here, and the reader is referred to the literature for further details (see Aiello and Molleson 1993; Bedford et al 1993; Brooks 1955; Gruspier and Mullen 1991; Liversidge 1994; Lovejoy et al. 1985; Lucy et al. 1995; Meindl et al. 1985b, 1990; Rogers and Saunders 1994; Saunders et al. 1992, 1993; Suchey et al. 1986).

Recognizing the problems with individual techniques for ageing skeletal remains, and following the standard convention of using all possible methods for any single individual, the next problem examined was how to incorporate multiple age estimates for a single individual. Lovejoy and colleagues (1985) have argued for what they term summary ages, which represent weighted averages of various ageing methods to determine an overall estimate of age. This was further corroborated by a second independent test by Bedford and colleagues (Bedford et al. 1993; Meindl et al 1995), despite concerns put forward regarding their test sample size (Fairgrieve and Oost 1995). However, Saunders and co-workers (1992) recently tested this technique and observed that summary age was no more accurate than simple averaging of estimates derived from each morphometric technique employed. On the other hand, based on their research on cadaver samples from the Los Angeles Coroner's Office, Brooks and Suchey (1990) have argued that while multiple methods should be employed whenever possible, averaging is not appropriate Rather, the single method with the smallest age range should be employed.

### *The Second Coming of (Palaeo)-demography*

The primary question is whether skeletal data alone is sufficient for accurate demographic reconstructions of past populations. As early as 1975 Petersen expressed concern over the paucity of evidence from which to make statements regarding palaeodemographic parameters, forcing investigators to extrapolate from models derived from other sources. Coale and Demeny's (1966) classic compendium of model life tables for modern demographic studies was the likely impetus for anthropological demographers to develop model life tables for past populations (eg. Weiss 1973). Weiss (1973) provided model life tables for various fertility schedules based on probability of death, $q_x$. Relating probability of death to life expectancy at age ten years by least squares linear regression and logarithmic regression equations from a variety of relatively contemporaneous populations based on census statistics, Coale and Demeny (1966) produced age-specific mortality rates for males and females presented as regional model life tables. The authors assert that the use of life expectancy at age ten years, rather than birth, is an unbiased general index of differences that can result from fitting model life tables

The use of model life tables in anthropological demography is two-fold. First, it provides a means of assessing or compensating for biased and incomplete data, and second, it allows for the estimation of fertility rates and construction of an initial population at risk — a useful tool for demographic reconstruction from cemetery samples. In the early 1970's Weiss (1973) developed a set of model fertility and mortality schedules derived from ethnographic samples of contemporary hunter-gather societies and prehistoric skeletal samples. Intended as a supplement to these, Roth (1992) provides a list of age-specific and total fertility rates for 14 populations grouped according to mode of subsistence. They represent demographic analogies of prehistoric fertility and assume uniformitarianism (Roth 1992:184). Milner and colleagues (1989) compared mortality profiles from a late prehistoric sample with expected age-at-death distribution derived from vital rates estimated for hunters and gatherers (Dobe !Kung, Howell 1979) and horticulturalists (Yanomamo, Neel and Weiss 1975). As discussed earlier (pp 15), variation in mortality rates produced minimal effects on the overall age structure as compared to variation in fertility rates (Milner et al. 1989). Most investigators agree that demographic statistics derived from contemporary non-Western societies represent an effective means of assessing skeletal age profiles of past populations (Milner et al. 1989; Paine 1989; Petersen 1975; Weiss 1973). On the other hand, given the variety of conditions under which many contemporary populations live, it is difficult to be certain that ethnographic analogies for demographic statistics will always be appropriate. Further, the application of ethnographic estimators to samples for which related sociocultural information is sparse, only serves to compound the problem. However, "comparing data from different groups, understanding the cultural context of the population, and critically evaluating the sources of the data can minimize some of the potential errors" (Hassan 1981:5).

A number of estimators for fertility from mortality profiles have been used (eg Corruccini et al. 1989; Bocquet-Appel 1979; Jackes 1986, 1988, 1994; Konigsberg et al. 1989) the most common of which are outlined in Table 2.2. Jackes (1994) notes that:

> One possible method of comparison of the age structures of archaeological

TABLE 2.2: Population ratios for estimating fertility from mortality profiles.

| ESTIMATOR | FORMULA | REFERENCES |
|---|---|---|
| Crude Birth Rate | $\frac{1}{e_0} \cdot 1000$ | cf Sattenspiel and Harpending (1983) |
| Juvenile Adult Ratio | $\frac{5-15}{20+}$ | Bocquet-Appel and Masset (1977), Masset and Parzysz (1985) |
| Mean Childhood Mortality | mean of $_5q_5$, $_5q_{10}$ and $_5q_{15}$ | Jackes (1986, 1988, 1992) |
|  | $\frac{30+}{5+}$ | Coale and Demeny (1966), cf Buikstra et al. (1986) |
|  | $\frac{20+}{5+}$ | Konigsberg et al (1989) |
| General Fertility Rate | $\frac{B}{♀P_{15-44}}$ | cf Wilson 1985, Pollard et al 1990 |

> groups is based on the assumption that there is a relationship between juvenile and adult mortality, and that age-at-death data within very broad age categories will carry some information about the age structure, and hence fertility rate of the population (Jackes 1994:161).

In her critique of palaeodemographic methods, Jackes (1992) analyses these various estimators by comparison with 18 Model West (Coale and Demeny 1966) life tables. She suggests that, for stationary populations, the juvenile/adult ratio proposed by Bocquet-Appel and Masset (1977) is the best predictor of fertility, having a correlation of 0.9999 with log general fertility. However, for populations that are undergoing growth or decline, the mean childhood mortality and log 20+/5+ statistics are more suitable, having equivalent correlations with log general fertility of 0.9970 (Jackes 1992). Piontek and Weber (1990) have further argued that the juvenile/adult ratio cannot be calculated directly from age-at-death distributions and more reliable information can be obtained from age-specific probability rates. They endorse a coefficient of reproduction proposed by Henneberg (1976) which calculates the proportion of individuals during the ages of reproduction to the post-reproduction ages The basis for this proportion is the argument that the most valuable information on the structure of a mortality sample is derived from the adult mortality structure, not the subadult mortality structure, as most other calculations imply (Piontek and Weber 1990). Of course, the coefficient of reproduction represents a theoretical maximum level of fertility (eg theoretical fecundity), with a population likely to have an actual coefficient lower than the projected (Piontek and Weber 1990). Such discrepancies have led Jackes (1986, 1988) to suggest that the use of both mean childhood mortality and juvenile/adult ratio are best because they can provide additional demographic information regarding population growth (Jackes 1992:216).

As discussed earlier, variation in mortality rates produce minimal effects on the overall age structure of populations as compared to variation in fertility rates (Konigsberg and Frankenberg 1994; Milner et al. 1989; Sattenspiel and Harpending 1986). Paine (1989) proposed a maximum likelihood function that could be used to determine the model distribution most probable to have produced the observed mortality sample.

> The method provides a frame of reference that can be used to identify and describe deviations of a specific data set from a generalized pattern of death. Deviation from such a pattern may be the result of cultural practices on the part of the group studied, unusual biological phenomena such as the impact of epidemic disease, preservations factors at a site, or biases in an archaeological recovery strategy (Paine 1992:156).

The fit between the model and observed mortality distributions can then be assessed by means of a Pearson's $\chi^2$ or likelihood ratio test (Paine 1989). Employing the Coale and Demeny (1966) model West regression coefficients for $q_x$, specific models are produced by changing two variables, gross reproductive rate (GRR) and life expectancy at age ten ($e_{10}$). Once the best model is determined from maximum likelihood estimation, associated model statistics such as crude birth and death rates, intrinsic growth rate and mean age-at-death can be observed, assuming stable population theory. Harpending and Paine (1992) later tested this technique on 180 simulated skeletal samples randomly drawn from hypothetical populations with known demographic parameters and found the model reliable, as compared to other commonly used ratio estimates (eg. Bocquet-Appel and Masset 1977; Buikstra et al. 1986). The reliability of the maximum likelihood technique for estimating fertility was evaluated using two criteria: first, the ratio of the standard deviation of the estimates to the mean birth rate estimate[5], and second, the ability of the method to distinguish between rapidly growing, stationary, and declining populations (Harpending and Paine 1992). The results of their sampling experiments suggested that the juvenile/adult ratio proposed by Bocquet-Appel and Masset (1977) is problematic for samples of less than 100, "especially in stationary or declining populations, [where] there simply are not enough deaths between the ages of 5 and 14 years to overcome stochastic variation" (Paine 1992: 179). Buikstra and colleagues (1986) 1-5/1-10 ratio was similarly influenced by small sample sizes. The 30+/5+ ratio (Buikstra et al. 1986; Coale and Demeny 1966) showed the smallest ratio of standard deviation to sample mean (less than five percent), but did not effectively differentiate between the three levels of population growth. The model life table fitting technique proved effective, even for small samples, being able to differentiate between the three population growth types, and had a

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[5] The magnitude of random variation is measured by the ratio of the standard deviation to the mean (Brown and Rothery 1993).

relatively low mean standard deviation to mean birth rate estimates of about 14 percent overall (Paine 1992).

Hazards analysis attempts to examine the probability or incidence of an event occurring (eg. death, birth, infection etc) during a time interval, given its observation of occurrence previous to that interval. It is not within the scope of this analysis to review the mathematics of hazards analysis, but both Gage (1990) and Wood and colleagues (1992b) provide excellent detailed presentations and applications of hazards modelling. Thus the underlying goal of hazards analysis is to "make inferences about underlying hazards from observations on the timing of events" (Wood et al. 1992b:46). Although a potentially powerful tool for anthropological and, particularly, palaeodemographic analyses, model life table fitting techniques are still subject to potential biases resulting from the use of inappropriate model populations (Gage 1988). As such, Gage (1988, 1989,1990) has proposed the use of a hazard model of age-at-death patterns that can be fitted to survivorship, death rate and age structure data. This technique provides a method of estimating age-specific mortality and fertility directly from anthropological data, and will smooth demographic data from a variety of populations without imposing a predetermined age structure (Gage 1988). The differences that can result from fitting model life tables and the hazard model presented were observed by Gage (1988) in a comparison of Yanomamo data. Gage argues that these potential differences, which likely result from the application of an inappropriate model population, can lead to improper or erroneous conclusions regarding the population under study. Gage (1990) later constructed a new set of model life tables using hazard models, for which there were no equivalent corresponding models in Coale and Demeny (1966), noting that the greatest variation between these models resulted from differences in adult mortality. This is an important conclusion, considering Jackes' (1992) recent claim of the importance of accurate adult enumeration in palaeodemographic studies.

Beyond this, more complex stochastic modelling has been employed on occasion to examine demographic features from skeletal samples. Howell's (1982) analysis of the Libben site using AMBUSH (Howell and Lehotay 1978) is perhaps the best known example of this type of analysis. Based on the mortality structure and assumptions about fertility of this large skeletal sample, Howell observed that serious social consequences would have been occurring within the Libben population for the demographic structure implied from the skeletal sample to have developed. Such problems included unstable marriage patterns and a two- rather than three human generation, both as a result of abnormally high adult mortality, a high proportion of orphaned children and a high dependency ratio[6] (Howell 1982). This led Howell to conclude that either biosocial interactions in prehistoric societies were very different from those observed in ethnographic populations or that the sample was biased in its representativeness of a complete mortality sample. The latter conclusion was similarly reached by Paine (1989) who observed a poor fit of any model life table schedule to the Libben skeletal sample.

Roth (1992) notes that stochastic microsimulations of the above nature hold the most promise for palaeodemographic studies as they simulate demographic parameters (birth, death, marriage, childbirth etc) for individuals on an annual basis, with subsequent runs of the

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[6] As Petersen (1975b) notes, age structure can be divided into three primary categories: dependent children (under 14 years), dependant aged (usually 60-65 years or older) and the active population (all others). Thus the ratio of dependency is calculated by the sum of the first two divided by the active population.

same initial parameters producing an infinite number of probable outcomes. While Paine's model life table fitting technique can be used as a simple method of observing the effects of changing population parameters on mortality structure, for more rigorous exploration of populations, controlling for more specific biocultural factors such as migration, resources, social structure, marriage patterns etc., other more complicated methods of simulation are required. However, despite the availability of stochastic simulation software (e.g. SOCSIM, Hammell 1976; AMBUSH, Howell and Lehotay 1978), anthropological demographers have been slow to take advantage of this technique (Roth 1992).

### *Back to Basics: The Real Issue at Hand (Representativeness)*

The issue of representativeness is well known in the literature and its importance for palaeodemography is clear by such statements as "The representativeness of skeletal series is a crucial factor in palaeodemographic studies" (Paine 1992:182) or "The greatest potential for error in demographic reconstructions based on skeletal remains lies in the representativeness of the sample" (Ubelaker 1989:135). While Ubelaker has noted that any recognizable bias should be accounted for in an analysis, a continuing problem for palaeodemography is that the "representativeness of skeletal samples cannot be determined" (Lamphear 1989:186).

As early as 1971, Lovejoy attempted to address the issue of representativeness for palaeodemography by suggesting techniques used in modern demography to compensate for census error within skeletal samples. Lovejoy proposed the use of straight forward statistical techniques to test the hypothesis that the core (accurately aged and sexed) and peripheral (fragmentary or incomplete) segments did not significantly differ from each other in various parameters such as sex ratio, age distribution etc. While perhaps too simplistic in that it assumes no differential factors affecting preservation, this represented the first real attempt at addressing the issue of representativeness in skeletal biology.

In the early 1980's Piontek and Henneberg (1981; cf Piontek and Weber 1990) compared the age structure for a skeletal sample (n=550) from a Medieval Polish cemetery (AD 1350-AD1650) to 19th century death registers for the same parish. While these sources are not directly comparable, based on the differences in life expectancy observed between the prehistoric and historic samples, they concluded that there was under-representation of juveniles and infants in the skeletal sample.

With the more detailed study of historic cemetery skeletal samples, researchers have begun to test the representativeness of their samples by comparing the mortality data derived from the skeletal sample to the documentary mortality data associated with the cemetery from which the sample was drawn. One of the first studies of this nature was undertaken by Walker and co-workers (1988). These authors compared the mortality profiles based on burial records to the skeletal remains excavated from the 19th century Purisima Mission Cemetery, California. They observed serious discrepancies between the two sources, concluding that differential preservation by age was a significant contributor to bias in the skeletal sample. However, the skeletal sample represents only two percent of the total interments within the cemetery. Given that the state of preservation in general was poor, differential preservation does seem a reasonable factor, but the sample size should not be entirely dismissed as a biasing factor. Walker does suggest that the "sample size per se, however, does not explain the difference in ages" (1995:33) noting that it is unlikely that a random sampling of burials would deviate as significantly from the expected distribution as they observed at Purisima. Saldavei and Macchiarelli (1994) arrived at a similar conclusion in their analysis of several series of Italian skeletal samples, stating that increased sample size does not always result in improved representativeness.

In 1989, Lamphear followed the lead of Walker and co-workers comparing skeletal age profiles against vital registration data for a 19th century poorhouse cemetery located in Rochester, Monroe County, New York. She found no significant differences in life expectancy, survivorship or age-at-death distribution between the two samples. Lamphear argued that this lack of difference was not simply the result of sample size and concludes by saying that her results show that palaeodemography *can* produce results similar to historical data. She is not, however, stating that palaeodemographic analyses can provide information regarding the once living population. For this study, no attempt is made to validate or gauge the accuracy of the historical records themselves, and thus the significance of her findings for palaeodemographic studies in general is difficult to ascertain. She does note however, that "...it cannot be assumed that the age at death structure of either the skeletal or vital registration sample is an accurate representation of the age structure of the living population..." (Lamphear 1989:190). Analysis of the Monroe County Almshouse Cemetery continues, and more recently the issue of representativeness has been further explored by Sirianni and colleagues (Sirianni and Higgins 1995; Higgins and Sirianni 1995). Of the 300 skeletal remains excavated from Highland Park, 254 are included in their comparisons to associated documentary records. These authors examined the representativeness of the skeletal sample to both the cemetery population (as inferred from the Brighton's Town clerk records which lists the individuals who died in the Almshouse between 1847 and 1850) and to the Mt. Hope Cemetery population as inferred from their burial records. In both cases, a similar pattern of age-at-death profiles was observed for the skeletal and historical samples with minor differences attributed to the imprecision of adult ageing techniques (Sirianni and Higgins 1995).

Similarly, Grauer and McNamara (1995) compared the demographic profiles observed from the Dunning Cemetery in Chicago with both historical records of mortality for Chicago, and to the Monroe County Poorhouse cemetery (above). The Dunning cemetery sample consists of 120 skeletons, 106 of which have ages-at-death assigned. Kolmogorov-Smirnov tests suggested that the cumulative mortality profile from the skeletal distribution was not significantly different from the federal and local health records for that time. Further comparisons to the Monroe County cemetery sample also revealed no significant differences. These authors concluded, somewhat cautiously, that "if the similar proportions of subadults to adults in the living and cemetery populations are used as a measure of similarity, then" their findings suggest that the Dunning skeletal sample is an adequate representation of the living population in late 19th century Chicago (Grauer and McNamara 1995:99).

Scheuer and Bowman (1995) did not find such promising results in their comparison of a skeletal sample and associated burial records for the St. Bride's Crypt. This 18th to 19th century sample consists of over 200 adult and 25 subadult documented skeletal remains buried in the crypts of St. Bride's Church, Fleet Street, London. Scheuer and Bowman (1995) observed that the demographic distribution of the skeletal series did not adequately represent the total burial population recorded in the documentary evidence. These authors recognize that the excavation of the skeletal sample likely contributed to the bias observed, but note that poor recording has made it impossible to assess the factors responsible for the biases. They conclude by stating that "the skeletons that belong to a particular sample consist solely of the bones of that collection and may well not be representative of either a smaller or larger group to which they appear to bear a relation" (Scheuer and Bowman 1995:65).

Saunders and co-workers (Saunders, Herring and Boyce 1991, 1995; Saunders et al. 1995) have done extensive work on the issue of representativeness with an historic 19th century pioneer cemetery sample from Belleville, Ontario. Initially, the relative representativeness of the skeletal sample was assessed by comparing it to the church burial records. The skeletal sample of about 600 graves was observed to represent 37 percent of the overall interments recorded for the 53 year duration of the cemetery, 1821-1874 (Herring, Saunders and Boyce 1991). Comparisons between the skeletal sample and parish burial records for St. Thomas' Anglican Church reveals that the demography of the skeletal series can closely approximate the known demography of the cemetery as a whole, even though the skeletal sample represents only one third of the total interments. When comparing the adult and subadult proportions between skeletons and records no significant differences were observed, although the proportion of infants (less than one year of age) to all others shows a significant (likelihood ratio $\chi^2 = 8.79$, $p=0.003$) over-enumeration in the skeletal series (Herring, Saunders and Boyce 1991; Saunders, Herring and Boyce 1995; Saunders et al. 1995). This is attributed by the authors to a temporal bias in the excavation sample in that the excavated series is biased towards the later period of the cemetery's use, and it is known that the proportion of infant burials in the cemetery increased with time (Saunders, Herring and

Boyce 1995; Saunders et al. 1995). Despite this observation, the distribution of infant ages-at-death within the skeletal sample does appear representative of the total interment sample (Saunders et al. 1995). More extensive demographic comparisons were made through comparisons of life tables generated from each of the samples using LifePro software (Sawchuk and Anthony 1990). The results of these comparisons suggest that the demographic parameters inferred from the skeletal sample (eg. life expectancy) are significantly different from that generated from the burial records (Saunders et al. 1995). This disparity led the authors to question the validity of either demographic parameters, both of which produced low life expectancy at birth values (19.4 and 26.5 years for the skeletal and record samples respectively). Subsequent comparisons to Coale and Demeny (1966) model life tables showed consistent departures from the expected patterns (Saunders et al. 1995). This observation is of particular importance since it demonstrates that even when a skeletal age-at-death distribution appears to be representative of its parent cemetery population, demographic data inferred from the sample may not be equally representative

### *Conclusions*

This chapter has outlined the methodological and theoretical evolution of palaeodemography as a discipline. As to methodological developments, it is clear that the emphasis in palaeodemographic reconstructions has shifted considerably. While specific methodologies for age and sex determination remain an important facet of analyses, there has been more emphasis towards modelling and understanding the distributions estimated from mortality samples. In the 1970's the fundamental tool used in palaeodemography was the life table with the calculations and estimates derived from it used to make interpretations regarding past populations' structure. Direct use of the life table is less common today, with most investigators attempting to assess how mortality samples differ in observed age and sex structure using model mortality samples generated by various model populations and vital statistics; there is less emphasis on attempting to describe the data and more emphasis on trying to understand the biological mechanisms responsible for or most likely to have produced the data. Freedman (1985) once criticized "social scientists" for applying mathematical models to describe data rather than, as researchers in the natural sciences do, applying models to examine the behaviour of the process being investigated. Often the purpose is to "fit a curve to the data, rather than figuring out the process which generated the data" (Freedman 1985:348). This is clearly no longer the case in palaeodemography. Gage (1990) has noted that mortality is affected by both endogenous and exogenous factors and that most studies of mortality structure examine only one of these aspects. Recently however, modelling techniques have been applied by many investigators who are interested in examining populations from a total biocultural perspective, encompassing a variety of biological and cultural factors that contribute to the mortality structure of a population. In particular, the application of hazards analysis to anthropological demography in general, represents a powerful tool for the development and testing of etiological models of the biological processes associated with birth and death (Wood et al. 1992b). Howell's (1986) review refers to the "Bad Old Days" of anthropological demography but is already optimistic about the future of these studies given the methodological improvements in palaeodemographic analysis in the mid-1980's. I would argue that palaeodemographic methodologies have improved dramatically in the last half of the 1980's and the beginning of the 1990's with powerful modelling techniques for analyses available to researchers to examine both the quality and implications of data drawn from archaeological sources.

Regarding the theoretical developments in palaeodemography, the major question remains whether mortality data alone is sufficient to reconstruct past population dynamics. From the above review three key points have been identified regarding this question. 1) the primary theoretical issue that impedes demographic reconstruction of past populations is the failure of samples to meet the conditions of stationarity, 2) mean age-at-death profiles derived from cemetery populations are in fact related to population fertility patterns rather than mortality patterns, an observation that is not necessarily intuitive, and 3) the issue of representativeness has re-emerged in palaeodemography, with a variety of studies beginning to question or test this assumption. The first observation is applicable to all demographic studies and therefore not unique to studies of past populations. However, violation of stationarity remains perhaps the single most difficult hurdle for studies to overcome. A number of investigators have attempted to understand how demographic reconstructions are affected by various disturbances and fluctuations. Population growth in particular, whether related to internal growth or the net effects of in-migration and out-migration is of particular importance for making accurate interpretations of past population dynamics. As Moore and co-workers (1975) note, correction for changing cohort sizes within a stable population is not difficult, however estimating growth rates is far more difficult. While some mathematical techniques have been presented to compensate for this problem (eg. Gage 1988) they remain, for the most part, only a small segment of the studies being presented. Criticisms of population biology research usually stem from the premise of a closed system that is unaffected by external forces. Ironically, palaeodemographic research necessarily begins with such an assumption; one that researchers do not expect to be true but which is required to utilize the resultant relationship between mortality and age structure for estimation of other vital statistics. Second, there is now a consensus among researchers that changes in mean age-at-death within skeletal samples are more a reflection of changes in fertility than mortality rates within the population. Clearly then, interpretations of differences in mean age-at-death between samples are no longer simple. Consideration of a variety of factors that contribute to both the mortality and fertility experiences of the population should be made to prevent overly simplistic explanations of the observed differences from being made. Finally, the issue of representativeness has re-emerged within the osteological literature. I would argue that the assumption of representativeness is perhaps the most important of the three for skeletal analyses because it does not matter whether the population was stationary or if mean age-at-death reflects mortality or fertility rates if the sample in question is not representative of some portion of the population.

In order to make valid interpretations regarding past health, researchers must acknowledge the presence of biases in the data, and unknown factors regarding the population such as differential susceptibility to disease. Potential biases in age and sex distributions can and should be addressed by careful examination and testing of the data to model mortality samples (Paine 1989). Skeletal distributions can also be compared to ethnohistoric age- and sex- structures as have been documented for developing countries (Waldron 1994). Grauer (1989, 1991) suggests that expectations of population health should be formulated from documentary evidence and then compared to skeletal observations of health. When the two agree one can be more comfortable with interpretations based on the skeletal evidence. If however, the observed and expected do not conform, further exploration of possible reasons is warranted (Grauer 1989). With the recent availability of more skeletal samples with associated historical records, skeletal biologists have begun to attempt to quantify representativeness by comparing the two sources of mortality data. While such comparisons are not without their difficulties[7], these studies mark the beginning of a progressive trend in skeletal biology in general toward a critical re-evaluation of the fundamental assumptions that govern many of our analyses.

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[7] The most crucial being that some investigations have, perhaps erroneously, assumed that the historically documented mortality structure to be representative of the living population. A variety of factors, including but not limited to the loss of records, periods of underrecording, failures to register, a long period of time between birth and baptism or rapid changes in the social or economic structure of the community, all act to potentially bias historical records of vital events (Lee 1977, Willigan and Lynch 1982; Wrigley 1977).

# CHAPTER 3

## REPRESENTATIVENESS

### *Introduction*

Chapter 3 examines the concept of representativeness for skeletal biology. While beginning with a brief review of the difficulties in defining the term *population* for skeletal biology, a hierarchical sampling model is presented which represents the various stages of sampling that a skeletal series can be considered to have been subject to. Associated with each transition is a filtering process which may result in the biasing or complete loss, of data from the sample. Having presented this model, a survey of the types of factors operating at each of these levels in provided. The chapter concludes with a summary and brief discussion of the implications of sampling bias for skeletal biology.

Sokal and Rohlf (1987) state that a frequent misapplication of statistical techniques is the failure to explicitly define the population. Therefore, before making statements regarding the demographic structure of a particular population, a clear definition of who constitutes the population is necessary. Petersen (1975a) notes that since archaeologists cannot define the population under study in the same terms as a modern demographer, that the term is used loosely to refer to a breeding group. The population in palaeodemography refers to the *contributing* population for a mortality sample, which may or may not represent all of the regional or geographic population surrounding or associated with the original burials. Whether, in fact, mortality samples adequately represent interbreeding biological populations or even temporally ordered lineages, is difficult to assess (Cadien et al. 1974). Boddington (1987) attempted to address this issue and defined the following levels of "populations" with respect to demographic reconstruction from cemetery samples. First is the *local population* living in the area or region served by the cemetery. Second is the *contributing population*, a subset of the local population, which is buried in the cemetery, and third is the *assessed population*. The latter is in turn the subset of the contributing population that survives deposition, post-depositional decay, excavation processing and curation and successfully yields age and sex data upon examination (Boddington 1987:181).

Excavated burials can be seen on several distinct levels. First, on the higher level, the cemetery as a whole is hoped to be representative of the living population from which it was derived. However, since we rarely have the opportunity to excavate an entire cemetery, we are forced to work from a secondary level, whereby the excavated remains represent a sample of the cemetery, which in turn is also hoped to be representative of the living population. Restricted by funds, time or legal and ethical responsibilities, the excavation of a cemetery site may in fact only be partial (cf. Goldstein, 1995; Ubelaker, 1995). In fact, another level, called an observable sub-sample, can be recognized when one considers that, as a result of differential preservation, not all individuals within the skeletal sample are available for analysis.

This difficulty brings us to the concept of random sampling and its application in cemetery archaeology. In order to attempt to compensate for possible sampling biases, the area of interest can be randomly excavated (cf. Nance 1990, 1994), although in reality this is often impractical. Archaeological excavation of human remains often occurs as a result of accidental discovery, usually under threat of destruction by modern commercial contractors. As a result, the archaeologist can only sample the area which is at risk of destruction. If cemeteries developed randomly through time, then there would be less concern regarding the excavation of a non-random area. However, cemeteries tend to develop within a non-random framework and often the bias within this framework does not remain constant throughout the duration of cemetery use, nor is the patterning of bias constant between different populations.

To elaborate on this slightly, it has been documented that among some native North American groups, individuals who died from certain causes of death, such as suicide or drowning, were not included in the cemetery. Similarly, stillborn infants were often omitted from normal burial practices (Kapches 1976; Saunders and Spence 1986). In Europe, we know that the development of the church cemetery initially followed a status trend with wealthy, high status individuals being buried within or just outside of the church while those of lesser wealth and status were buried at greater distances from the structure (Ariès 1981). Other factors also affected the development of the cemetery. For example, the placement of stillborn and infant deaths in a separate area may have begun for religious reasons related to whether the child had been baptized, but likely continued to occur within later times for economic reasons (ie. it is more feasible to place all the small plots together than to have them intermixed with full sized graves) This practise is still reflected in municipal cemeteries today with infants often buried in what is termed the "unrecorded area" of the cemetery (of course, these burials are in fact recorded in cemetery or church documents). For a final example, I refer to the complex developmental history of a large municipal cemetery in Hamilton, Ontario. This cemetery of over 70,000 interments began as an unmarked grave for eight soldiers executed as traitors in 1814, only later to become the municipal cemetery for the city of Hamilton. Within its borders are the graves of the wealthy, some in standard plots marked by prestigious stones, others in one of three communal mausoleums; and of the poor, including children from the Hamilton orphanage. In addition, there are at least two mass graves, one marked and the other not, the burial sites of hundreds of victims of cholera in the summer of 1854 (Elliot 1993).

Clearly the task is difficult for the skeletal biologist attempting to formulate an understanding of past peoples based on mortality samples that are created within this non-random framework. A skeletal sample can be tested for its relationship to the total cemetery population by using any number of comparative statistical methods which provide a probability value that any differences observed are due to chance alone. For example, age-at-death profiles can be evaluated by chi-square tests to demonstrate whether there are significant differences between the skeletal sample and the complete cemetery. Unfortunately, while projects for which skeletal samples and associated documents for the cemetery are growing (eg. Walker et al. 1988; Lamphear 1989; Grauer 1995; Molleson et al. 1993; Saunders and Herring 1995) such data remain relatively sparse. Hence, for those who only have a skeletal sample, determination of the bounds of representativeness within a sample is difficult.

### *From Living to Dead: A Model for Sample Transition*

Ultimately, all research in skeletal biology revolves around frequency data; the frequency of age, sex, pathological lesions, etc. While researchers do not expect that the sample will represent the population in absolute numbers, the fundamental assumption governing the analysis and interpretation of skeletal samples is that: *the patterning of any specific parameter in the skeletal sample is the same, in terms of distribution and patterning, as the cemetery as a whole, and in turn the living population that contributed to that cemetery.* At a very basic level, we must consider the relationship between the individual, the sample and the population. If we are to make inferences about the latter from the former two, then a clear understanding of how they are related and to what extent the sample represents the once living population is necessary. Figure 3.1 presents a hierarchical sampling model for understanding this assumption. At the top, level I, is the living population, and at the bottom, level V, is the observable skeletal series. In this model any lower level can be considered a sample while any level above it a population. Thus the cemetery (III) is a sample of the living population (I), but similarly the cemetery may be the population from which the skeletal sample is drawn.

The transition between levels in the model will result in the differential filtering of samples. The filtering of samples between levels can be stated to be the introduction of biases or removal of information from the data set such that it no longer accurately reflects the populations from which it was drawn. There are four types of filters (biological, cultural, environmental, and methodological) that act on skeletal samples, all of which have been addressed in various manners and under a variety of terms within the literature (Nawrocki

I. **Living Population**
↕ Biological Filter
II. **Mortality Sample**
↕ Cultural Filter
III. **Cemetery Sample**
↕ Environmental Filter
IV. **Excavation Sample** ↕
↕ Methodological Filter
V. **Observable Skeletal Sample**

FIGURE 3.1: Sampling hierarchy in skeletal biology.

1995; Paine 1992; Saunders and Hoppa 1993; Waldron 1987; Wood et al. 1993). The transition between I and II is unique from all others in that the two sets are independent of each other with death acting to remove an individual from I to II. The primary filter operating at this level is biological mortality bias — that is, the processes which result in death also affect the various parameters to be examined.

While the basic assumption in skeletal studies is that the observable skeletal series (level V) can be considered representative of the living population (level I), we can argue that if there are significant differences between levels V (the skeletal series) and III (the cemetery) then there is no reason to assume that the skeletal sample is representative of the living population. While this is true of the relationship between any two levels in the model, given that the lower three levels are the least difficult to quantify, testing this hypothesis (that being representativeness between two levels) is most readily accomplished at the lower levels of the model.

The transition from one level to the next in the model proposed in Figure 3.1 can act as a filter so that the subset may not be representative of the contributing set. Within the model, any level lower on the hierarchy can be considered a sample of a population represented by a higher level. Thus, the mortality cohort is a *sample* or subset of the living *population*, and in turn the cemetery is a sample of the mortality population. This may be extrapolated all the way to the observable skeletal series which is a sample of all of the higher levels, having been filtered or become distorted with each transition between levels.

### *Filters*

A number of taphonomic models have been proposed for the alterations that occur to skeletal remains once they have been deposited (eg. Waldron 1987, Nawrocki 1995). For all models "each subsequent category is generally accompanied by a loss of information, with the successive modification or complete removal of elements from the assemblage" (Nawrocki 1995:50). Nawrocki (1995) identified three major classes of taphonomic change for skeletal samples: environmental or external factors such as climate and animals, individual factors such as body size and age, and cultural factors such as mortuary practices. Nawrocki (1995) states that with a few exceptions, cultural factors are the most important for human skeletal remains.

Paine (1992) notes four major factors that can bias a skeletal sample. These are 1) differential recovery based on treatment of the dead by the population, 2) differential preservation, 3) infant under-representation as a factor of archaeological strategies or methods, and 4) bias in age estimation techniques. Waldron (1994) identifies a similar model which entails four extrinsic factors and one intrinsic factor that contribute to sample bias in skeletal biology. This model, shown in Figure 3.2, presents four extrinsic factors which tend to reduce the size of the skeletal sample from its original population. They are: i) the proportion of individuals who die and who are buried at the site under study, ii) the proportion of those buried that survive to be discovered, iii) the proportion of those that are in fact discovered, and iv) the proportion of those that are excavated (Waldron 1994).

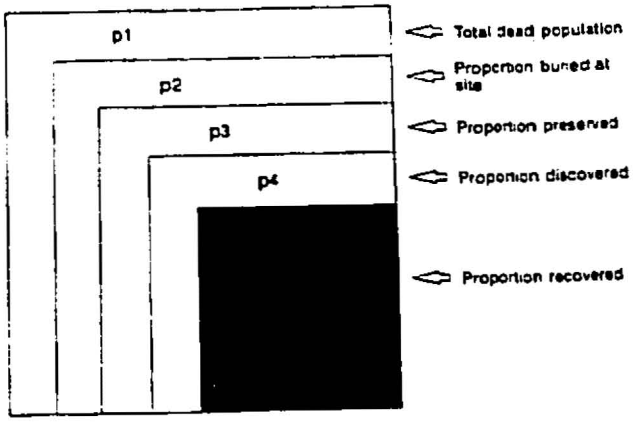

FIGURE 3.2: Model proposed by Waldron (1994:13, Figure 2.1) showing the reduction in skeletal sample size at various stages.

> The magnitude of the proportions lost at each stage (p1-p4) will vary one from the other in a manner which will certainly not be constant and may not be known, although there is a better chance of estimating some than others...(Waldron 1994:12).

Separate from this 4-tiered model, Waldron (1994) identifies one intrinsic factor that affects the relative representativeness of a sample to the population, which has been defined as biological mortality bias (Saunders and Hoppa 1993) or the fact that we are dealing with distributions of non-survivors. These categories can be very broadly placed into the filter scheme described in Figure 3.1. The first is cultural and relates to the transition from the living to the dead, the second is an environmental filter between the cemetery sample and the skeletal sample, and the final two are methodological biases between the cemetery sample and the observable skeletal sample. It is of interest to note that Paine suggests infant under-presentation is a result of methodological problems rather than the traditional preservation problem, a conclusion that has been supported in recent years by other authors (Hoppa and

Gruspier 1996; Saunders 1992).

To re-iterate, the filtering analogy may, in the most general sense, be described as the introduction of biases or removal of information from the data set such that it no longer accurately reflects the populations from which it was drawn. Recently, Saunders and Hoppa (1993) described this problem in terms of mortality bias — that is, biases in a sample that are a direct result of the sample being a mortality cohort as opposed to a living cohort. Although they focused specifically on biological mortality bias with respect to studies of skeletal growth and development, they also recognized the impact of what they termed cultural and environmental mortality biases. Finally, a fourth and final filter or biasing level can be added: methodological biases that affect the representativeness of the observable skeletal series as compared to its excavation population. While the four types of filters are not unique to any one transitional stage in the sampling hierarchy, each operates primarily (but not exclusively) between the levels described. Environmental and methodological filters are perhaps prone to operating at both the cemetery-excavation and excavation-observable series level since preservation affects both recovery and analysis, and both excavation and analysis have their own methodological protocols. For example: while a lack of preservation may prevent a skeleton from being excavated, the techniques used to excavate may also result in missing some skeletal remains, intentionally or otherwise. Similarly estimation of age from a skeleton may be biased because the method applied is not 100 percent precise and/or because the method requires analysis of a feature (eg pubic symphyseal face) that is not observable.

### *Biological*

Biological mortality bias has been the focus of most theoretical studies of representativeness. Here, researchers address the issue of whether the mortality cohort is intrinsically biased because it is dead. Demography and palaeopathology have been the primary areas of focus in the past. Biological mortality bias represents the "physiological and morphological difference between those who die and those who survive" (Saunders and Hoppa 1993:129). Observable biological traits that may be biased in mortality samples include age, sex, and pathological lesions, to name a few. Hence there may be selective observation of each of these in the mortality sample as a result of differing prevalence within the living population. There has been much debate regarding the biasing effects of mortality, particularly with respect to palaeopathological studies.

Wood et. al (1992) brought this issue to the forefront of theoretical concerns when they reminded us that prevalence of disease within a mortality sample is biased as a result of selective mortality and differential susceptibility among the living. There are two primary issues related to the idea of selective mortality. First, investigators will over-estimate the prevalence of specific diseases in the living population since skeletal data, like clinical data, does not "constitute a representative sample of the entire population at risk" (Wood et al. 1992:334). Thus skeletal samples do not represent all susceptibles for a given age cohort, but only those individuals who have died at that age. For example, five-year old individuals in the skeletal sample represent only those five-year olds who died and not all of the five-year olds who were alive in the population at risk; other susceptibles who survived, went on to contribute to older mortality cohorts (Saunders and Hoppa 1993:128). Whether the evidence for disease processes in a mortality sample accurately represents the real prevalence of infectious agents in the living population during the past is thus problematic.

Two factors affect the prevalence of skeletal lesions in an archaeological sample beyond its original prevalence in the living population. The first is the interaction between the frequency of the indicator and causes of death, and the second is the effect of age and/or sex on the indicator as it interacts with age-specific death rates (Saunders and Hoppa, 1993:129). Wood and colleagues also recognize that disease prevalence is further under-estimated because of the small portion of infected individuals that will actually manifest skeletal lesions. They state, quite rightly, that there is no reason to assume the two opposing factors will cancel each other out. Second, in order for more complicated modelling and simulation of disease processes, there is a need for an accurate representation of the total population at risk, an inadequacy that has continually plagued population reconstructions from skeletal data. The second important issue raised by Wood and co-workers (1992) is that of hidden heterogeneity of risks. Hidden heterogeneity refers to the unknown composition of individuals of varying degrees of susceptibility within a skeletal sample. Palaeopathological interpretations of health assume that host resistance and environmental conditions are constant and therefore related to cultural differences (Goodman et al. 1984a). Further, it is argued that disease prevalence inferred from skeletal lesion frequencies can be compared between skeletal samples if the samples have comparable cause of death distributions (Cohen 1989). Wood and co-workers, however, strongly urge palaeopathologists to reconsider this supposition and critically examine the concepts of differential risk and susceptibility to disease and death in population samples. This problem, associated with demographic analyses in general, and not restricted to archaeological samples, is the result of many factors including genetics, temporal trends in health, differential socio-economic status, or other environmental variation (Goodman et al. 1984b; Wood et al. 1992). As a result of these many factors, hidden heterogeneity of risk refers not only to differential risk between individuals within the population, but also within individuals. Thus, there is differential susceptibility to infection, differential risk of infection leading to disease (e.g. carriers may transmit disease but will not manifest the symptoms), differential risk of a disease leading to skeletal lesions and differential risk of a disease (with or without lesions) leading to death. Further, these risks change with the life experiences of the individual and the population. For example, an individual is more susceptible to a disease that he or she has not been in contact with in the past. The same can be said for the population as a whole (virgin soil epidemics are the most devastating because of this). However, having survived an infection, both the individual and the population are often at reduced risk of its effects in the future, a trait that may or may not be inherited by new generations within the population.

Wood and colleagues (1992) illustrate the concept of hidden heterogeneity by a hypothetical population, socially stratified with three distinct levels. When exposed to a specific pathological load, the middle level experiences a moderate amount of the disease with most individuals surviving through the chronic condition and thus manifesting skeletal lesions. In contrast the upper and lower levels do not manifest skeletal lesions; the upper level because other mechanisms (e.g. increased nutrition, better sanitation etc.) prevent the pathogen from taking hold, the lower level because they are more likely to die during the acute phase. Thus, based on the analysis of the skeletal remains there appears to be only two distinct levels of health within the "population," while there are in fact three. Membership in each of these segments is associated with a varying degree of susceptibility, some of which affect the distribution of the skeletal lesions similarly, but result from different biocultural mechanisms (eg. hygiene, health care, availability of food and fresh water etc). This problem led Ortner (1991) and others to state that those individuals that exhibited evidence of chronic infectious disease were in fact healthier or, as Wood and colleagues (1992) would argue, less frail, than those members of the population for which no evidence of chronic disease exists. It is not unreasonable to further extrapolate this model to individuals within each segment of a population and with respect to a variety of ailments, a proposition that results in a very complicated relationship between true health (as defined by an investigator) and apparent conditions of health as inferred from skeletal samples.[8] There is little doubt then, that equating the frequency of skeletal lesions observed in an archaeological sample with the prevalence of the disease in the population is often dubious at best. A possible solution to this problem is to simply use those frequencies as a gauge of relative mortality within the population associated with a specific disease (Cohen 1989) although this raises the question of to what degree the absence of skeletal lesions constitutes an absence of the disease. Further, without an understanding of the interaction of various diseases with each other (there is no reason to assume that a population will suffer from single, independent disease loads) interpretations of health within the population can become too simplistic and unrealistic[9].

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[8] While having many possible definitions, Dunn and Janes (1986) define health as "the capacity of the individual or group (or society) to profit from experience and respond to insults — physical, biological, social, and psychological" (Dunn and Janes 1986: 30, note1). However, most osteological studies do not define the term health, which is implicitly assumed to represent some relative quality of life, but rather focus on the quantification and interpretation of various proxies for health (e.g. patterns of long bone growth, prevalence of bony lesions, mean age-at-death etc.)

[9] The interaction between tuberculosis and leprosy is perhaps one of the best illustrations. Both are caused by the mycobacterium bacillus and both can produce diagnostic skeletal lesions at the later stages of development. Cross immunity between the two diseases was proposed in the early 1950's; an interaction that has since been applied

### *Cultural*

Cultural factors which act to bias mortality samples operate primarily between levels II and III (see Figure 3.1), that is when the dead are transferred from the total mortality sample to the cemetery sample. Factors such as religion, age, sex and social status will all act to bias the original mortality sample into what will eventually become the cemetery.

> A plethora of cultural practices, such as postmortem preparation of the body, deliberate below ground burial, the construction of stone vaults, the design of ritually recognized cemeteries, multiple disinterments and repeated reburials, cremations, and many more death-related activities have an immense impact... (Nawrocki 1995:54).

The most obvious practice for historic cemeteries in colonial and post-colonial North America is the use of the coffin. As will be discussed below, the use of coffins to contain bodies can be considered both a cultural and environmental filter, as its use is dictated by cultural norms while its presence or absence will differentially affect the preservation of the interred individual.

Lamphear (1989) focused on cultural factors as the major potential bias in skeletal

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to the history of the two diseases in human populations. Tuberculosis is a chronic infectious disease whose mode of transmission is by entry into the upper respiratory tract by airborne droplets carrying the bacilli. Primary infection usually occurs in children under five years of age with an initial inflammatory focus followed by recovery or secondary infection that is usually fatal (Manchester 1991). Individuals who recover from the initial infection acquire a degree of immunity to subsequent infection, while additional stressors imposed on a survivor later in life can result in post secondary tuberculosis occurring in the second or third decade. Such a reaction may be the result of a reactivation of the pathological lesion (tubercle follicle) due to reduced immunity, or a new inoculation. The post-secondary stage results in a chronic inflammatory response in the lungs that may then spread via the bloodstream to other areas of the body including the skeleton. While the exact age of maximum risk to leprosy is not known, some modern evidence suggests that exposure occurs at a much later age. As a result, the *Mycobacterium leprae* may have been in the population that is already immune to tuberculosis from survived primary infection with *M. tuberculosis* (Manchester 1991). The cross immunity that exists between the two diseases may have resulted in limited immunity to leprosy which prevented the establishment of the clinical disease (Manchester 1984, 1991). Clinical studies have noted that in simultaneous exposure to both mycobacteria in populations sensitized to the *Mycobacterium tuberculosis* the development of both diseases may be inhibited (Manchester 1991). From this, Manchester (1984, 1991) argues that the observed decline in leprosy from the end of the medieval period was facilitated by the rise of tuberculosis in Britain associated with the development of large, population dense urban centres through the middle ages.

samples. She notes that Petersen's (1975a) second criticism regarding prehistoric cemetery samples not being representative of the population from which they are drawn "refers to cultural filters, such as age and sex differences in mortuary rituals, which would remove some segment of the population of a cemetery" (Lamphear 1989:185). Dependent variables including age, class, status or cause of death may further affect the probability of interment within cemetery samples (Bradley 1988; Buikstra and Mielke, 1985; Cook, 1981; Walker et al. 1988).

Macchiarelli and Saldavei (1994) in fact have recently examined the impact of differential funerary practices on palaeodemographic reconstructions. These authors noted that for their Iron Age sample from Osteria dell'Osa, Italy, biases in the age-at-death and sex distribution within the skeletal remains were a reflection of differential burial practices; those being the exclusion of children under 3 years of age and the cremation of adult males.

Cultural factors that relate to burial are numerous and there is a great deal of literature dealing with the various customs, both past and present, regarding the treatment of the dead (cf Ariès 1981; Cannon 1995; Gittings 1984; Metcalf and Huntington 1991; Morris 1992). In Europe, the first churchyard cemeteries were the result of an evolutionary process whereby pagan cemeteries were converted to Christian graveyards, with perhaps the addition of a church at some point (Ariès 1981). This transition probably occurred with the burial of the aristocracy close to the tombs of renowned saints and martyrs, while the common person had to make due with burial in proximity to the site. Cannon explored the issue of material cultural change and the cemetery in a study of 19th and 20th century grave monuments in Cambridgeshire. He noted that

> ...the pattern of representation in English grave monuments shows how changing fashions of mortuary practice could affect the structure of burial populations over time. Through the nineteenth and twentieth centuries, the English burial population would come to include increasing numbers of women, children and lower class individuals... (Cannon 1995:13).

From this, he argues that the demographic changes observed in monuments would be reflected in the cultural material associated with the burials, and that palaeodemographers might be able to use "changing material culture associations to assess the probability of changes in representation within a skeletal sample" (Cannon 1995:14).

Although the method of disposal of the body (cremation, inhumation with or without a coffin or sarcophagus) is by far the most investigated aspect of burials, it is also the factor most clearly associated with function (Clarke 1975). Clarke suggests that the tradition for disposal of the body is likely to be whatever is easiest. Newcomers to an area, he proposes, will be more liable to adopt the local traditions of disposal rather than attempting to import their own traditions. Although disposal, however elaborate, falls directly under cultural biases, the effects of these practices can been seen on a second level with differential methods of disposal resulting in differential preservation at both the individual and cemetery level. As noted above, burial within a coffin is a cultural factor associated with funerary customs, however it also has very specific effects on the preservation of the interred individual.

Many other cultural factors can also contribute toward biasing a cemetery sample. Migration and changes in sanitation or laws governing burial and disposal of the body for example can differentially affect the probability of an individual becoming incorporated into a specific cemetery sample. The relationship between cemeteries and living populations may not always be a simple one. It is not unusual, for example, for a single cemetery to be utilized by one or more populations; thus, trying to attribute distinct cultural qualities to a single set of graves, can in some instances be difficult. Paine (1992) examined the impact of migration on mortality structure observing that the primary effect of in-migration was an increase in infant deaths and a decrease in older adult deaths with an overall decrease in mean age-at-death. Paine notes that this is the same effect on the mortality distribution that is observed from an increasing fertility rate in the living population. The explanation for this result stems from the migration model followed for his study. Paine utilized migration schedules determined from a variety of modern populations, in which the primary age of migrants is around the time of marriage and household set up. Applying this schedule to a prehistoric sample, the impact of the migrants is seen, not in their added mortality, but rather in their added fertility to the population (Paine 1992).

A variety of other factors may also serve to prevent certain individuals from being included in the cemetery associated with their community. Occupations in the military or navy, for example, may result in the death of individuals away from home. Rural versus urban living may also affect probability of interment. Saunders and colleagues (1995) suggested that the reduced number of infants observed in the earlier period of the St. Thomas' Church cemetery may have been related to church membership during that time being drawn largely from the rural areas surrounding the town of Belleville. "The lack of doctors in Belleville, the high fees charged by those in practice at the time, coupled with the travel distance from home to town, probably lessened the inclination to seek treatment in town for a sick child or a church burial for a dead one" (Saunders et al. 1995:79). Later, as the town grew, church membership shifted so that most members of the parish were now living in town and more likely to bury dead infants at the church (Saunders et al. 1995).

### *Environmental*

A number of reviews of the various factors that can differentially affect the survival of skeletal remains have been undertaken (eg. Garland 1989; Gordon and Buikstra 1981; Hendersen 1987; Nawrocki 1995). Clarke (1979) observed that a biased sex ratio in the skeletal sample from the Lankhills cemetery at Winchester is partly a result of differential preservation of the sexes. Figure 3.3, reproduced from Clarke (1979) illustrates the cumulative percentage of adults and subadults by preservation category, showing that males are consistently better preserved than females. Whether in fact this relationship is being biased by methodological factors related to the techniques used to determine sex is unknown, but the results are consistent with known physiological difference in bone density between the sexes which may make females more susceptible to postmortem decay (Walker 1995). Similarly, Walker and colleagues (1988; Walker 1995) suggest age-specific differences in skeletal preservation at Purisima Mission, California, observing that middle aged adults were better recovered (and thus preserved) than subadults or elderly individuals. In the Romano-British, West Tenter Street material from London, Waldron (1987) observed an association between bone size and anatomical position with bone survival. Similarly, Meiklejohn and co-workers (1984) examined the issue of

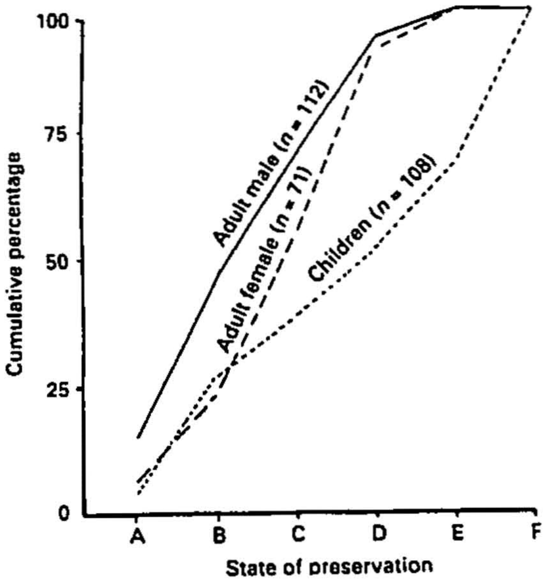

FIGURE 3.3: Cumulative percent preservation vs preservation rating (A best, F worst) for adult males and females, and subadults (from Morris 1992, after Clarke 1979).

preservation for Neolithic European samples, conducting multiple regression analysis on several independent variables. They confirmed that the completeness of a skeleton showed a direct linear relationship with the presence of pathological lesions, although "there appear to be systematic occurrences of reported pathology in relatively fragmented materials" (Meiklejohn et al. 1984: 80). Differential preservation of skeletal remains within an archaeological sample, associated with soil composition, acidity, humidity, and interment conditions as well as mortuary practices is also a major factor for interpretations. Since various diseases will differentially affect the skeleton depending upon age and/or sex, poor preservation that results in either incomplete or unrepresentative remains will bias interpretations of health. As a result of reduced survival, poor preservation of skeletal remains will further have the effect of under-enumerating skeletal lesions within the sample, and thus underestimating the frequency of the disease. Lesion prevalence will be further biased toward those pathological lesions that occur on bones more likely to be recovered, such as the long bones. For example, in individuals with skeletal tuberculosis, over one third of the lesions occur in the spine with a decreasing probability of lesions in other areas (Manchester n.d.). In contrast, skeletal lesions associated with leprosy focus on the nasal region and the hands and feet (Manchester 1991; Møller-Christensen 1961). Hence, if preservation is differentially biasing the recovery of particular skeletal elements, the frequency of lesions observable in the skeletal record may not be accurate, and therefore interpretation of disease load, and thus health, will be inaccurate..

While most investigators have simply dealt with differential preservation as it affected their specific analysis, others have attempted to quantify the various levels of preservation.

In the example illustrated above (Fig. 3.3), Clarke assigned five categorical stages for preservation: A-almost prefect, B-slight decomposition, C-smaller bones decayed, D-only major bones left, E-only skull and legs left, and F-little or nothing left (Morris 1992). Unfortunately, this type of ranking is too subjective to be easily applied by other researchers for comparative purposes. What constitutes 'almost perfect' or 'slight decomposition' is highly subjective, and the degree to which poor excavation techniques or prior removal or destruction plays a role may be unknown and unaccounted for. A less subjective index of preservation was made by Walker and colleagues (1988; Walker 1995) who took counts of long bones preserved in burials in order to assess differential preservation within the cemetery. Other more quantitatively rigorous indices of preservation would include the number of measurable long bones, or the number of measurements available for each long bone or even comparisons of bone mass (Saunders, Herring and Boyce 1995; Walker 1995), although the latter may be confounded by age (and thus, is not applicable to subadults), sex and pathological changes.

### *Methodological*

Methodological biases are perhaps the most dangerous of all the biasing factors in skeletal studies. Such biases result from the inaccuracies and imprecisions of the techniques utilized to acquire and analyze skeletal samples. While the process of excavation can be a biasing factor in the representativeness of the excavation sample, methodological filters related to the techniques of analysis are equally important for palaeodemography. The problems associated with the accuracy and precision of specific ageing techniques have been addressed earlier (pp. 24). It is worth re-iterating however, the further compounding effects of multivariate age estimations which are not consistent for all individuals. Thus, the reliance on summary ages, mean ages or age ranges for each individual within any skeletal series will create different ranges of variation or levels of confidence. This is problematic for creating an accurate mortality profile.

In the early 1970's Weiss observed "a regular and systematic bias in the sexing of adult skeletons. This bias, which is about 12% in favour of males, is due to the nature of secondary sex characteristics in bone" (Weiss 1972:239). This conclusion was based on observations on 43 skeletal samples from three time periods and for which Weiss recommended that researchers correct for this bias before attempting demographic reconstructions. To further compound the issue, Walker (1995) noted that for the personally identified individuals in the St. Bride's Street Crypt sample, significantly more ($\chi^2$=4.7, p=0.030) females are among the group for which sex is classed as indeterminate from the skeleton. Based on this observation, he concluded that elderly females may be under-represented in demographic reconstructions. Another methodological bias in sexing noted by Walker (1995) is the development of 'male' cranial features in post-menopausal women. Similarly, young male adults, for which these cranial traits have not fully developed may also be misclassed as female if no other sources for sex determination are available.

Other methodological issues related to the procurement and analysis of skeletal samples can also be addressed. Issues of preferential excavation, poor sample size, or inappropriate use of statistics can all serve to potentially bias interpretations regarding past populations from skeletal data. While long gone are the days when anatomists or archaeologists excavated burial sites and removed only the well preserved skulls and major bones, preferential excavation may still play a role in terms of sampling bias, depending on the needs and limitations of those excavating the site.

As noted earlier, sites or portions thereof are often excavated under the threat of destruction and thus the boundaries of the excavations may not always correspond to the boundaries of the actual cemetery or burial site. Further, limited resources in terms of time and or money may prevent extensive excavation with the results of remote surveying and sample pitting becoming the key factor for whether an area is excavated. Clearly a product of these obstacles, sample size is of particular importance given the number of studies on samples of considerably smaller size (eg. Larsen et al. 1995; Walker et al. 1988). Walker (1995:33) notes that "sample size per se, however, does not explain the differences in ages" observed between the skeletal and burial samples. As illustrated in Figure 3.4 the burial population for the Purisima Mission produced a typical U-shaped mortality distribution, while the skeletal sample produced an inverted U-shaped curve. Walker (1995) notes that a random sample would not deviate so radically from the population distribution, and concludes that it is age-related differential preservation which is biasing the sample. Larsen and co-workers similarly present a brief palaeodemographic assessment of 28 individuals excavated from a 19th century family cemetery in Illinois. The authors do note, however, the problems associated with their sample, stating that "skeletal series are often subject to a variety of

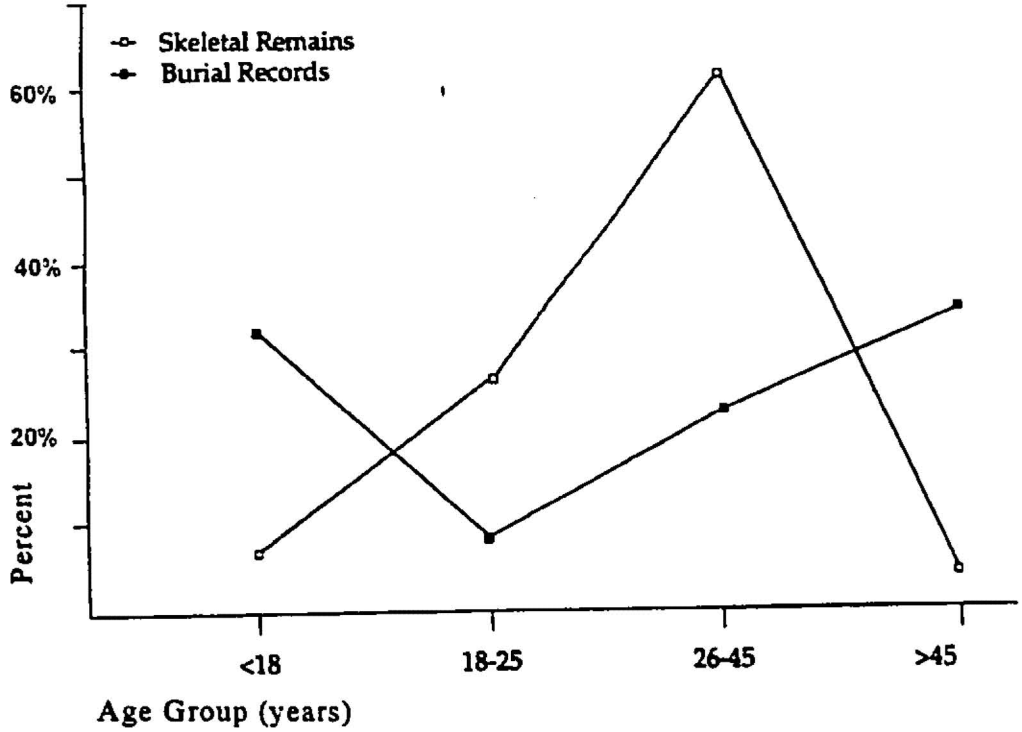

FIGURE 3.4 Comparison of mortality profiles for the Purisima Mission skeletal sample and cemetery population (from Walker 1995:32, Figure 1)

factors that will result in unrepresentative demographic profiles" (Larsen et al. 1995:147).

### *Conclusions*

Until recently there have been few attempts to directly assess the validity of interpretations of past health and demography based on samples of human skeletal remains. The primary problem for any investigator is that it is difficult to obtain a skeletal sample that is known to be representative of the larger population of the past.

> In a Panglossian world, all past members of a population could be recovered in archaeological samples. In the real world, this is probably never the case. Instead, a number of natural and cultural filters conspire to produce

> archaeological skeletal samples that cannot be considered as random samples of all members of a population who died within a certain period (Konigsberg and Frankenberg 1994:92).

While various researchers have made reference to the problem of representativeness and bias in skeletal samples, few have attempted to quantitatively assess the validity of mortality samples as a source for drawing conclusions about health and well-being among past living populations. Wood and colleagues (1992) argue that skeletal samples are intrinsically biased because they are the products of selective mortality or non-random entry. While others have argued that on average mortality will operate randomly within a population (Cohen 1994), Wood and Milner (1994) rightly note that, while there is a stochastic element to mortality, clearly there are also deterministic elements for which specific individuals or segments of the population are at greater or lesser risk of death. Many researchers (Cook and Buikstra 1979; Cook 1981, 1984; Rathbun 1984; Saunders 1992; Saunders and Hoppa 1993; Wood et al. 1992) have expressed concern regarding this problem, recognizing that archaeological samples are composed of a special subset of the past population — those who died.

> It is axiomatic although often forgotten by palaeo-osteologists that skeletal series first of all represent dead people and this means that direct extrapolation from their data to a living populations is problematic (Jankauskas and Česnys 1992:360).

Recognizing the theoretical difficulties imposed by this issue, many investigators are cautiously optimistic that valid interpretations based on skeletal samples can be made.

> ...it is important to remember that sampling problems do not preclude the formulation of general statements about the disease experience, mortality, and/or fertility of the population represented (Ubelaker 1992: 364).

However, it is critical that such interpretations be made with some understanding of the kinds of factors that have led to the observed distributions of age, sex, disease prevalence or other parameter of interest, within a skeletal sample. Limitations for interpreting general health in a population from skeletal evidence at a variety of levels are clear from the review presented in this chapter. Biological factors related to the fact the skeletal samples are the non-survivor portion of a population, cultural factors related to the burial of the body, environmental factors related to post-depositional processes and methodological factors related to the procurement and analysis of skeletal series will all serve to potentially bias interpretations. In order to make valid interpretations regarding past health, researchers must acknowledge the presence of biases in the data, and unknown factors regarding the population such as differential susceptibility to disease.

Potential biases in age and sex distributions can and should be addressed by careful examination and testing of the data to model mortality samples (Paine 1989). In order to control for biases with samples it is essential that researchers examine the factors that can affect representativeness with the sample. At the very least, assessments of environmental and methodological filters should be made to quantify any differences between the analyzable and excavated skeletal series. While the recent trend toward comparative analyses of skeletal samples with associated historical records represents a strong beginning, researchers must also be careful of the implications of these studies. In particular one must be careful not to make the same assumption of the historical records that is being tested for the skeletal record — that the historical records are free of bias themselves. The next step that is required is a more rigorous exploration of the potential impact of these factors on interpretations (eg. Wood et al. 1992; Saunders and Hoppa 1993). This study examines this problem, specifically with regard to palaeodemographic reconstructions.

# CHAPTER 4

## MATERIALS AND METHODS

### *Introduction*

As described earlier, many authors (eg. Moore et al. 1975; Weiss 1975; Wood et al. 1992) have made significant contributions to palaeodemographic theory by modelling the effects of populations which do not conform to stable population theory. However, there have been no substantial efforts towards investigating the validity of cemetery samples as representative of the larger, once living population of the past. Both Weiss (1975) and Wood and colleagues (1992) to some extent were referring to factors affecting the transition from Living population (I) to Mortality sample (II), while the examples presented here deal with a lower level in the sample hierarchy; Cemetery population (III) to Excavation (IV) or even Observable skeletal (V) samples. The basis for this study is the assumption that if we cannot attain good representativeness between levels V (observable skeletal series) and III (cemetery), then there is little reason to support the notion of representativeness between levels V (observable skeletal series) and I (living population).

By its very nature, skeletal biology is an historical science in that the data utilized (ie. skeletons) is collected after the fact. Unlike many sciences in which a hypothesis is proposed and an experiment conducted to collect data to accept or reject the hypothesis, osteological studies collect the data and then put forward a number of questions and hypotheses. Even for very broad questions which can be tested from the skeletal record, investigators must make do with the samples that have been excavated in the past. Since skeletal samples are collected retrospectively, there can be no premeditated control over factors of interest. Therefore, to examine the issue of representativeness in skeletal biology, it is necessary to simulate the processes in question.

In order to explore representativeness in skeletal samples prospectively, one of two methods can be employed. First, stochastic simulations can generate burial samples based on a variety of pre-defined population parameters. By pre-defining mathematical relationships between various factors and demographic structure, studies like those conducted by Weiss (1975) can observe the impact of changing a variety of factors on the resultant mortality structure for a series of hypothetical samples. Such models are limited however, in that any single run will produce the exact same outcome if all factors remain unchanged. For a more realistic model, stochastic simulations produce an infinite number of possible outcomes from the same set of factors by introducing random fluctuations.

> Demographic stochasticity arises because populations consist of a finite and integer number of individuals subject to chance events. The effect leads to chance fluctuations which are most marked in small populations with few individuals. In a large population, the effects of demographic stochasticity are ironed out (Brown and Rothery 1993:136).

For palaeodemography, such models rely heavily on ethnographic analogy for both the construction of the population and for the relationships between factors.

The second method, and the one chosen for this study, simulates hypothetical skeletal samples through a series of sampling experiments utilizing documented burial distributions.

*Simple random sampling* is a technique in which a series of individual units are removed from a population; each one being selected independently of all others (Brown and Rothery 1993). This method assumes, by sampling without replacement, that the population distribution being sampled from is infinite in size. Thus, in any one sampling distribution, some individuals may not have been sampled at all while others may have been sampled several times each. This type of simulation is useful for two reasons. First, the simple random sample is free of bias, and second, it provides estimates of population parameters with known properties and a theoretical basis for measuring possible errors in the estimates (Brown and Rothery 1993:241).

This study employs the simple random sampling technique in order to generate and examine the palaeodemographic data for a series of hypothetical skeletal samples. The samples are drawn from 19th century burial data from three cemetery populations of reasonable size. While it is not assumed (or even expected) that these sources are without error, they nevertheless still represent nonstatic burial populations derived from once living populations. Further, while the composition of the 19th-20th century cemetery populations will not reflect the mortality structure of all anthropological populations, it is assumed that the observed relationship between cemeteries and skeletal series created by this study can be generalized to palaeodemographic studies as a whole.

### *Definitions*

The subsequent analysis and discussion is presented within the framework of the sampling hierarchy presented in Figure 3.1 (pp. 52). In order to avoid confusion, several terms utilized can be defined as follows. In general, this study examines the relationship between levels III (cemetery) and V (observable skeletal series) in the sampling hierarchy. As such, the three sets of burial data are termed the *cemetery populations* since they are intended to represent burial populations from which subsequent *skeletal samples* will be drawn. In addition to these hypothetical skeletal samples, the issue of preservation is examined, as an example of a single filter, in the *St. Thomas' Skeletal Sample*, an archaeological sample excavated from a portion of the cemetery site from St. Thomas' Anglican Church, Belleville (see below).

Another term used that may require clarification is *cohort.* A cohort in demography is used to refer to a section of a population who lived simultaneously during a specific period. Thus, cohort effect is the influence that a single cohort can have on a demographic analysis which covers a broader period than that during which the cohort is living. For example, a demographic analysis of 20th century mortality in Canada would be affected by World War I and II. However, mortality peaks associated with these events would be observable, for the most part, in men between the ages of 18 and 40 representing the age most likely to be killed in combat. For this study, the term is used with reference to either the decade of birth for an individual (*birth cohort*) or the decade of death for an individual (*death cohort*).

## *The Data*

The present analysis was conducted utilizing three independent sources of burial data which acted as cemetery populations from which to generate hypothetical skeletal samples. In addition, the issue of preservation as an example of an environmental filter was explored for the excavated skeletal sample associated with the St. Thomas' parish burial records. Examination of the impact of sampling bias was accomplished through a statistical analysis

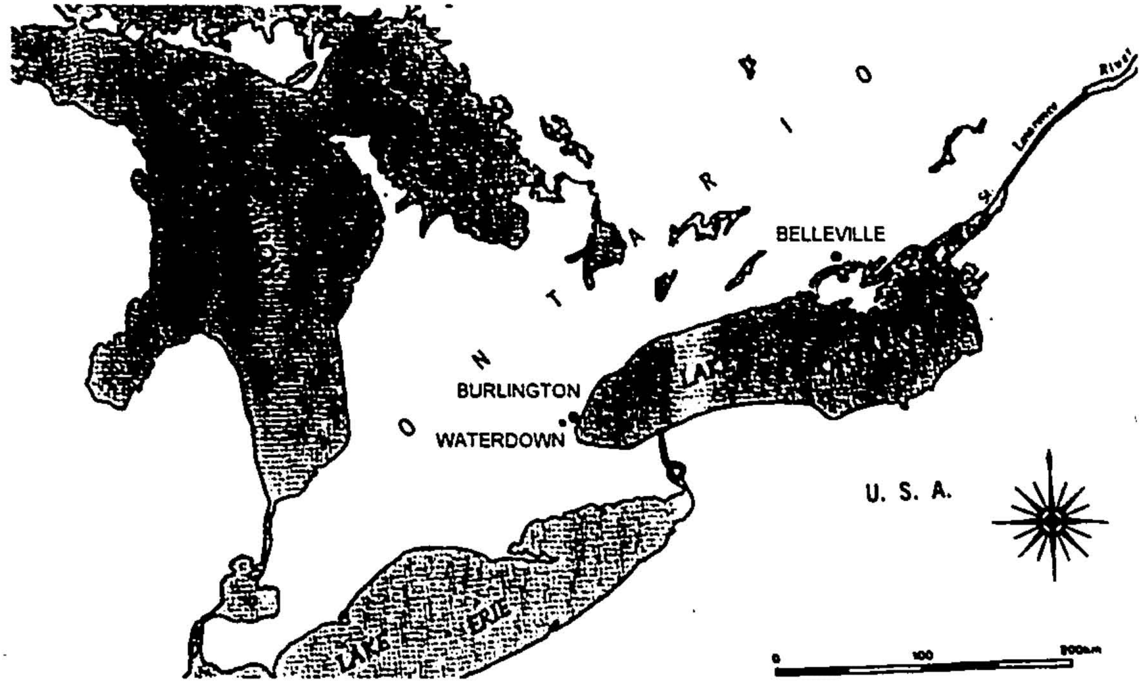

FIGURE 4.1: Map of Southern Ontario showing the location of the three communities from which the burial populations are drawn — Waterdown (Union), Burlington (St. Luke's) and Belleville (St. Thomas').

of transcribed records for these 19th century cemeteries from southern Ontario. The location of the three communities which these cemeteries are from (Waterdown, Burlington and Belleville) are shown in Figure 4.1 above.

The first source of mortality data is derived from the epitaph transcriptions of Union Cemetery, East Flamborough Township collected in 1977 by the Hamilton Branch of the Ontario Genealogical Society (OGS 1977). Union Cemetery is located approximately 300 feet north of Dundas Street at the junction of William and Margaret Streets just inside the north-eastern border of the village of Waterdown, Ontario. Still in use today and under the management of the Cemetery Board of the Village of Waterdown, Union Cemetery was first used sometime around 1830. The earliest recorded burial in the cemetery occurred in 1830 with the interment of a young girl aged 1 year, 3 months and 3 days. The name Union was suggested to have been derived from the joint use of the land by early Presbyterian and Episcopal Methodist churches, each of which stood not far from one another on the top of what was once known as Vinegar Hill (OGS 1977). Nearly 800 grave markers, spanning the period 1830-1977, produced a cemetery population of over 1500 individuals ranging in age from one day to 103 years of age. For 1375 individuals age at death is known.

The village of Waterdown had a population of 165 in 1841 and its primary industries were the saw mill, flour mill and woollen mill (one of the first in Upper Canada) established by the Griffin family (WEFCC 1967). By 1867, there were 600 inhabitants and 100 households, and in 1878, the village of Waterdown was incorporated. Waterdown was primarily a rural community with lumber and flour mills built around a small river that ran through the area. The waterfalls of Grindstone Creek provided the power for most of the mills in the area up until the turn of the century. While other smaller settlements along the Grindstone Creek disappeared when the lumber mills shut down at the turn of the century, Waterdown continued to thrive.

The second source of mortality data was derived from the Anglican Church Parish records for Nelson Township (Burlington, Ontario) for St. Luke's church. St. Luke's is the oldest Anglican Church in Burlington. It was built by Elizabeth Brant, the daughter of Joseph Brant. The church was completed in 1834 and consecrated four years later (Loverseed 1988). The first baptism at St. Luke's occurred on 15 November 1835, and the first marriage occurred in December of the same year. Between 1835 and 1838 the church was ministered by travelling missionaries, but in 1838 St. Luke's first rector, Dr. Thomas Greene, began what would be a long tenure until his death in 1867 (Loverseed 1988; Turcotte 1989). Burial data from these records were transcribed from a microfilm copy of the parish registry housed in Mills Memorial Library at McMaster University. St. Luke's church represents a small and less consistent sample of burials with 185 of 203 individuals of known age-at-death, spanning the years 1839 to 1868.

Burlington originated from a land grant to Joseph Brant in 1784. Joseph Brant was a Captain in the British Army and a Six Nations leader. During the Revolutionary War he led the Six Nations people in support of the United Empire Loyalists against the American colonists. For this service, he was granted 3450 acres of land on the north shore of Lake Ontario (Loverseed 1988; Turcotte 1989). Over the years, blocks of his land were sold off and eventually a small community on the north shore of Lake Ontario developed (Loverseed 1988). In 1806, a portion of Nelson Township was purchased from the Mississauga Indians and sold off to new settlers (Turcotte 1989). Brant Street and Guelph Line were the two main roads to the lakeshore, and at the bottom of each shipping docks and warehouses quickly sprang up and more pioneer families settled in the community. Up until the opening of the Burlington Canal in 1832, the village of Wellington Square at the foot of Brant Street was the most important port in the area. When the canal opened and Hamilton ports began to take over, the lumber industry became more important for Wellington port (Turcotte 1989). In 1873, the villages of Wellington Square and Port Nelson combined to form the township of Burlington. By the turn of the century, Burlington was successfully established in the business of shipping and exporting fresh and perishable fruits (Turcotte 1992).

The third source of mortality data comes from the St. Thomas' Church cemetery burial records and skeletal sample. St. Thomas' is a 19th century pioneer cemetery located in

Belleville, Ontario. As a result of church construction, a portion of the cemetery was excavated by archaeologists and the remains made available for scientific study. The skeletal sample is composed of 577 individual skeletons and represents approximately one third of the total 1564 interments for the site which was in use from 1821 to 1874 (Saunders et al. 1995). Of the total sample, 72 individuals are personally identifiable, and the full parish burial records for the cemetery were transcribed. Of the 1564 total records, 1423 (91%) are of known age-at-death and sex. This provides an excellent opportunity for examining the simulation models initiated here while the issue of representativeness between the sample and the cemetery as a whole has been examined to some degree (Saunders et al. 1995; Saunders, Herring and Boyce 1995). The opportunity to further make use of the St Thomas' sample for this research allowed for a comparative retrospective analysis of the issue of palaeodemographic reconstruction.

The historical development of Belleville has been reviewed by a number of studies undertaken on the St. Thomas' skeletal sample and parish records (Saunders et al. 1994; Saunders, Herring and Boyce 1995). Briefly, Belleville was an early 19th century pioneer community which was settled by United Empire Loyalists from the early to mid part of the 19th century (Saunders, Herring and Boyce 1995). A population of about 100 individuals in the earliest days of the town's founding grew to about 700 by the end of the 1820's. By 1851 the town's population had quickly reached about 4500 and by 1874, the population had grown to about 7500 and thrived as a farm and lumbar market centre (Saunders, Herring and Boyce 1995). St. Thomas's Church was founded in 1818 and its first service held in 1821. The Church provided the first public cemetery for the community. In 1874, with the opening of the municipal cemetery, St. Thomas' Church cemetery was closed (Saunders, Herring and Boyce 1995).

### *Assessment of the Cemetery Populations*

Assessment of historical records can be made through a number of tests (eg. Drake 1974). Drake's (1974) protocol essentially involves examining the records for the number of entries per year and any gaps in vital events, and assessing the reliability of the recorder (are there many individuals or a long period for which the same individual is recording events) and the degree to which the community is represented by those records. Appendix I provides the number and cumulative percentage of burials per year for each of the three cemetery populations. The St. Thomas parish records have previously been assessed in this regard (DeVito n.d.; Rogers 1991) and have been found to be "well-preserved and quite complete" (Saunders et al. 1995:101).

Applying these rules to the St. Luke's sample suggests some areas that may be problematic (eg. no deaths recorded in a one year interval) although they are perhaps more related to the fact that the records are for a small parish and for a relatively short duration (1835-1868). While the number of events per year are often less than the recommended 100 (Drake 1974), they do not fall below Eversley's (1966) minimum of 15 to 20 until 1857 (see Appendix I for the annual breakdown of events). Up until this time, all parish events (baptisms, burials and marriages) were entered in sequence, in a single record book. However, around about 1857-58, the single recording book is replaced by three separate record books for each event. It is at this time the annual number of events seem to drop significantly (see Figure 4.2). Whether this decline is associated with the change in record keeping (or further

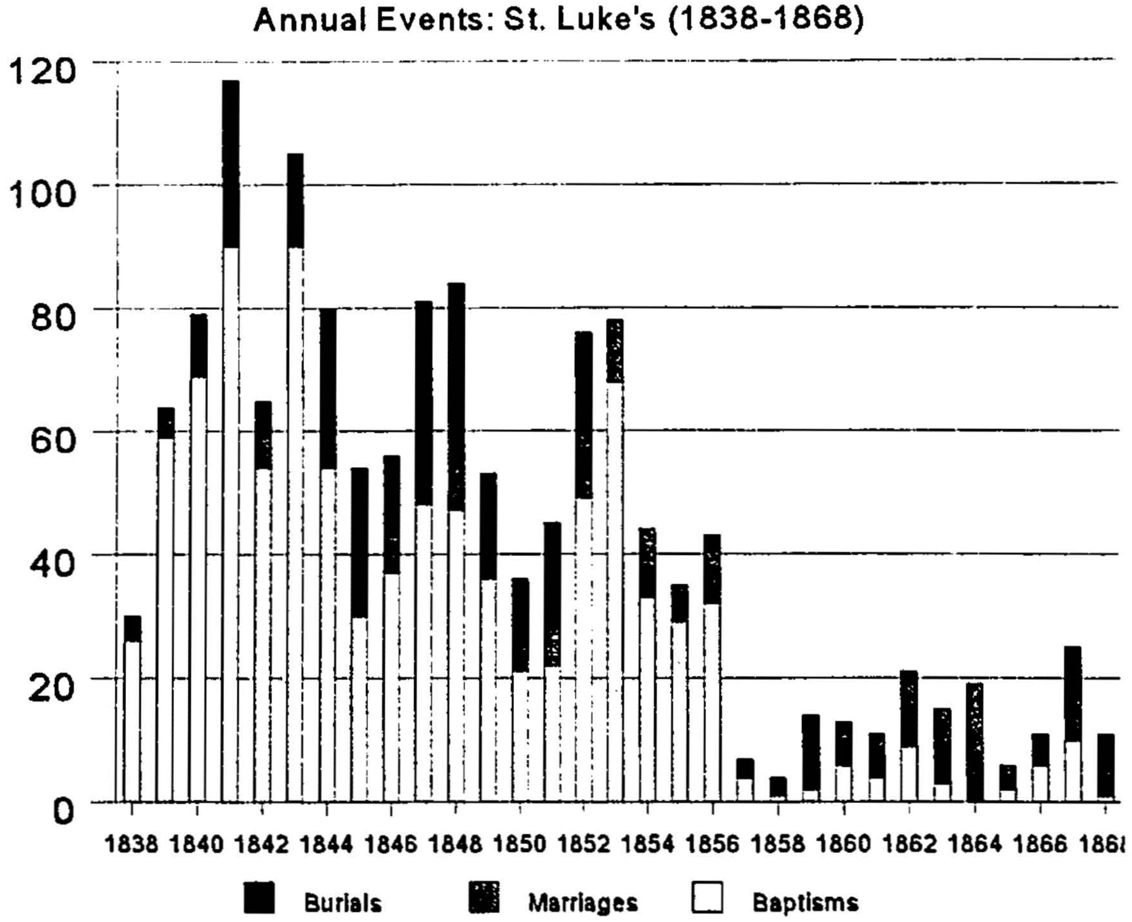

FIGURE 4.2: Annual number of baptisms, marriages and burials from St. Luke's parish records (1838-1868).

the survival of interim records) or an actual reduction in the events themselves at St. Luke's is not known. It is clear from the records that the early frequency of baptisms is over-inflated as a result of new families migrating to Nelson township during its infancy, at which time, many families brought multiple children to be baptized at once. In addition, there were no gaps of one year throughout the period (1835 to 1868) although there are often one month gaps in recorded events occurring once or twice a year (the mean number of months without events is 0.6 for the period 1838 to 1857). It should be noted also that while there are a consistent number of marriages and baptisms during the period 1853 to 1855, there is an

TABLE 4.1: Sample size and composition of the three cemetery populations based on the mortality data.

| NAME | SOURCE | N | LESS CENSORED* | % | LESS UNKNOWN SEX & AGE | % |
|---|---|---|---|---|---|---|
| St. Thomas' | Parish burial records | 1564 | | | 1423 | 91.0 |
| Union | Tombstone transcription | 1549 | 1446 | 93.4 | 1375 | 88.8 |
| St. Luke's | Parish burial records | 203 | | | 185 | 91.1 |

* Censored individuals are those who were identified in the interment records but not present in the tombstone transcriptions for the Union cemetery population.

absence of burials recorded in the parish records. It may be that the burials were the first to be recorded separately, and that due to circumstances those recorded in this interim period before 1857 were lost. Determination of sex was clear, in most cases being identified by the terms 'wife', 'husband', 'son' or 'daughter' in the records. Finally, burials elsewhere were noted in some instances (e.g. 'buried at Oakville' or 'buried at Bronte') and these individuals were not included in the final distributions. A further sense of the quality of these records can be inferred from the fact that, with the exception of the first few years, the majority of the records were entered by the same minister. The earliest records are sporadic and a result of the parish being ministered by a variety of missionaries at different times prior to the arrival of the Reverend Thomas Greene, St. Luke's first and longest attending rector. While the St. Luke's cemetery population is relatively short in duration, it is likely that the records are relatively consistent and an accurate reflection of the mortality experiences of the parish, up until the last decade. From then, entries are also made by an church assistant, John Butler, and are more sporadic.

Assessing the Union cemetery population is more difficult, given that it is derived from tombstone transcriptions. While tombstone transcriptions are problematic and known often to grossly under-represent the true demography of a cemetery (Cannon 1995, Dethlefsen 1969; Morris 1992; Parkin 1992), the transcriptions have been compared to the interment records for the cemetery and observed to have less than a 10 percent discrepancy (after OGS 1977). This is a considerably small percentage of error compared to many studies for which tombstone transcriptions account for as little as 10-25 percent of the total burials within the cemetery (Cannon 1995). Further, for the purposes of this study, the total percentage of cases missing from the transcriptions (6%, as assessed from comparisons to the cemetery lists) or imprecise data resulting in unknown age or sex (5%) is comparable to the 9% censored in the St. Thomas' and St. Luke's cemetery populations (see Table 4.1).

### *Simulation of the Skeletal Samples*

In order to examine the issue of representativeness using the transcribed burial records, a variety of simulated skeletal series were generated. Simulation of the skeletal samples was conducted either by sampling without replacement for individual or small group samples, or by a bootstrapping resampling method using SimStat statistical software (Peladeau 1994). While sampling without replacement (ie. an individual is removed from the population once sampled) is more appropriate for generating hypothetical skeletal series, in some cases where a distribution of the statistical parameters was required, the bootstrapping method was employed. Bootstrap simulation is a resampling technique that can be used to assess the accuracy and sampling variability of various statistical estimators. The primary advantage to the bootstrapping technique is that the sampling distribution is not mathematically estimated, but rather empirically constructed from the data (Peladeau 1994). This approach then can be considered analogous to the excavation of skeletal samples, given a known cemetery distribution. While the method is not new, this technique provides a potentially powerful tool for examining variability in both theory and practice[10]. All bootstrapped samples were conducted with 1000 random runs of the known age-at-death distribution for each cemetery population.

### *St. Thomas' Skeletal Sample: Exploring Preservation Bias*

While simulations can provide a prospective assessment of representativeness and bias within skeletal samples, the St. Thomas' skeletal sample allows the opportunity for a retrospective examination of the issue. Although the issue of representativeness between the skeletal sample and cemetery populations has been explored (Herring et al. 1991; Saunders, Herring and Boyce 1995; Saunders et al. 1991, 1995), this study specifically examines the issue of preservation as an example of an environmental filter. Preservation is perhaps the one type of filter that has been examined most frequently by researchers in the past (eg. Garland 1989; Gordon and Buikstra 1981; Hendersen 1987; Meiklejohn et al. 1984; Nawrocki 1995; Waldron 1987), possibly because it is the most easily quantifiable factor. Exploring this issue for the St. Thomas' skeletal sample then, can provide some comparative data on the impact of preservation for skeletal biology.

The issue of preservation was explored directly for the St. Thomas' skeletal sample. In order to assess the relative degree of preservation within the sample, a simple index was calculated. This *index of preservation* is calculated as the number of measurements taken

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[10] In fact, bootstrapping was developed in order to more rigorously examine statistical estimators in data that may not conform to all the requirements and assumptions necessary. "Bootstrap results provide improved standard error estimates in situations in which original-sample standard errors are either untrustworthy due to false assumptions or unavailable due to theoretical or computational complexity" (Hamilton 1992:315).

divided by the total number of possible measurements for each individual. Thus, for each individual, the percentage of measurements taken is a proxy for the degree of skeletal preservation for that individual. The mean of the index for the entire skeletal sample can be used as a gauge of relative level of preservation within the sample. This index was calculated for all infracranial metrics (all measures of the skeleton recorded, excluding those taken on the skull) as a whole and then by subgroups (side, sex, bone etc) in order to assess differential preservation within these subgroups. To further examine the potential effects of environmental filters on the sample, data on burial depth recorded on the archaeological recovery sheets, was examined and correlated with the above mentioned index of preservation for various subgroups.

### *Palaeodemographic Estimators*

Demographic statistics were generated for each of the complete cemetery samples using Survivorship Analysis techniques in SPSS for Windows 6.1 (Norušis 1993) and Lifepro 1.0 (Sawchuk and Anthony 1990). Resampling analysis was conducted using SimStat v3.5e (Peladeau 1994). Cumulative survivorship and hazards functions and their standard errors were generated by SPSS for each of the three burial populations. As noted earlier, hazards analysis estimates the probability of an event occurring during a time interval, given its observation of occurrence previous to that interval. In this case, the hazards function is equivalent to the age-specific mortality rate since the event being examined is age-at-death.

There are three basic components to this study:

1) An analysis of the three parent populations. This provides both a descriptive and comparative base for discussing the results of the sampling experiments.

2) Simulation, through random sampling, of skeletal sample distributions from each of the three populations. Simulations examined the following effects on sample representativeness: i) simple sample size, ii) age-specific biases, iii) sex-specific biases and iv) temporal biases in the age-at-death distribution of the samples.

3) An examination of preservation within the St. Thomas' skeletal sample as an example of an environmental filter.

Demographic estimators including mean age-at-death (MAD), life expectancy, sex ratio and other population ratios (outlined in Table 2.2) are calculated for each of the parent cemetery populations. Once sampled, the simulated skeletal series were analysed using a variety of palaeodemographic tools and the results compared to the parent cemetery. Distribution of burials by birth and death cohort were also examined to assess the effects of temporal biases in skeletal samples.

# CHAPTER 5

## RESULTS AND DISCUSSION

### *Introduction*

This chapter presents the results of the analysis for both the parent cemetery populations and the test samples. The first part, presented below, outlines the results of the palaeodemographic analysis of the three parent cemetery populations. This is done first, as a descriptive tool for evaluating differences between the three cemetery populations and second, as a source of comparison with the test samples. Differences between the burial *populations* (III) and the test *samples* (V) should emerge as different levels of bias are introduced into the samples. This is a heuristic device to aid in understanding the issue of representativeness in palaeodemographic studies. In the second part, the results for the test samples are presented for the simulated skeletal samples and for the actual St. Thomas' skeletal sample. The latter provides the unique opportunity to directly assess the degree of representativeness between a known cemetery (III) and its observable skeletal series (V).

### *The Cemetery Populations*

There are several factors that should be considered when making comparisons between the three populations. First, all three burial populations represent early 19th century pioneer cemeteries for which the number of early burials are sparse. Second and perhaps more important is that the St. Thomas' cemetery is complete; that is, the burials reflect the beginning and the end of the cemetery's use. In contrast, the Union cemetery population reflects only those burials up to 1977. Perhaps the most striking contrast between the cemetery samples is the very high proportion of infants in the St. Thomas' cemetery as compared with the other samples. This factor has some very obvious and important effects on the subsequent analyses.

### *Survivorship*

While the mathematics of survivorship and hazards analysis are not particularly new, application of these techniques within anthropology has been a fairly recent event (eg. Gage 1988, 1989, 1990; Whittington 1991; Wood et al. 1992b). The purpose of survival analysis is to examine the relationship between any number of factors and the survival time of individuals. Initial applications of this technique were developed for examining age-specific probabilities of death (hence the term survivorship), however, its use is widely applicable to questions of time-related change in many areas of study. Survival analysis provides a robust statistical technique for not only describing the relative risk of death for individuals in skeletal samples, but for examining differences between subgroups within a skeletal sample (Whittington 1991). This is of particular use for quickly assessing differences in observed risks of death between the sexes, and economically, culturally or temporally distinct groups. Further, survival analysis can be used reliably on samples that are unlikely to represent a stable population "since measurable sources of heterogeneity in a non-random sample are likely to characterize a random sample as well" (Whittington 1991:172).

Tables 5.1-5.3 present the survivorship data generated in SPSS (Norušis 1993) for each of the cemetery populations In these tables, the proportion terminating column (column 5) is equivalent to $q_x$ in the life table when using the cohort method. The proportion surviving (column 6) is $1-q_x$ or the proportion of individuals at risk on entering the age category who fail to die. A cumulative proportion surviving (column 7) is also calculated. The probability density function (column 8) calculates an estimate of the probability per unit time of dying, while the hazard rate is an estimate of the probability per unit time that an individual who has survived to the beginning of the age category will die in that age category.

Figures 5.1 and 5.2 present the cumulative survivorship and hazards functions respectively, for each of the cemetery populations. Examination of the survivorship data show high early childhood mortality in the St. Thomas and St. Luke's populations, while the Union cemetery population has a considerably higher early childhood survivorship. The Union cemetery survivorship curve is comparable to the classic modern curve in which there is a slight drop from infant mortality followed by a slow decline as death rates are relatively slow up until about 50 years of age. Around this time, the survivorship begins to decline more rapidly. "With the death rates increasing with age, the curve becomes steeper in the seventies and early eighties and then flattens out because the numbers at risk have fallen" (Lancaster 1990:39*ff*).

Comparisons of the survivorship curves were made for the three cemetery populations. For each of these comparisons three test statistics and their associated p-values are provided by the SPSS software (Norusis 1993). The log rank or Mantel-Cox test weights all ages equally, while the Breslow or generalized Wilcoxon test weights age by the number of cases at risk in the sample. Finally the Tarone-Ware test weights ages by the square root of the number of cases at risk (Norušis 1993). Thus the Breslow test weights younger deaths more than older deaths because the number at risk decreases with age (Norušis 1993), making it more sensitive to early childhood mortality differences. An examination of the survivorship analysis results will quickly reveal that there are distinct differences between each of the three cemetery populations. Life expectancy at birth ($e_0$) is comparable for the two parish cemeteries (St. Thomas' and St. Luke's) at 26.96 and 30.77 years respectively[11]. However, $e_0$ for the Union cemetery is considerably higher at 58.56 years. Table 5.4 presents the calculated life expectancies and their standard errors for each of the cemetery populations. In all cases, the survivorship curves are significantly different ($p<0.05$) for the three cemetery populations. However, if divided by sex, the St. Thomas' and St. Luke's cemetery samples have both male and female survivorship curves that are not statistically different ($p>0.05$ for all three test statistics). Comparisons of survival distributions within each population, by sex (Table 5.5), birth cohort (Table 5.6), and death cohort (Table 5.7) were made, partly to assess the quality of the cemetery data for this study, and partly to make comparisons between the cemetery populations and the test samples. Comparison of survivorship for males and females separately shows a significant difference (log rank $p<0.01$) between the sexes for only the St. Thomas' cemetery population. Overall comparisons of survivorship for birth and death cohorts also revealed some differences between the cemetery populations. All three cemetery populations showed significantly different survival distributions by birth cohort (log rank $p<0.001$). However, only the Union cemetery population showed significant differences between death cohorts ($p<0.001$). The St. Thomas' population was significant for the Log

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[11] The 95% confidence intervals (alpha=0.05) overlap for life expectancy at birth.

TABLE 5.1: Survivorship data for the St. Thomas' cemetery population (1821-1874).

| Intrvl Start Time | (1) Number Entrng this Intrvl | (2) Number Wdrawn During Intrvl | (3) Number Exposd to Risk | (4) Number of Termnl Events | (5) Propn Termi-nating | (6) Propn Sur-viving | (7) Cumul Propn Surv at End | (8) Proba-bility Densty | (9) Hazard Rate | (10) SE of Cumul Sur-viving | (11) SE of Proba-bility Densty | (12) SE of Hazard Rate |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| .0 | 1423.0 | .0 | 1423.0 | 559.0 | .3928 | .6072 | .6072 | .0786 | .0978 | .0129 | .0026 | .0040 |
| 5.0 | 864.0 | .0 | 864.0 | 74.0 | .0856 | .9144 | .5552 | .0104 | .0179 | .0132 | .0012 | .0021 |
| 10.0 | 790.0 | .0 | 790.0 | 44.0 | .0557 | .9443 | .5242 | .0062 | .0115 | .0132 | .0009 | .0017 |
| 15.0 | 746.0 | .0 | 746.0 | 47.0 | .0630 | .9370 | .4912 | .0066 | .0130 | .0133 | .0009 | .0019 |
| 20.0 | 699.0 | .0 | 699.0 | 73.0 | .1044 | .8956 | .4399 | .0103 | .0220 | .0132 | .0012 | .0026 |
| 25.0 | 626.0 | .0 | 626.0 | 58.0 | .0927 | .9073 | .3992 | .0082 | .0194 | .0130 | .0010 | .0025 |
| 30.0 | 568.0 | .0 | 568.0 | 56.0 | .0986 | .9014 | .3598 | .0079 | .0207 | .0127 | .0010 | .0028 |
| 35.0 | 512.0 | .0 | 512.0 | 57.0 | .1113 | .8887 | .3197 | .0080 | .0236 | .0124 | .0010 | .0031 |
| 40.0 | 455.0 | .0 | 455.0 | 61.0 | .1341 | .8659 | .2769 | .0086 | .0287 | .0119 | .0011 | .0037 |
| 45.0 | 394.0 | .0 | 394.0 | 56.0 | .1421 | .8579 | .2375 | .0079 | .0306 | .0113 | .0010 | .0041 |
| 50.0 | 338.0 | .0 | 338.0 | 55.0 | .1627 | .8373 | .1989 | .0077 | .0354 | .0106 | .0010 | .0048 |
| 55.0 | 283.0 | .0 | 283.0 | 53.0 | .1873 | .8127 | .1616 | .0074 | .0413 | .0098 | .0010 | .0056 |
| 60.0 | 230.0 | .0 | 230.0 | 57.0 | .2478 | .7522 | .1216 | .0080 | .0566 | .0087 | .0010 | .0074 |
| 65.0 | 173.0 | .0 | 173.0 | 45.0 | .2601 | .7399 | .0900 | .0063 | .0598 | .0076 | .0009 | .0088 |
| 70.0 | 128.0 | .0 | 128.0 | 49.0 | .3828 | .6172 | .0555 | .0069 | .0947 | .0061 | .0010 | .0131 |
| 75.0 | 79.0 | .0 | 79.0 | 32.0 | .4051 | .5949 | .0330 | .0045 | .1016 | .0047 | .0008 | .0174 |
| 80.0 | 47.0 | .0 | 47.0 | 30.0 | .6383 | .3617 | .0119 | .0042 | .1875 | .0029 | .0008 | .0302 |
| 85.0 | 17.0 | .0 | 17.0 | 9.0 | .5294 | .4706 | .0056 | .0013 | .1440 | .0020 | .0004 | .0448 |
| 90.0 | 8.0 | .0 | 8.0 | 6.0 | .7500 | .2500 | .0014 | .0008 | .2400 | .0010 | .0003 | .0784 |
| 95.0 | 2.0 | .0 | 2.0 | 1.0 | .5000 | .5000 | .0007 | .0001 | .1333 | .0007 | .0001 | .1257 |
| 100.0 | 1.0 | .0 | 1.0 | 1.0 | 1.0000 | .0000 | .0000 | .0001 | .4000 | .0000 | .0001 | .0000 |

The median survival time for these data is 18.67

TABLE 5.2: Survivorship data for the Union cemetery population (1810-1977).

| Intrvl Start Time | (1) Number Entrng this Intrvl | (2) Number Wdrawn During Intrvl | (3) Number Exposd to Risk | (4) Number of Termnl Events | (5) Propn Termi-nating | (6) Propn Sur-viving | (7) Cumul Propn Surv at End | (8) Proba-bility Densty | (9) Hazard Rate | (10) SE of Cumul Sur-viving | (11) SE of Proba-bility Densty | (12) SE of Hazard Rate |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| .0 | 1375.0 | .0 | 1375.0 | 142.0 | .1033 | .8967 | .8967 | .0207 | .0218 | .0082 | .0016 | .0018 |
| 5.0 | 1233.0 | .0 | 1233.0 | 31.0 | .0251 | .9749 | .8742 | .0045 | .0051 | .0089 | .0008 | .0009 |
| 10.0 | 1202.0 | .0 | 1202.0 | 14.0 | .0116 | .9884 | .8640 | .0020 | .0023 | .0092 | .0005 | .0006 |
| 15.0 | 1188.0 | .0 | 1188.0 | 26.0 | .0219 | .9781 | .8451 | .0038 | .0044 | .0098 | .0007 | .0009 |
| 20.0 | 1162.0 | .0 | 1162.0 | 32.0 | .0275 | .9725 | .8218 | .0047 | .0056 | .0103 | .0008 | .0010 |
| 25.0 | 1130.0 | .0 | 1130.0 | 28.0 | .0248 | .9752 | .8015 | .0041 | .0050 | .0108 | .0008 | .0009 |
| 30.0 | 1102.0 | .0 | 1102.0 | 31.0 | .0281 | .9719 | .7789 | .0045 | .0057 | .0112 | .0008 | .0010 |
| 35.0 | 1071.0 | .0 | 1071.0 | 27.0 | .0252 | .9748 | .7593 | .0039 | .0051 | .0115 | .0007 | .0010 |
| 40.0 | 1044.0 | .0 | 1044.0 | 32.0 | .0307 | .9693 | .7360 | .0047 | .0062 | .0119 | .0008 | .0011 |
| 45.0 | 1012.0 | .0 | 1012.0 | 38.0 | .0375 | .9625 | .7084 | .0055 | .0077 | .0123 | .0009 | .0012 |
| 50.0 | 974.0 | .0 | 974.0 | 41.0 | .0421 | .9579 | .6785 | .0060 | .0086 | .0126 | .0009 | .0013 |
| 55.0 | 933.0 | .0 | 933.0 | 67.0 | .0718 | .9282 | .6298 | .0097 | .0149 | .0130 | .0012 | .0018 |
| 60.0 | 866.0 | .0 | 866.0 | 87.0 | .1005 | .8995 | .5665 | .0127 | .0212 | .0134 | .0013 | .0023 |
| 65.0 | 779.0 | .0 | 779.0 | 118.0 | .1515 | .8485 | .4807 | .0172 | .0328 | .0135 | .0015 | .0030 |
| 70.0 | 661.0 | .0 | 661.0 | 160.0 | .2421 | .7579 | .3644 | .0233 | .0551 | .0130 | .0017 | .0043 |
| 75.0 | 501.0 | .0 | 501.0 | 178.0 | .3553 | .6447 | .2349 | .0259 | .0864 | .0114 | .0018 | .0063 |
| 80.0 | 323.0 | .0 | 323.0 | 166.0 | .5139 | .4861 | .1142 | .0241 | .1383 | .0086 | .0018 | .0101 |
| 85.0 | 157.0 | .0 | 157.0 | 94.0 | .5987 | .4013 | .0458 | .0137 | .1709 | .0056 | .0014 | .0159 |
| 90.0 | 63.0 | .0 | 63.0 | 51.0 | .8095 | .1905 | .0087 | .0074 | .2720 | .0025 | .0010 | .0279 |
| 95.0 | 12.0 | .0 | 12.0 | 8.0 | .6667 | .3333 | .0029 | .0012 | .2000 | .0015 | .0004 | .0612 |
| 100.0 | 4.0 | .0 | 4.0 | 4.0 | 1.0000 | .0000 | .0000 | .0006 | .4000 | .0000 | .0003 | .0000 |

The median survival time for these data is 68.88

TABLE 5.3: Survivorship data for the St. Luke's cemetery population (1839-1868).

| Intrvl Start Time | (1) Number Entrng this Intrvl | (2) Number Wdrawn During Intrvl | (3) Number Exposd to Risk | (4) Number of Termnl Events | (5) Propn Terminating | (6) Propn Surviving | (7) Cumul Propn Surv at End | (8) Probability Densty | (9) Hazard Rate | (10) SE of Cumul Surviving | (11) SE of Probability Densty | (12) SE of Hazard Rate |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| .0 | 185.0 | .0 | 185.0 | 54.0 | .2919 | .7081 | .7081 | .0584 | .0684 | .0334 | .0067 | .0092 |
| 5.0 | 131.0 | .0 | 131.0 | 16.0 | .1221 | .8779 | .6216 | .0173 | .0260 | .0357 | .0041 | .0065 |
| 10.0 | 115.0 | .0 | 115.0 | 6.0 | .0522 | .9478 | .5892 | .0065 | .0107 | .0362 | .0026 | .0044 |
| 15.0 | 109.0 | .0 | 109.0 | 6.0 | .0550 | .9450 | .5568 | .0065 | .0113 | .0365 | .0026 | .0046 |
| 20.0 | 103.0 | .0 | 103.0 | 14.0 | .1359 | .8641 | .4811 | .0151 | .0292 | .0367 | .0039 | .0078 |
| 25.0 | 89.0 | .0 | 89.0 | 9.0 | .1011 | .8989 | .4324 | .0097 | .0213 | .0364 | .0032 | .0071 |
| 30.0 | 80.0 | .0 | 80.0 | 8.0 | .1000 | .9000 | .3892 | .0086 | .0211 | .0358 | .0030 | .0074 |
| 35.0 | 72.0 | .0 | 72.0 | 8.0 | .1111 | .8889 | .3459 | .0086 | .0235 | .0350 | .0030 | .0083 |
| 40.0 | 64.0 | .0 | 64.0 | 4.0 | .0625 | .9375 | .3243 | .0043 | .0129 | .0344 | .0021 | .0064 |
| 45.0 | 60.0 | .0 | 60.0 | 4.0 | .0667 | .9333 | .3027 | .0043 | .0138 | .0338 | .0021 | .0069 |
| 50.0 | 56.0 | .0 | 56.0 | 7.0 | .1250 | .8750 | .2649 | .0076 | .0267 | .0324 | .0028 | .0101 |
| 55.0 | 49.0 | .0 | 49.0 | 10.0 | .2041 | .7959 | .2108 | .0108 | .0455 | .0300 | .0033 | .0143 |
| 60.0 | 39.0 | .0 | 39.0 | 10.0 | .2564 | .7436 | .1568 | .0108 | .0588 | .0267 | .0033 | .0184 |
| 65.0 | 29.0 | .0 | 29.0 | 9.0 | .3103 | .6897 | .1081 | .0097 | .0735 | .0228 | .0032 | .0241 |
| 70.0 | 20.0 | .0 | 20.0 | 5.0 | .2500 | .7500 | .0811 | .0054 | .0571 | .0201 | .0024 | .0253 |
| 75.0 | 15.0 | .0 | 15.0 | 5.0 | .3333 | .6667 | .0541 | .0054 | .0800 | .0166 | .0024 | .0351 |
| 80.0 | 10.0 | .0 | 10.0 | 5.0 | .5000 | .5000 | .0270 | .0054 | .1333 | .0119 | .0024 | .0562 |
| 85.0 | 5.0 | .0 | 5.0 | 5.0 | 1.0000 | .0000 | .0000 | .0054 | .4000 | .0000 | .0024 | .0000 |

The median survival time for these data is 23.75

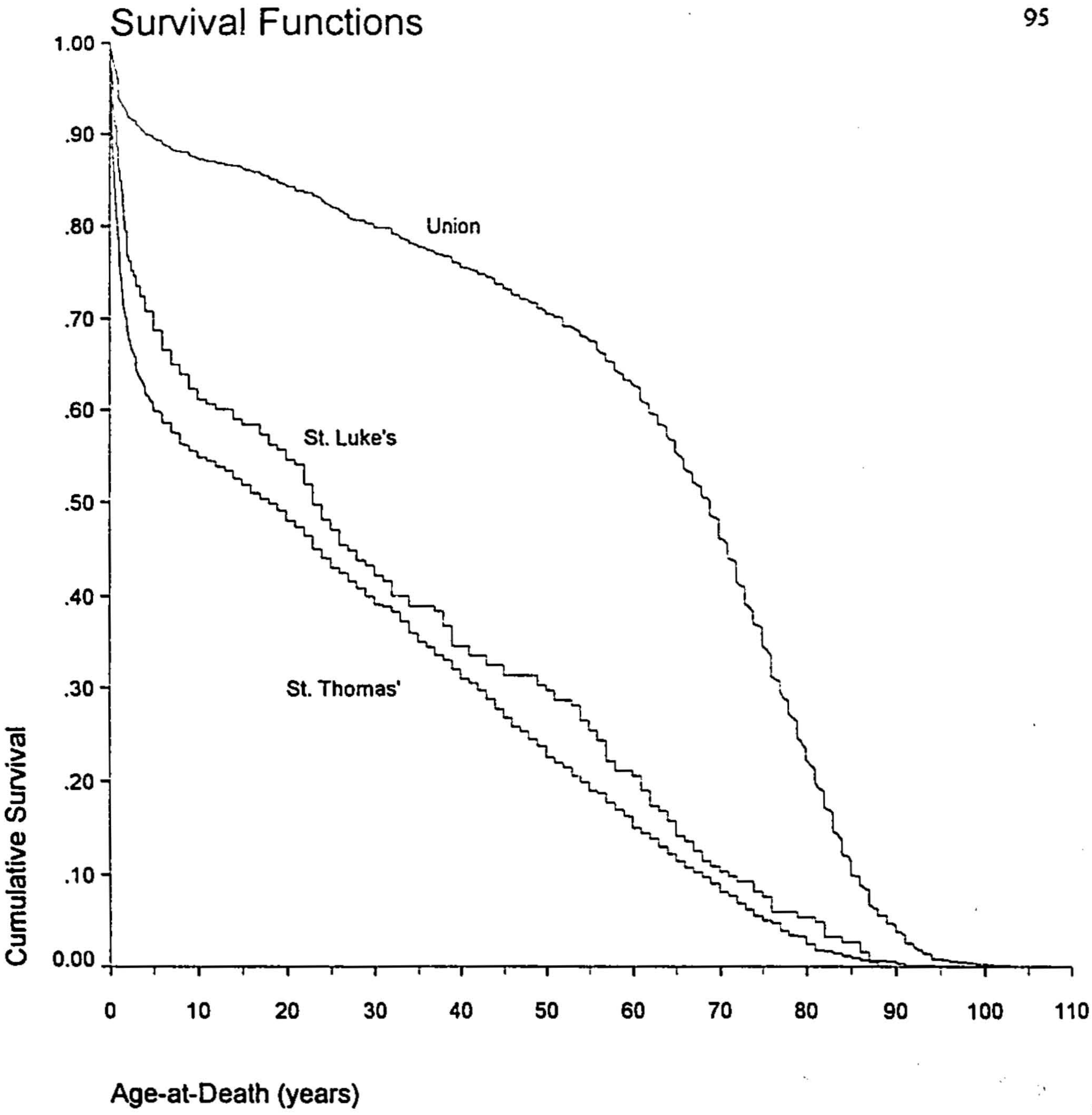

FIGURE 5.1: Cumulative survivorship curve for the St. Thomas', Union and St. Luke's cemetery populations

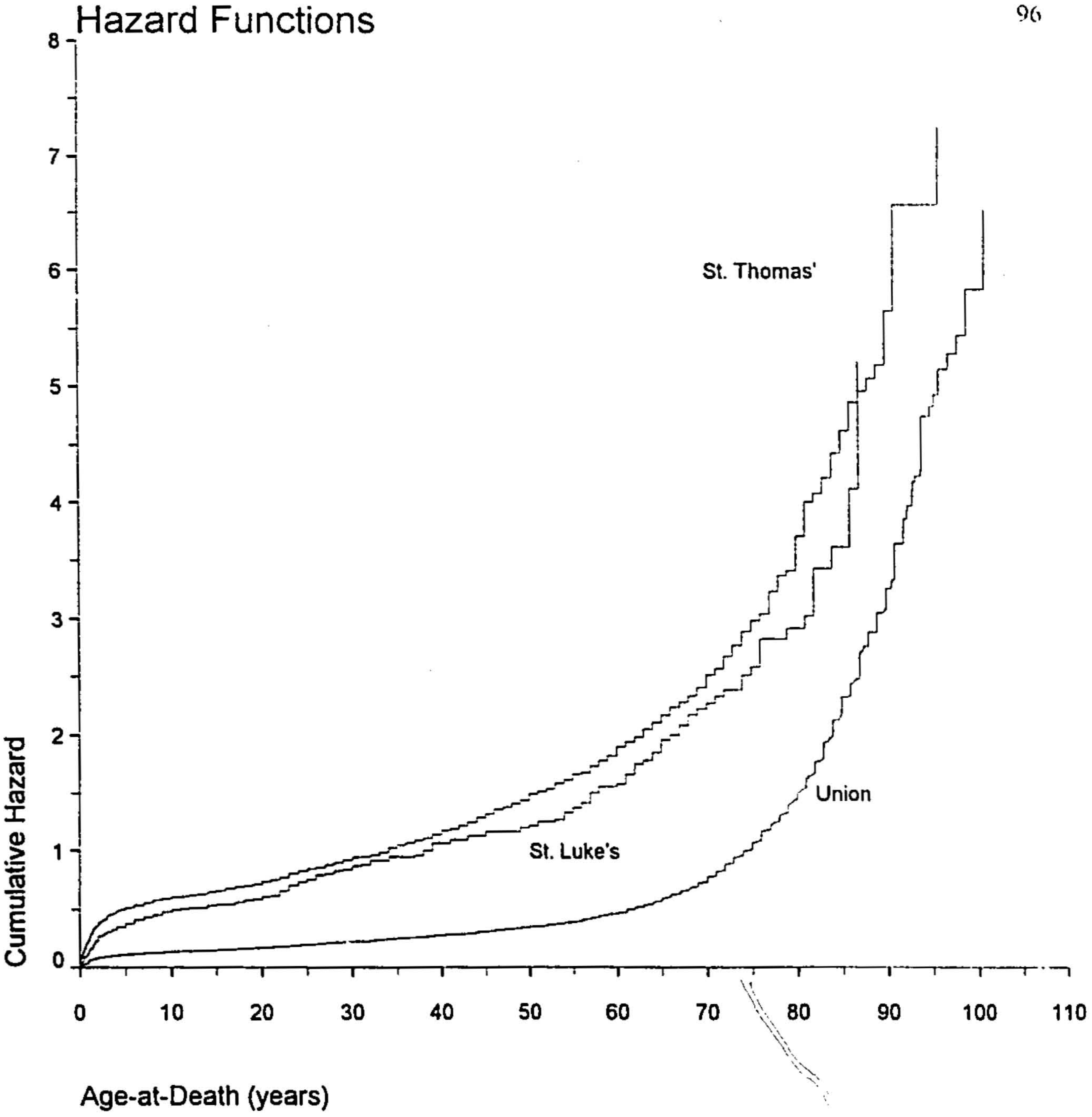

FIGURE 5.2: Cumulative hazards function curve for the St. Thomas', Union and St. Luke's cemetery populations

TABLE 5.4: Life expectancy and their standard errors calculated using LifePro (Sawchuk and Anthony 1994) for each of the three cemetery populations.

| | St Thomas' | | Union | | St. Luke's | |
|---|---|---|---|---|---|---|
| Age Group | $e_x$ | se $e_x$ | $e_x$ | se $e_x$ | $e_x$ | se $e_x$ |
| 0-5 | 26.96 | 0.702865 | 58.56 | 0.754035 | 30.77 | 2.020686 |
| 5-10 | 37.78 | 0.776184 | 60.02 | 0.616200 | 37.42 | 2.142841 |
| 10-15 | 36.08 | 0.747815 | 56.50 | 0.571598 | 37.28 | 2.068206 |
| 15-20 | 33.06 | 0.729874 | 52.14 | 0.552451 | 34.20 | 2.028977 |
| 20-25 | 30.12 | 0.714750 | 48.25 | 0.520101 | 31.04 | 2.002252 |
| 25-30 | 28.34 | 0.691595 | 44.54 | 0.481776 | 30.53 | 1.924301 |
| 30-35 | 25.98 | 0.669845 | 40.61 | 0.449733 | 28.69 | 1.831249 |
| 35-40 | 23.54 | 0.649299 | 36.72 | 0.416827 | 26.60 | 1.721682 |
| 40-45 | 21.18 | 0.629776 | 32.60 | 0.391275 | 24.61 | 1.573420 |
| 45-50 | 19.07 | 0.608742 | 28.55 | 0.365686 | 21.08 | 1.495791 |
| 50-55 | 16.82 | 0.588708 | 24.57 | 0.340759 | 17.41 | 1.447924 |
| 55-60 | 14.60 | 0.571137 | 20.54 | 0.320311 | 14.54 | 1.413321 |
| 60-65 | 12.39 | 0.559722 | 16.93 | 0.296259 | 12.63 | 1.398406 |
| 65-70 | 10.65 | 0.553186 | 13.55 | 0.274342 | 11.12 | 1.377085 |
| 70-75 | 8.52 | 0.558937 | 10.52 | 0.256314 | 10.00 | 1.250009 |
| 75-80 | 7.25 | 0.599820 | 8.08 | 0.245538 | 7.50 | 1.054105 |
| 80-85 | 5.48 | 0.683963 | 6.15 | 0.250363 | 5.00 | 0.790588 |
| 85-90 | 5.74 | 1.014321 | 5.02 | 0.283529 | 2.50 | |
| 90-95 | 4.39 | 1.231532 | 3.77 | 0.354438 | | |
| 95-100 | 5.01 | 1.771942 | 4.17 | 0.680801 | | |
| 100+ | 2.51 | | 2.50 | | | |
| MAD | 26.12 | | 58.13 | | 30.11 | |
| se MAD | 0.71 | | 0.76 | | 2.04 | |

TABLE 5.5: Comparisons of survival distributions by sex for each of the cemetery populations.

| Sex | N | MAD | s.e. | 95% c.i. | Log Rank | p | Breslow | p | Tarone-Ware | p |
|---|---|---|---|---|---|---|---|---|---|---|
| **St. Thomas' Cemetery Population** | | | | | | | | | | |
| Male | 805 | 27.88 | 0.96 | 26.00-29.75 | 7.69 | .0055 | 8.85 | .0029 | 8.46 | .0036 |
| Female | 618 | 23.82 | 1.05 | 27.77-25.88 | | | | | | |
| **Union Cemetery Population** | | | | | | | | | | |
| Male | 701 | 58.61 | 1.03 | 56.59-60.63 | .30 | .5826 | .06 | .8018 | .17 | .6811 |
| Female | 668 | 57.79 | 1.11 | 55.60-59.97 | | | | | | |
| **St. Lukes Cemetery Population** | | | | | | | | | | |
| Male | 54 | 29.39 | 3.63 | 22.27-36.51 | 1.31 | .2521 | 2.15 | .1425 | 1.80 | .1799 |
| Female | 50 | 22.99 | 3.61 | 15.92-30.06 | | | | | | |

TABLE 5.6: Comparisons of survival distributions by birth cohort (decade of birth) for each of the cemetery populations.

| Birth Cohort | N | MAD | s.e. | 95% c.i. | Log Rank | p | Breslow | p | Tarone-Ware | p |
|---|---|---|---|---|---|---|---|---|---|---|
| **St. Thomas' Cemetery Population** | | | | | | | | | | |
| **1730** | 1 | 86.00 | | | | | | | | |
| **1740** | 2 | 77.00 | | | | | | | | |
| **1750** | 10 | 77.30 | 2.74 | 71.94-82.66 | | | | | | |
| **1760** | 29 | 75.79 | 2.27 | 71.35-80.24 | | | | | | |
| **1770** | 48 | 69.85 | 1.59 | 66.72-72.97 | | | | | | |
| **1780** | 71 | 64.55 | 1.63 | 61.46-67.83 | | | | | | |
| **1790** | 129 | 59.54 | 1.22 | 57.15-61.94 | | | | | | |
| **1800** | 108 | 49.90 | 1.28 | 47.39-52.41 | | | | | | |
| **1810** | 118 | 39.44 | 1.20 | 37.08-41.80 | | | | | | |
| **1820** | 148 | 23.17 | 1.28 | 20.67-25.68 | | | | | | |
| **1830** | 146 | 15.71 | 1.11 | 13.54-17.88 | | | | | | |
| **1840** | 196 | 7.76 | 0.65 | 6.49-9.04 | | | | | | |
| **1850** | 197 | 3.37 | 0.36 | 2.66-4.08 | | | | | | |
| **1860** | 183 | 1.83 | 0.17 | 1.51-2.16 | | | | | | |
| **1870** | 35 | 0.48 | 0.09 | 0.31-0.65 | | | | | | |
| Overall | | | | | 1928.90 | <.0001 | 1421.25 | <.0001 | 1648.78 | <.0001 |
| **Union Cemetery Population** | | | | | | | | | | |
| **1750** | 2 | 85.16 | 2.16 | 80.93-89.38 | | | | | | |
| **1760** | 3 | 92.62 | 1.80 | 89.10-96.15 | | | | | | |
| **1770** | 5 | 79.59 | 2.11 | 75.46-83.72 | | | | | | |
| **1780** | 6 | 78.77 | 5.61 | 67.78-89.76 | | | | | | |
| **1790** | 19 | 71.04 | 3.20 | 64.77-77.31 | | | | | | |
| **1800** | 36 | 71.43 | 2.35 | 66.83-76.03 | | | | | | |
| **1810** | 54 | 71.48 | 1.80 | 67.95-75.02 | | | | | | |
| **1820** | 63 | 70.39 | 2.16 | 66.15-74.62 | | | | | | |
| **1830** | 110 | 63.14 | 2.23 | 58.77-67.50 | | | | | | |
| **1840** | 109 | 55.74 | 2.75 | 50.35-61.12 | | | | | | |
| **1850** | 122 | 59.51 | 2.59 | 54.44-64.58 | | | | | | |

TABLE 5.6 (cont)

| Birth Cohort | N | MAD | s.e. | 95% c.i. | Log Rank | p | Breslow | p | Tarone-Ware | p |
|---|---|---|---|---|---|---|---|---|---|---|
| 1860 | 166 | 62.10 | 2.23 | 57.74-66.46 | | | | | | |
| 1870 | 149 | 66.00 | 2.05 | 61.99-70.02 | | | | | | |
| 1880 | 195 | 60.00 | 2.03 | 56.03-63.98 | | | | | | |
| 1890 | 129 | 57.62 | 2.28 | 53.15-62.08 | | | | | | |
| 1900 | 75 | 51.59 | 2.56 | 46.57-56.62 | | | | | | |
| 1910 | 470 | 33.48 | 3.56 | 26.50-40.45 | | | | | | |
| 1920 | 25 | 27.48 | 4.14 | 19.36-35.60 | | | | | | |
| 1930 | 12 | 12.88 | 3.16 | 6.68-19.08 | | | | | | |
| 1940 | 14 | 14.99 | 2.67 | 9.76-20.23 | | | | | | |
| 1950 | 16 | 4.60 | 1.57 | 1.52-7.68 | | | | | | |
| 1960 | 6 | 7.44 | 2.49 | 2.55-12.33 | | | | | | |
| 1970 | 3 | 0.10 | 0.05 | 0-0.19 | | | | | | |
| Overall | 1366 | | | | 1010.10 | <.0001 | 913.34 | <.0001 | 959.54 | <.0001 |
| St. Lukes Cemetery Population | | | | | | | | | | |
| 1750 | 3 | 87.00 | 0.58 | 85.87-88.13 | | | | | | |
| 1760 | 5 | 83.60 | 1.21 | 81.23-85.97 | | | | | | |
| 1770 | 10 | 74.00 | 1.70 | 70.67-77.33 | | | | | | |
| 1780 | 18 | 63.22 | 1.19 | 60.90-65.55 | | | | | | |
| 1790 | 14 | 55.93 | 1.94 | 52.13-59.73 | | | | | | |
| 1800 | 13 | 47.38 | 3.04 | 41.44-53.33 | | | | | | |
| 1810 | 11 | 37.09 | 2.13 | 32.91-41.27 | | | | | | |
| 1820 | 20 | 25.50 | 1.23 | 23.09-27.91 | | | | | | |
| 1830 | 21 | 12.70 | 1.60 | 9.58-15.83 | | | | | | |
| 1840 | 51 | 3.15 | 0.71 | 1.76-4.54 | | | | | | |
| 1850 | 8 | 3.34 | 2.07 | 0-7.39 | | | | | | |
| 1860 | 3 | 2.75 | 2.15 | 0-6.96 | | | | | | |
| Overall | 177 | | | | 320.93 | <.0001 | 244.02 | <.0001 | 277.16 | <.0001 |

Table 5.7: Comparisons of survival distributions by death cohort (decade of burial) for each of the cemetery populations.

| Death Cohort | N | MAD | s.e. | 95% c.i. | Log Rank | p | Breslow | p | Tarone-Ware | p |
|---|---|---|---|---|---|---|---|---|---|---|
| **St. Thomas' Cemetery Population** | | | | | | | | | | |
| 1820 | 78 | 29.72 | 2.92 | 23.99-35.44 | | | | | | |
| 1830 | 114 | 20.29 | 2.08 | 16.20-24.37 | | | | | | |
| 1840 | 260 | 25.43 | 1.66 | 22.18-28.69 | | | | | | |
| 1850 | 395 | 25.91 | 1.35 | 23.27-28.55 | | | | | | |
| 1860 | 402 | 26.27 | 1.33 | 23.66-28.88 | | | | | | |
| 1870 | 173 | 29.20 | 2.22 | 24.84-33.56 | | | | | | |
| Overall | 1422 | | | | 12.83 | .0250 | 6.98 | .2220 | 9.11 | .1047 |
| **Union Cemetery Population** | | | | | | | | | | |
| 1830 | 3 | 29.18 | 26.91 | 0-81.94 | | | | | | |
| 1840 | 25 | 20.78 | 4.97 | 11.04-30.52 | | | | | | |
| 1850 | 32 | 34.24 | 5.50 | 23.46-45.01 | | | | | | |
| 1860 | 58 | 29.41 | 3.69 | 22.19-36.64 | | | | | | |
| 1870 | 61 | 40.53 | 3.68 | 33.32-47.74 | | | | | | |
| 1880 | 92 | 40.89 | 3.18 | 34.66-47.11 | | | | | | |
| 1890 | 88 | 51.05 | 3.12 | 44.94-57.15 | | | | | | |
| 1900 | 100 | 59.97 | 2.65 | 54.74-65.17 | | | | | | |
| 1910 | 99 | 59.73 | 2.60 | 54.63-64.83 | | | | | | |
| 1920 | 113 | 59.30 | 2.48 | 54.44-64.16 | | | | | | |
| 1930 | 107 | 63.62 | 2.27 | 59.17-68.06 | | | | | | |
| 1940 | 134 | 67.68 | 1.68 | 64.38-70.98 | | | | | | |
| 1950 | 167 | 66.89 | 1.84 | 63.29-70.48 | | | | | | |
| 1960 | 164 | 69.90 | 1.60 | 66.77-73.04 | | | | | | |
| 1970 | 123 | 68.70 | 1.98 | 64.82-72.58 | | | | | | |
| Overall | 1366 | | | | 237.33 | <.0001 | 344.76 | <.0001 | 313.85 | <.0001 |
| **St. Lukes' Cemetery Population** | | | | | | | | | | |
| 1840 | 118 | 29.17 | 2.71 | 23.85-34.48 | | | | | | |
| 1850 | 45 | 30.04 | 3.46 | 23.26-36.82 | | | | | | |
| 1860 | 17 | 37.07 | 7.23 | 22.91-51.23 | | | | | | |
| Overall | 177 | | | | 1.33 | .5132 | 1.33 | .5142 | 1.00 | .6071 |

Rank test ($p<0.05$) but not for Breslow or Tarone-Ware which weight by sample size. These results seem to be related to the duration of the cemetery with a longer time span more likely to reflect distinct cohort survivorship curves; in this case 150 years for the Union cemetery population versus 30 or 50 years for the other two. This is of particular interest and will be discussed further, given the arguments that cemeteries of relatively long duration will tend to reflect the average mortality composition of the living population.

### *Mean Age-at-Death*

Figures 5.3-5.5 present boxplots[12] of the age-at-death distributions by birth cohort and Figures 5.6-5.8 present the age-at-death distributions by burial cohort for each of the three cemetery populations. Again, it is interesting to note that the shape of these distributions is similar for the St. Thomas' and St. Luke's cemetery populations. For the birth cohorts, both show a near linear decrease in median age by birth cohort over time. Oddly enough, the distributions by death cohort also are similar with an early drop in the age distribution followed by a slow incline. In contrast, the Union cemetery population exhibits the expected pattern of high ages for early birth cohorts and low ages for more recent birth cohorts but with a more wide-spread distributions of ages through the middle of the period. This is due to its long duration — whereas the other two cemeteries do not span the human lifespan, Union's 150 year period of use means that during the middle of the period all ages will be represented simply because all of the population at risk for those cohorts will *have to* die.

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[12] Boxplots display the median and interquartile range. The bold line represents the median for the group while the upper and lower limit of the box are the third and first quartile values respectively. The error bars represent the highest and lowest non-outlier value for the group, while circles are individual outliers (values beyond 1.5 box lengths from the median) and the asterisks are extreme cases (values beyond 3 box lengths from the median).

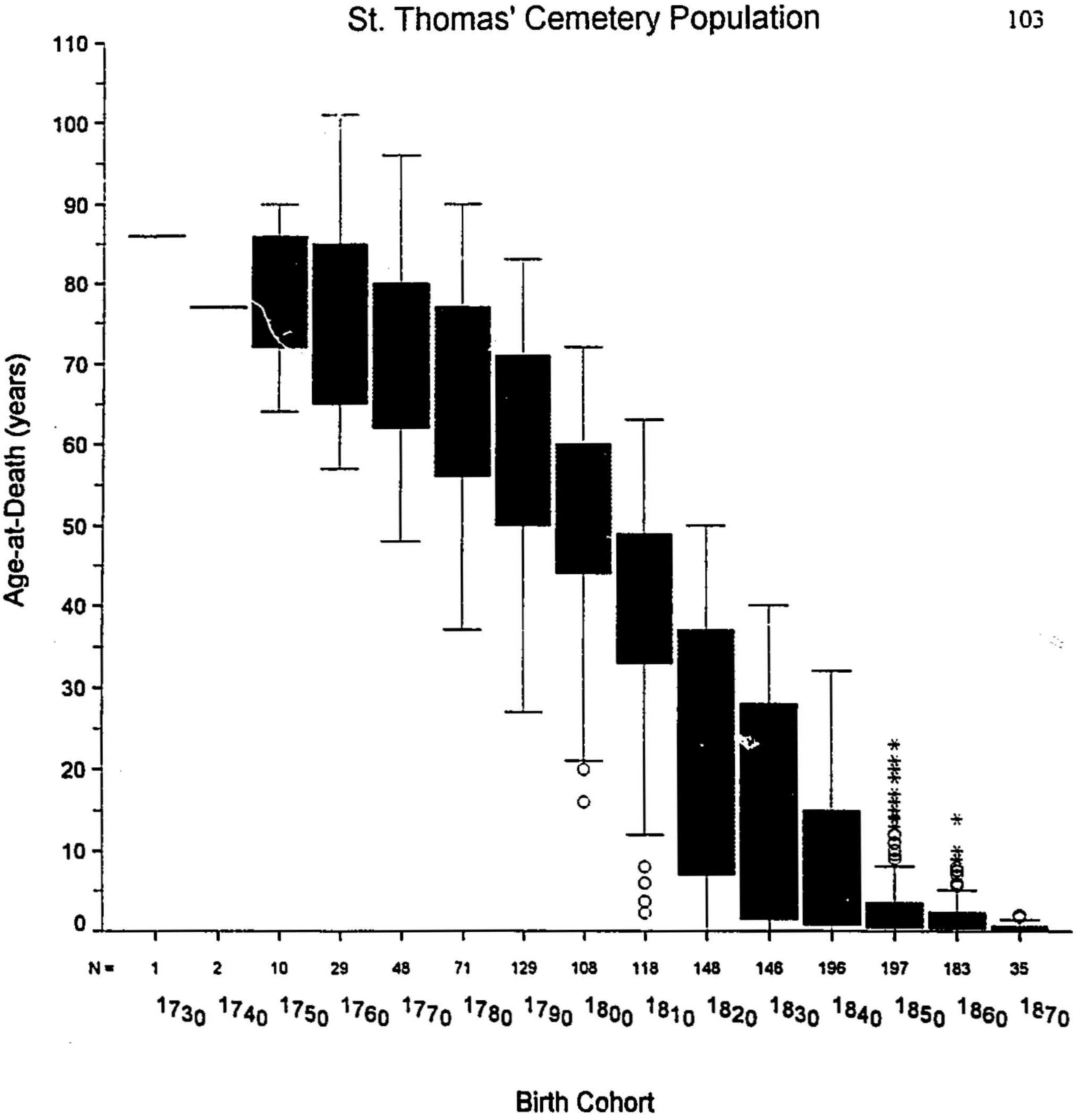

FIGURE 5.3: Box plot showing the distribution of burials within the St. Thomas' cemetery population, grouped by birth cohort (decade of birth)

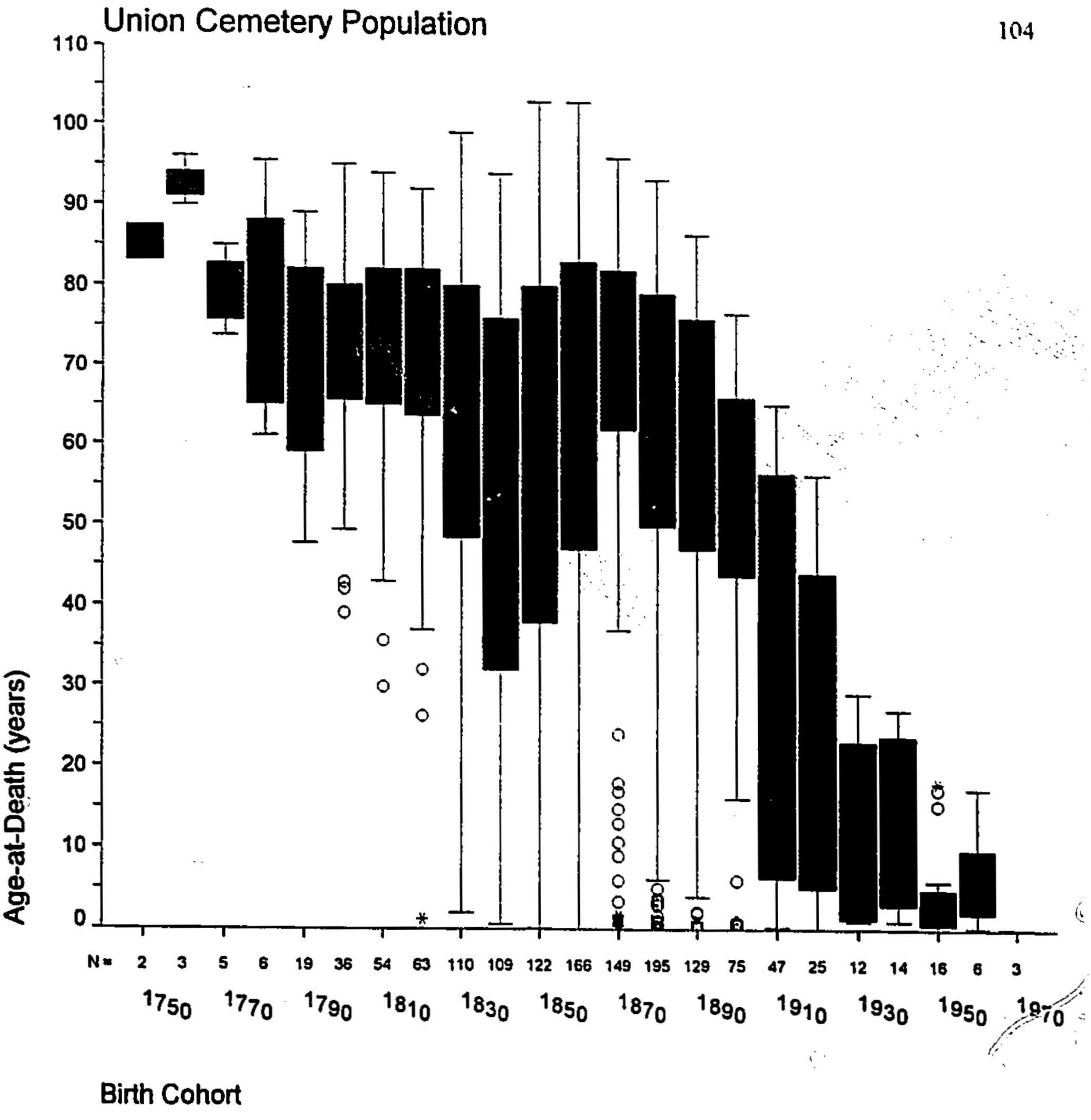

FIGURE 5.4: Box plot showing the distribution of burials within the Union cemetery population, grouped by birth cohort (decade of birth)

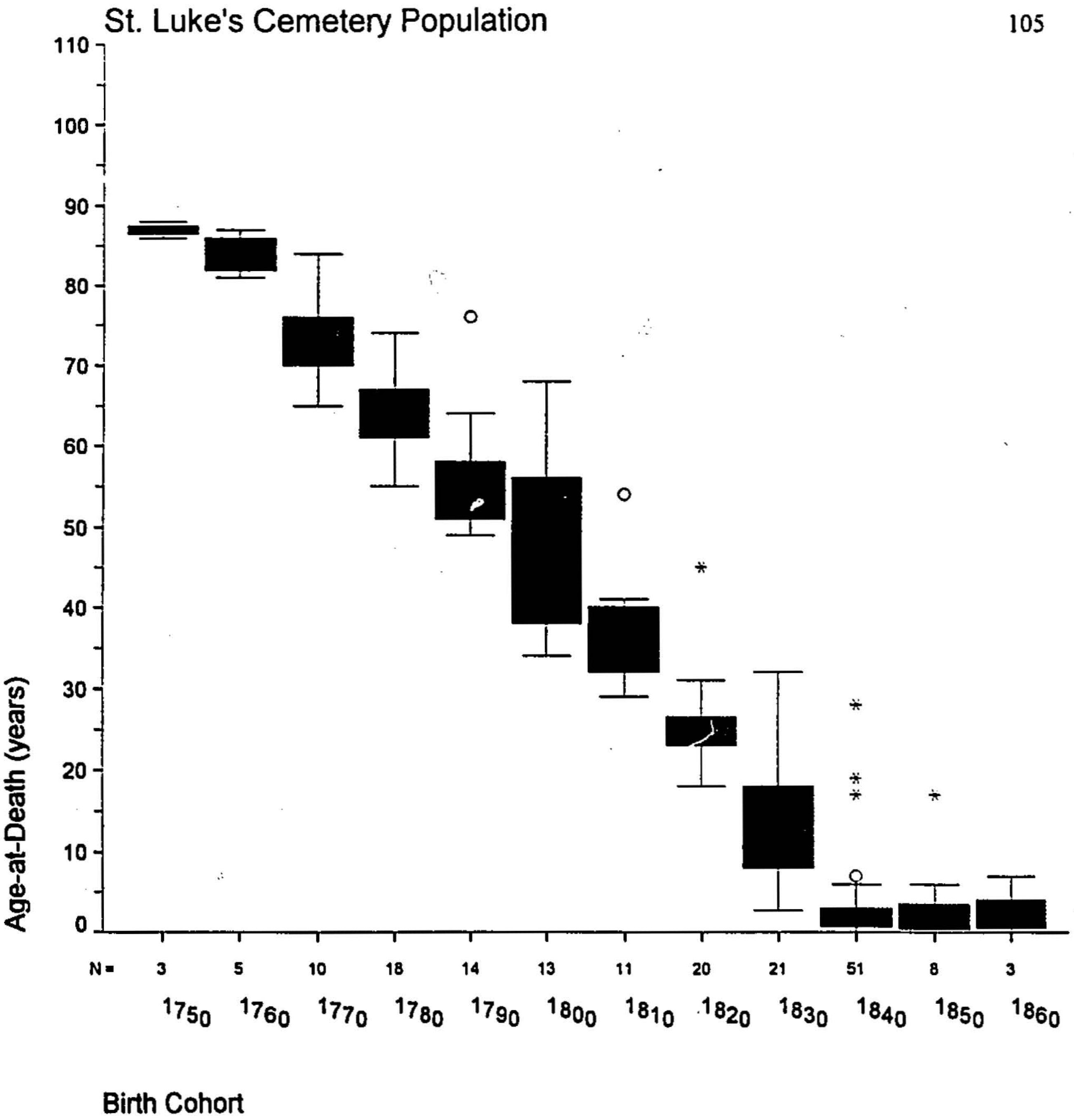

FIGURE 5.5: Box plot showing the distribution of burials within the St. Luke's cemetery population, grouped by birth cohort (decade of birth)

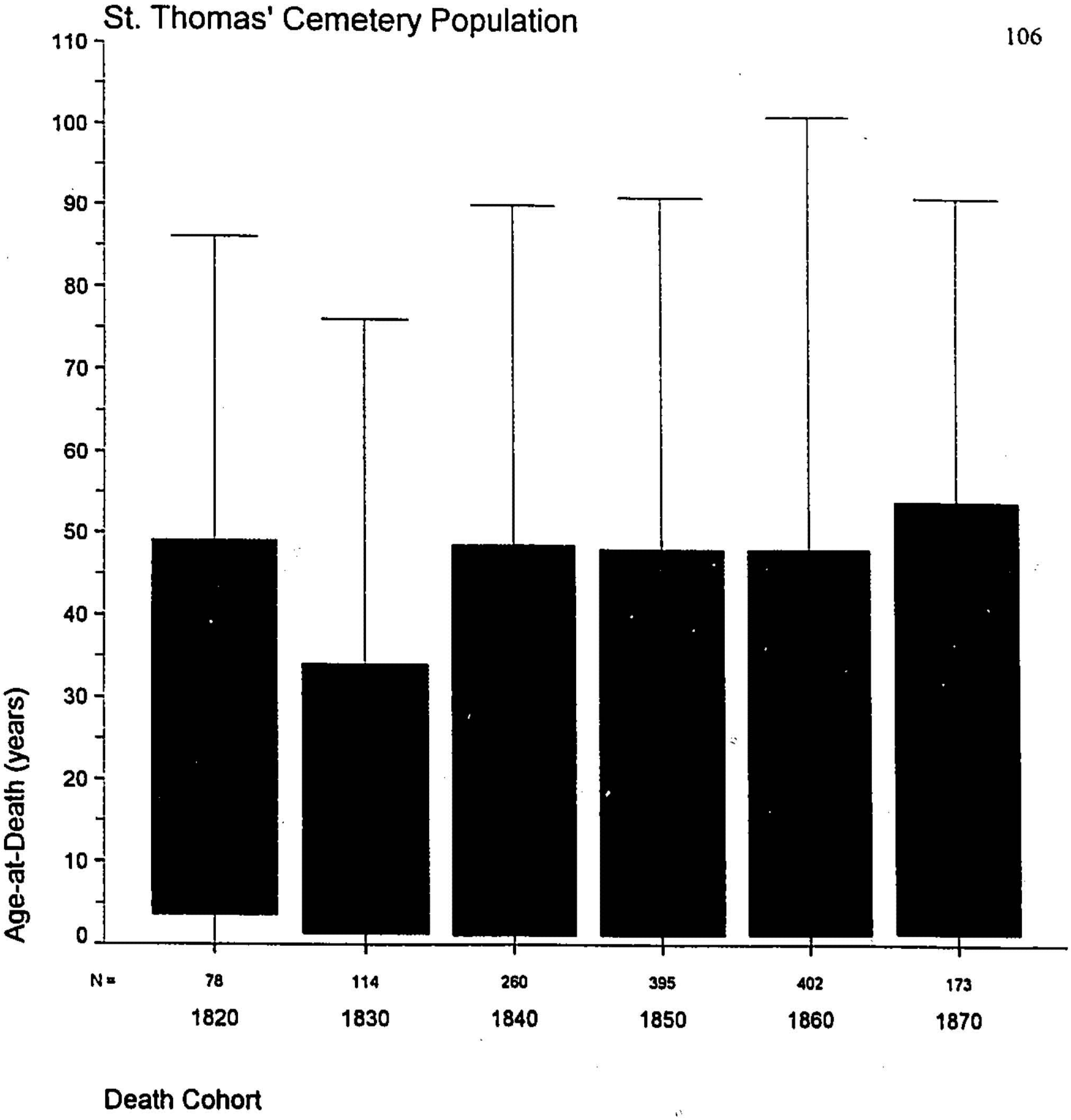

FIGURE 5.6: Box plot showing the distribution of burials within the St. Thomas' cemetery population, grouped by death cohort (decade of death)

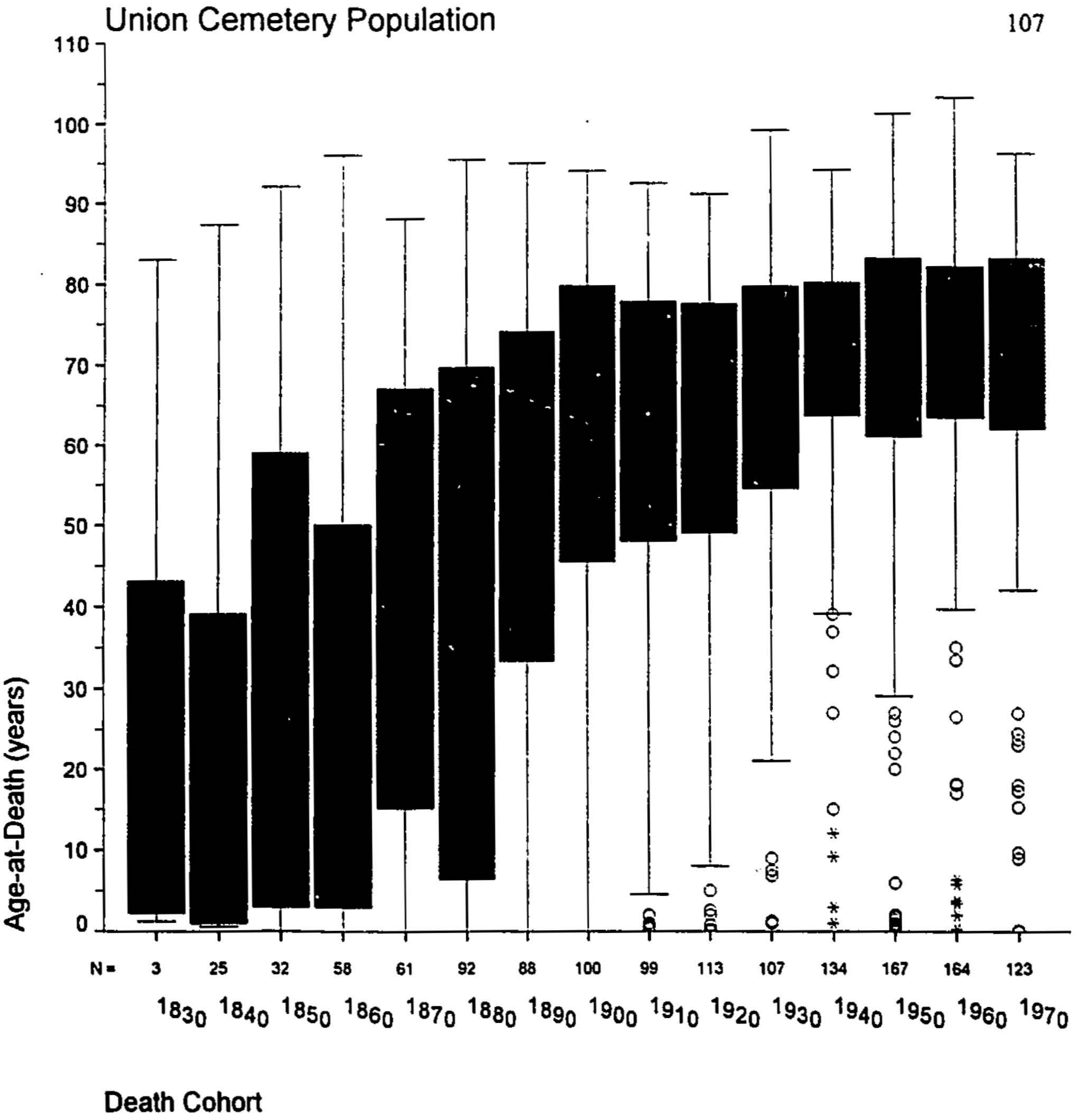

FIGURE 5.7: Box plot showing the distribution of burials within the Union cemetery population, grouped by death cohort (decade of death)

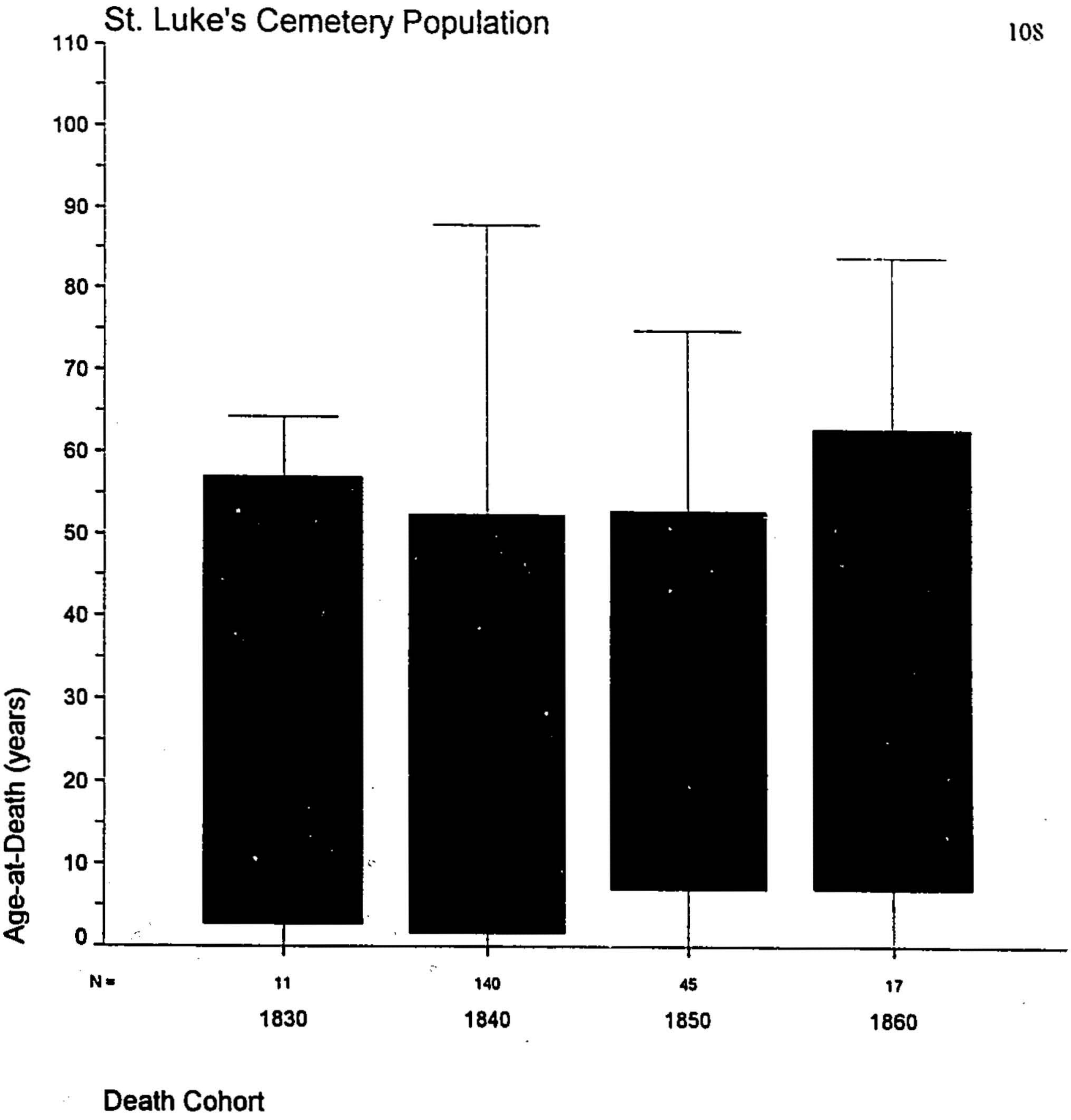

FIGURE 5.8: Box plot showing the distribution of burials within the St. Luke's cemetery population, grouped by death cohort (decade of death)

With respect to the distributions of ages-at-death by death cohort, the later period (1940 and on) are represented primarily by older adults for the opposite reason — many of the children and young adults at risk in these decades will not die until after the 1970's.

Figures 5.9 and 5.10 plot age-at-death versus year of burial, illustrating the relative density of ages over time for the two larger cemeteries. While the St. Thomas' population appears to have a nearly constant rate of burials (ie all ages are equally represented), the Union population clearly shows a higher density of older adult burials toward the later period. Not only is the upper boundary more densely plotted than that for St. Thomas', but there is a clear increase in density in the older age groups beginning at the turn of the century and continuing through the mid to late 20th century. This contrast is likely a reflection of the changes in mortality patterns in the 20th century that cannot be observed in the St. Thomas' sample because it ends in 1874. The fact that Union represents a period of a century and a half and St. Thomas' covers only 50 years may also contribute to the observed differences.

### *Other Demographic Parameters*

Table 5.8 presents populations ratios for each of the three cemeteries (cf pp 31-32; Table 2.2). For each of the three cemetery populations, model mortality distributions were fitted using Paine's (1989) maximum likelihood technique. This technique uses a maximum likelihood algorithm to predict the population parameters that most probably produced the mortality distribution observed (see discussion pp. 33-34). As in the original application of this technique, Coale and Demeny's (1966) Model West life tables are used to predict the demographic parameters. These (as opposed to the Model East, North and South) are the most applicable to the cemetery populations utilized here, and are widely used for

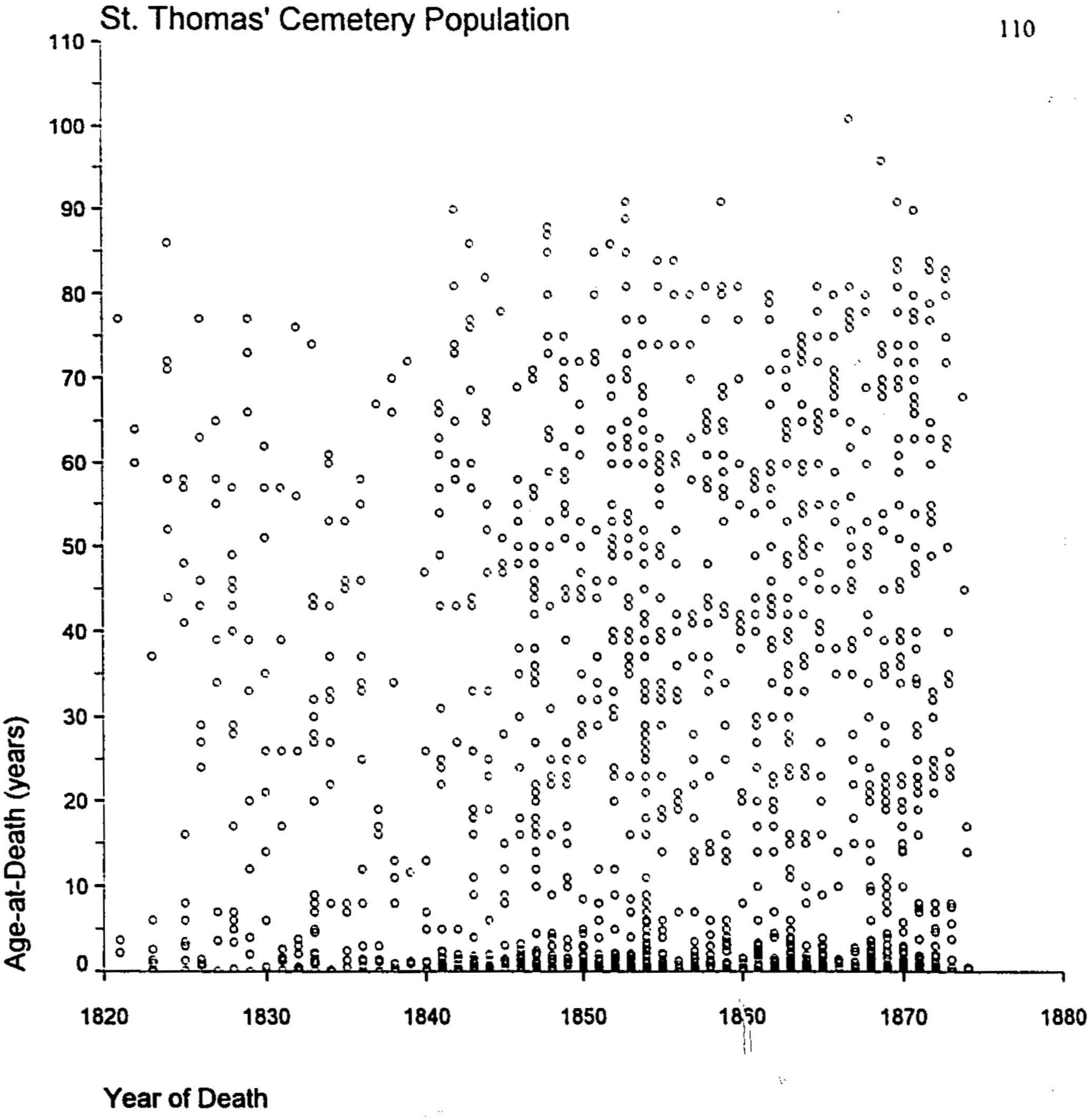

FIGURE 5.9: Scattergram plotting the year of death versus age at death for all individuals in the St. Thomas' cemetery population

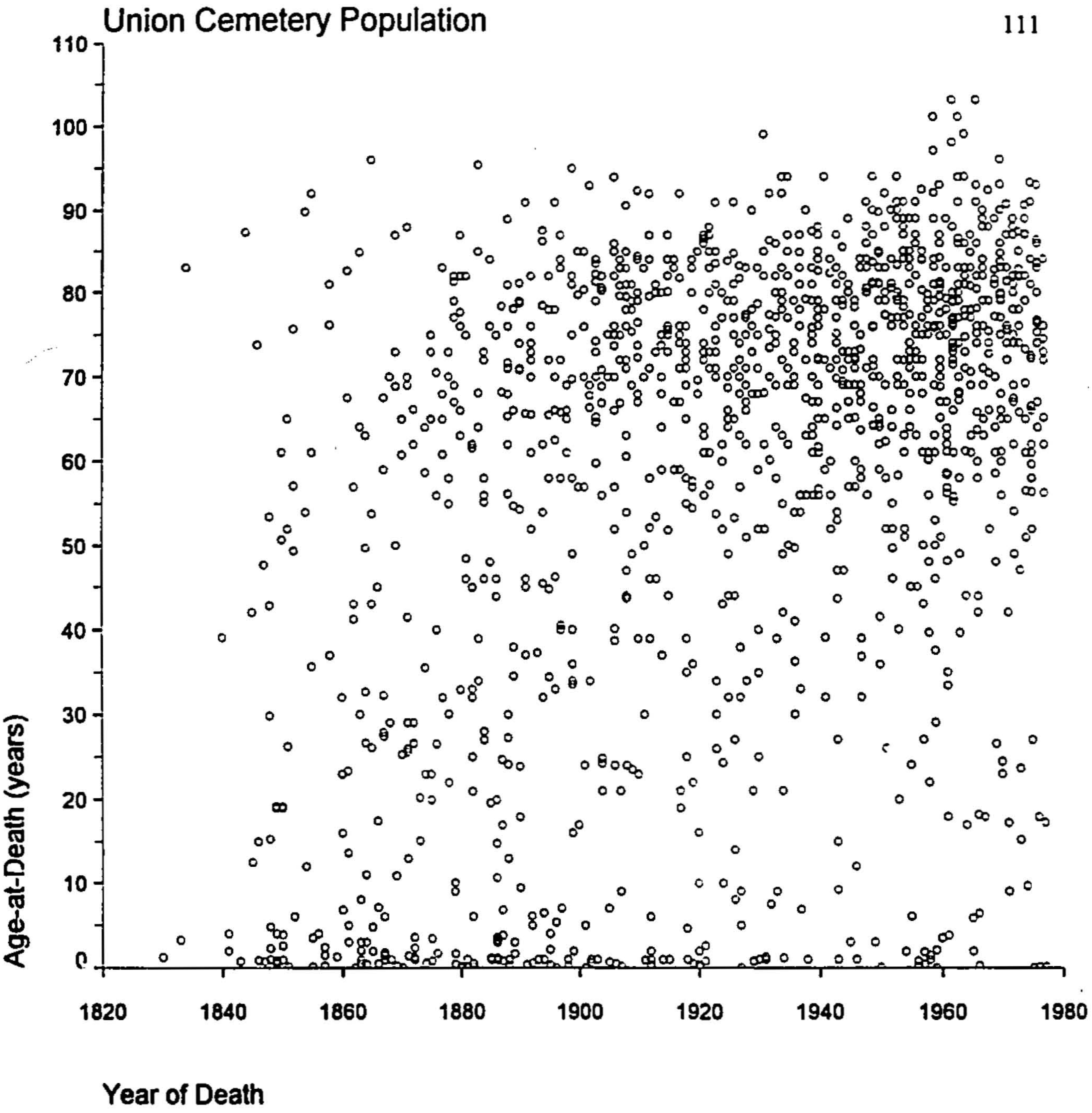

FIGURE 5.10: Scattergram plotting the year of death versus age at death for all individuals in the Union cemetery population. The scatter suggests an increasing density of burials of older adults throughout the duration of the cemetery

TABLE 5.8 Population ratios for each of the three cemetery populations.

| SAMPLE | Sex<br>Ratio | Dependency<br>Ratio (%) | Juvenile/<br>Adult Ratio | MCM | 30+<br>5+ | 20+<br>5+ |
|---|---|---|---|---|---|---|
| St. Thomas' | 1.298 | 69.6416 | .18448 | .068 | .614173 | .795276 |
| Union | 1.030 | 74.9091 | .040552 | .02 | .892596 | .943043 |
| St. Luke's | 1.036 | 66.4865 | .227723 | .076 | .652582 | .801643 |

TABLE 5.9: Parameter values for Paine's (1989) maximum likelihood models for each of the three cemetery populations.

| SAMPLE | GRR | $e_{10}$ | Pearson's $x^2$ | $P$ | Likelihood Ratio $-2(L_1-L_2)$ |
|---|---|---|---|---|---|
| St. Thomas' | 2.556 | 34.378 | 44.404 | <.0001 | -52.415 |
| Union | 1.116 | 52.452 | 20.473 | .001 | -58.853 |
| St. Luke's | 2.389 | 42.419 | 26.271 | <.0001 | 11.439 |

TABLE 5.10: Demographic rates estimated by Paine's (1989) maximum likelihood fitting technique. Crude birth and death rates are per 1000.

| SAMPLE | CBR | CDR | r | MAD | MAD >5 years |
|---|---|---|---|---|---|
| St. Thomas' | 40 | 34 | .006 | 25.102 | 35.820 |
| Union | 15 | 22 | -.007 | 55.414 | 60.244 |
| St. Luke's | 37 | 26 | .011 | 27.907 | 38.442 |

comparisons in anthropological populations in general (eg. Jackes 1992; Paine 1989; Saunders et al. 1995). Table 5.9 presents the parameter values of the maximum likelihood models, and Table 5.10 presents the demographic rates estimated by those models. The fitted model mortality distributions are illustrated in Figures 5.11-5.13.

The demographic parameters estimated from Paine's (1989) model life table fitting technique suggests, again, that St. Thomas' and St. Luke's are the most similar in terms of fertility, with estimated gross reproductive rates (GRR) of approximately 2.5. In contrast, the Union cemetery population's gross reproductive rate (GRR) is estimated to be approximately 1.1. As such the former two are suggested to be drawn from living populations which were undergoing very moderate growth (r=0.006 and 0.11 respectively) while the living population contributing to the Union cemetery appears to have been in decline (r=-0.007). The crude birth (CBR) and death rates (CDR) for the populations also reflect this growth. The estimated CBR's for the St. Thomas' and St. Luke's cemeteries is toward the high end of the scale being 40 and 37 respectively (55+ can be found in some developing countries), while the Union cemetery has a very low estimated CBR of 15 per 1000. All three populations show CDR's which fall within normal historical ranges of 30 to 40 per 1000, as levels much greater than this could not have been sustained for very long (Wilson 1985). This is somewhat odd given that the lowest CDR's should occur in rapidly growing, young populations with a high life expectancy (Wilson 1985). Union cemetery has an estimated growth rate that is negative, but the $e_{10}$ is the highest of the three.

The dependency ratio (sum of children under 14 years and adults over 60-65 years divided by all others), calculated as a percentage, is quite high for all three burial populations,

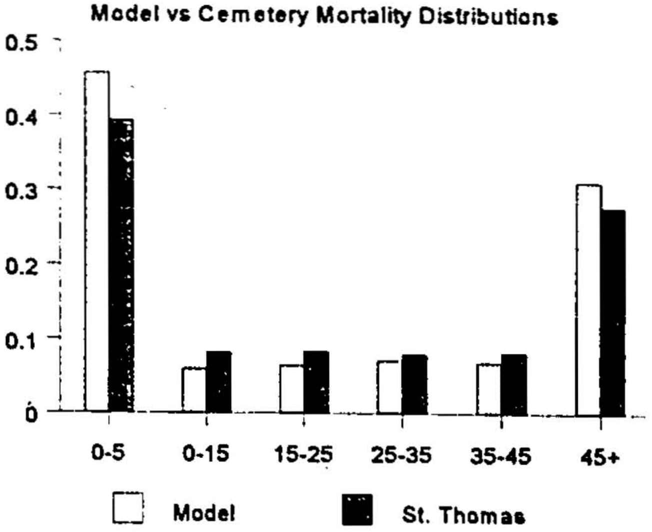

FIGURE 5.11 Model West (Coale and Demeny 1966) mortality distribution best fitted to the St, Thomas cemetery age distribution using Paine's (1989) maximum likelihood fitting technique.

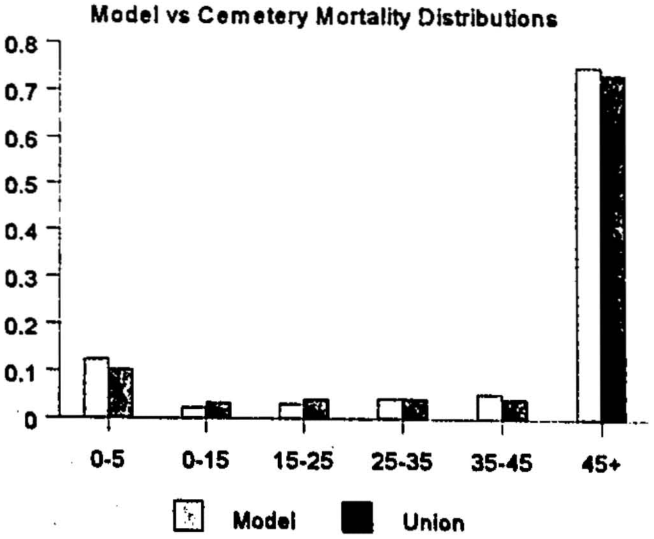

FIGURE 5.12: Model West (Coale and Demeny 1966) mortality distribution best fitted to the Union cemetery age distribution using Paine's (1989) maximum likelihood fitting technique.

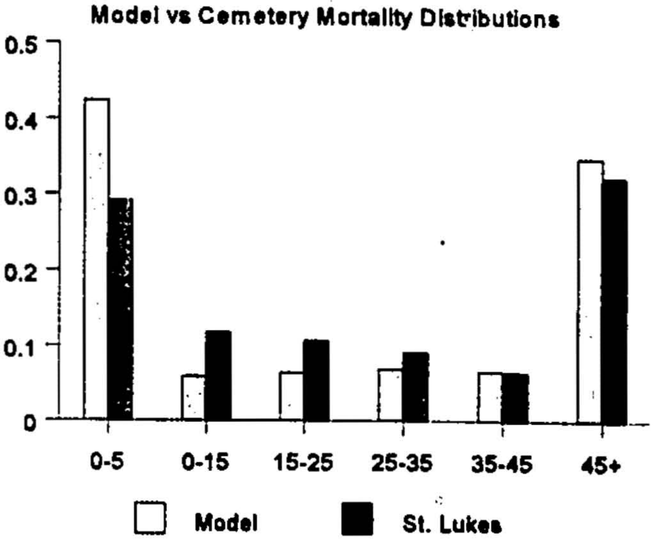

FIGURE 5.13: Model West (Coale and Demeny 1966) mortality distribution best fitted to the St, Luke's cemetery age distribution using Paine's (1989) maximum likelihood fitting technique.

with values comparable to those observed in developing countries. It should be noted however, that the level of fertility and mortality in developing countries results in a higher proportion of child-dependents (as opposed to elderly dependents), and thus the ratio is significantly affected by the levels of fertility and mortality within the population (Pollard et al. 1990). Because of this, it has been suggested that two dependency ratios be calculated in order to assess differences between the two groups. In this case we know that there are a substantial number of infants in the St. Thomas' population (291 of 1423 or 20.4% of the total cemetery population) which are likely contributing to the high value. In contrast, it is the excessive number of elderly individuals (60 years of age and over) which are causing a large ratio for the Union cemetery population (866 of 1375 or 63.0% of the total cemetery

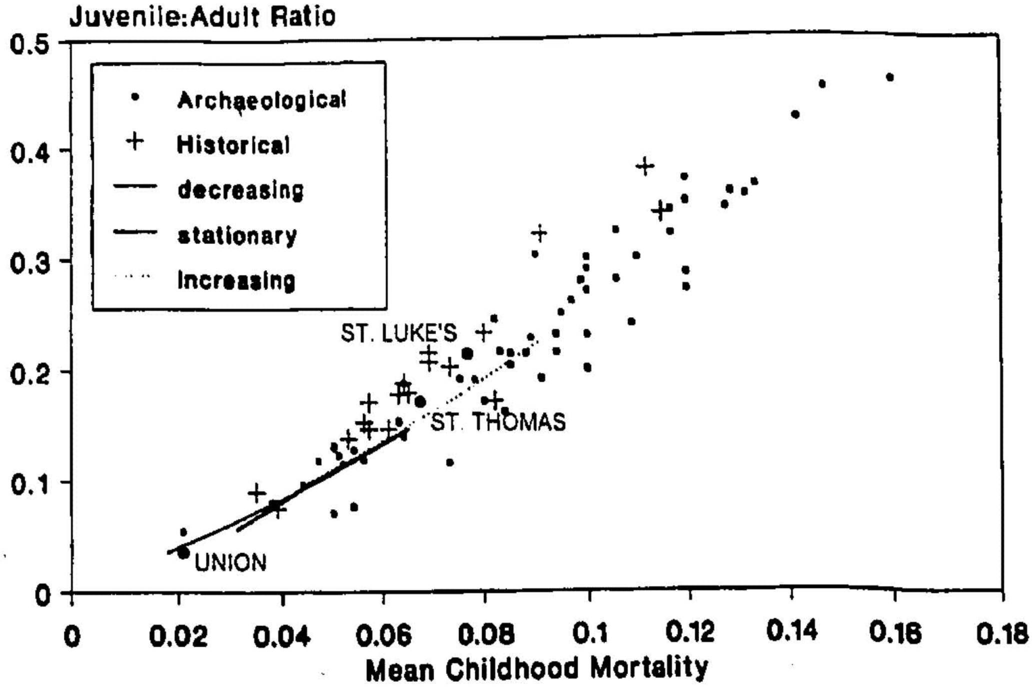

FIGURE 5.14: Mean childhood mortality versus juvenile/adult ratio (after Jackes 1992:216, Figure 8) showing the relationship between the two estimators for 60 archaeological sites compared with data from 17 historical life tables. The three cemetery populations used in this study are plotted.

population). The other ratios presented (with the exception of the sex ratio) are more similar in the St. Thomas' and St. Luke's cemeteries than the Union cemetery. Clearly, for the Union cemetery, there is a considerable excess of adults, which serve to create an unrealistically low Juvenile/Adult ratio (or high for the other two ratios). The sex ratio is approximately one for both the Union and St. Luke's population, while the St. Thomas' population shows a slight, albeit significant excess of males (Pearson's $\chi^2$=9.54161, df=3, p=0.02289).

Figure 5.14 (reproduced from Figure 8, Jackes 1992:216) illustrates the relationship between the mean childhood mortality and the juvenile/adult ratio for 60 archaeological sites compared with data from 17 historical life tables. All three cemetery populations fall close to the line, but the St. Thomas' and St. Luke's populations show higher mean childhood mortalities and juvenile adult ratios. Jackes (1992) notes that sites that are far from the line may be biased by preferential or incomplete excavation and the exclusion of adults of indeterminate age from the mortality profile. In this case, the latter is not at issue since all individuals are considered aged precisely. This suggests then, that these two mortality populations may not reflect the expected mortality distribution for historical populations (in either growth or decline). This is not surprising given that the best fitting model mortality distributions fitted by Paine's (1989) method (Tables 5.9 and 5.10, Figures 5.11-5.13) are still significantly different (p<.005 for all three) from that observed. However, the initial reasoning for using documented mortality samples for this study was that the use of model or simulated populations might miss the subtle nuances present in these real mortality samples. Clearly, this is the case here and while the three population do not reflect the expected mortality structure for a living population, they perhaps more closely approximate the kind of mortality distribution that one might find in an excavated cemetery sample. As such, they are perhaps more appropriate to use in a study which seeks to examine the relationship between the cemetery distribution and subsequent samples.

## *The Test Samples*

### *I: Simulations*

For this phase of the analysis, a variety of palaeodemographic parameters are examined for a series of samples generated from the three cemetery populations. These include the distributions of age-at-death, life tables, sex ratio and fertility. Each of these are examined for a variety of simulated samples generated from the three cemetery populations. To begin, the simple effects of random under-representation in the samples are examined. After this, additional biasing factors are examined. These are temporal, age, sex, methodological and environmental biases. Each of the biasing factors is explored by controlling the sampling procedure to reflect the respective bias. Although many of these biases can be introduced at various sampling levels (eg. sex bias in burials for cultural reasons vs sex bias in preservation for environmental reasons vs sex bias in assessment for methodological reasons), the present analysis does not attempt to model the cumulative effects of multiple sampling filters on an eventual skeletal or analyzable skeletal sample. In order to examine these effects simultaneously, more extensive data would be required on the actual relationship between each factor and the degree of representativeness within a skeletal sample. Without this kind of *a priori* knowledge, such models would provide little, if any, information on the impact of these factors on the overall representativeness of the sample.

In a preliminary study by Hoppa (1993), comparisons of random samples of sizes n=600, 400, 250 and 100 burials derived from a hypothetical burial population showed that differences in frequency distributions between the population and the sample are typically minimal (<1%) in samples over 100, but become highly variable for samples of 100 or less. The same result can be seen when examining specific statistics such as the mean age-at-death (MAD). On skeletal samples consisting of less than about 100 burials of known age, the mean age-at-death may be as much as 3 to 8 years above or below the actual MAD for the cemetery — again this difference is a result of chance alone. However, for samples of over approximately 250 individuals, this range is reduced one year above or below the actual MAD. This is important given that many palaeodemographic studies are dealing with samples of less than 250 individuals.

Based on these preliminary results (Hoppa 1993) it was deemed that samples of 500+ show approximately the same degree of representativeness or variation in the resampling distributions. These results are presented again here. Figure 5.15 presents the distributions of MAD (mean ± 2 s.d.) plotted against percent of total burial populations for the three cemetery populations.. The pattern observed is virtually the same for all three burial populations with deviation from the population MAD increasing for samples of about 40 percent and less of the total population. Figures 5.16a,b,c similarly present the resampling distributions of MAD (mean ± 2 s.d.) plotted against absolute sample size. Here, the confidence intervals for the population mean are overlaid to show at what point the sampling distribution becomes significantly different from the parent cemetery population. Consistent with the preliminary study (Hoppa 1993) these figures clearly demonstrate that variability in MAD is affected by absolute sample size, and that deviations away from the actual population

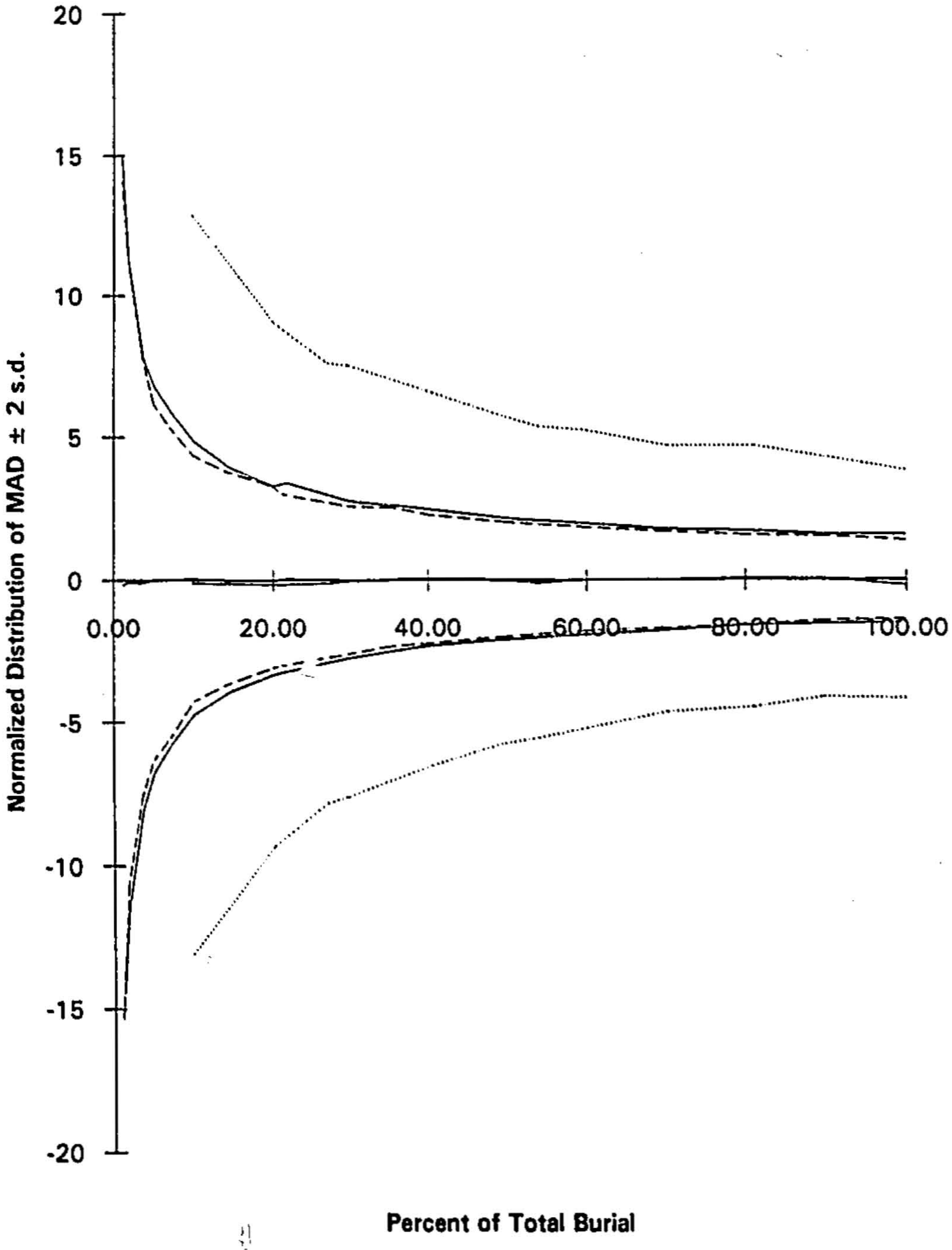

FIGURE 5.15: Resampling distribution of MAD (mean ± 2 s.d.) for decreasing samples which represent decreasing percentages of the total cemetery population. The three cemetery populations are depicted as follows: St. Thomas' (-----), Union (—), and St. Luke's (······)

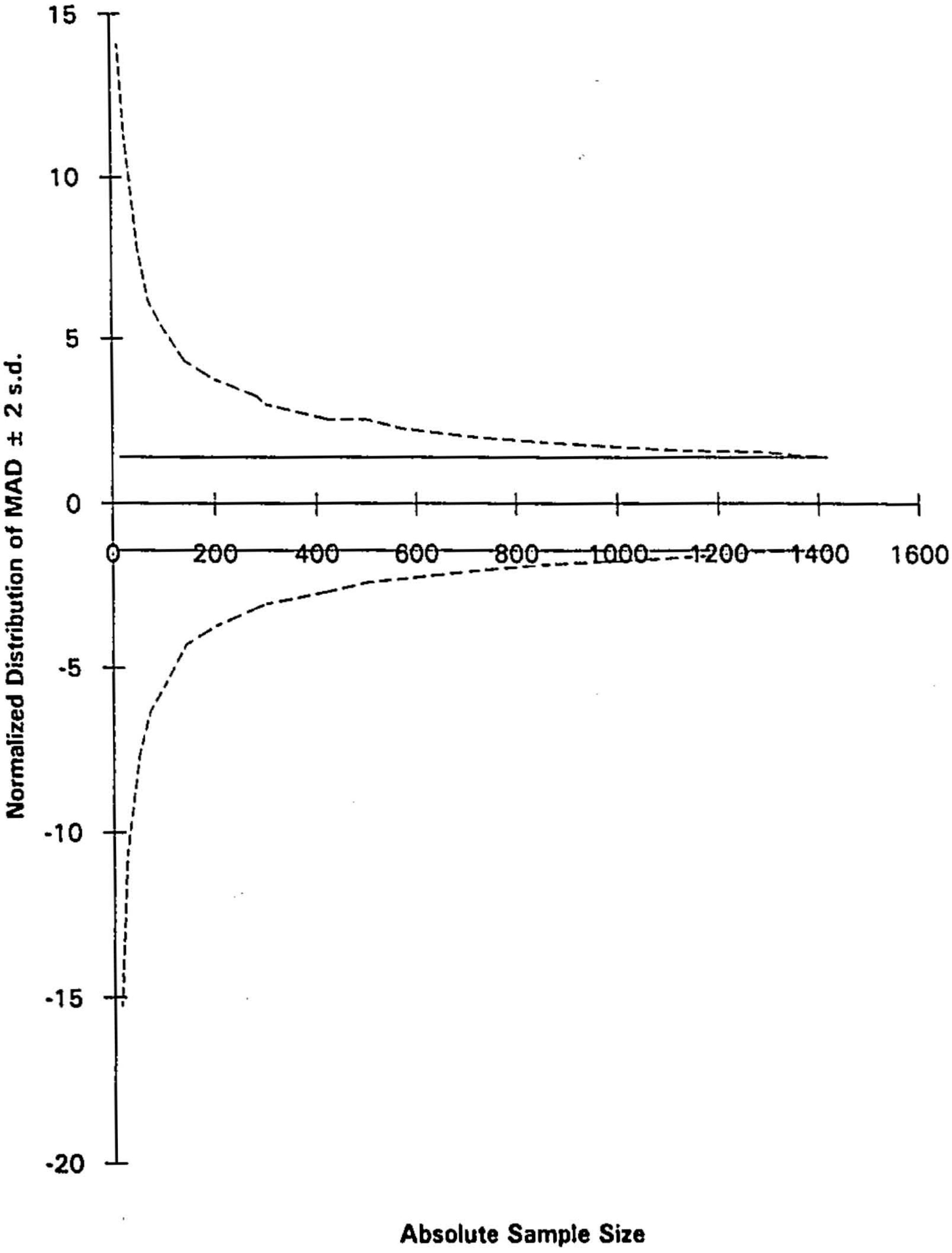

FIGURE 5.16A: Resampling distribution of MAD (mean ± 2 s.d.) for decreasing samples in absolute numbers. The two horizontal lines represent the upper and lower boundaries of the 95% confidence interval for the St. Thomas' cemetery population mean

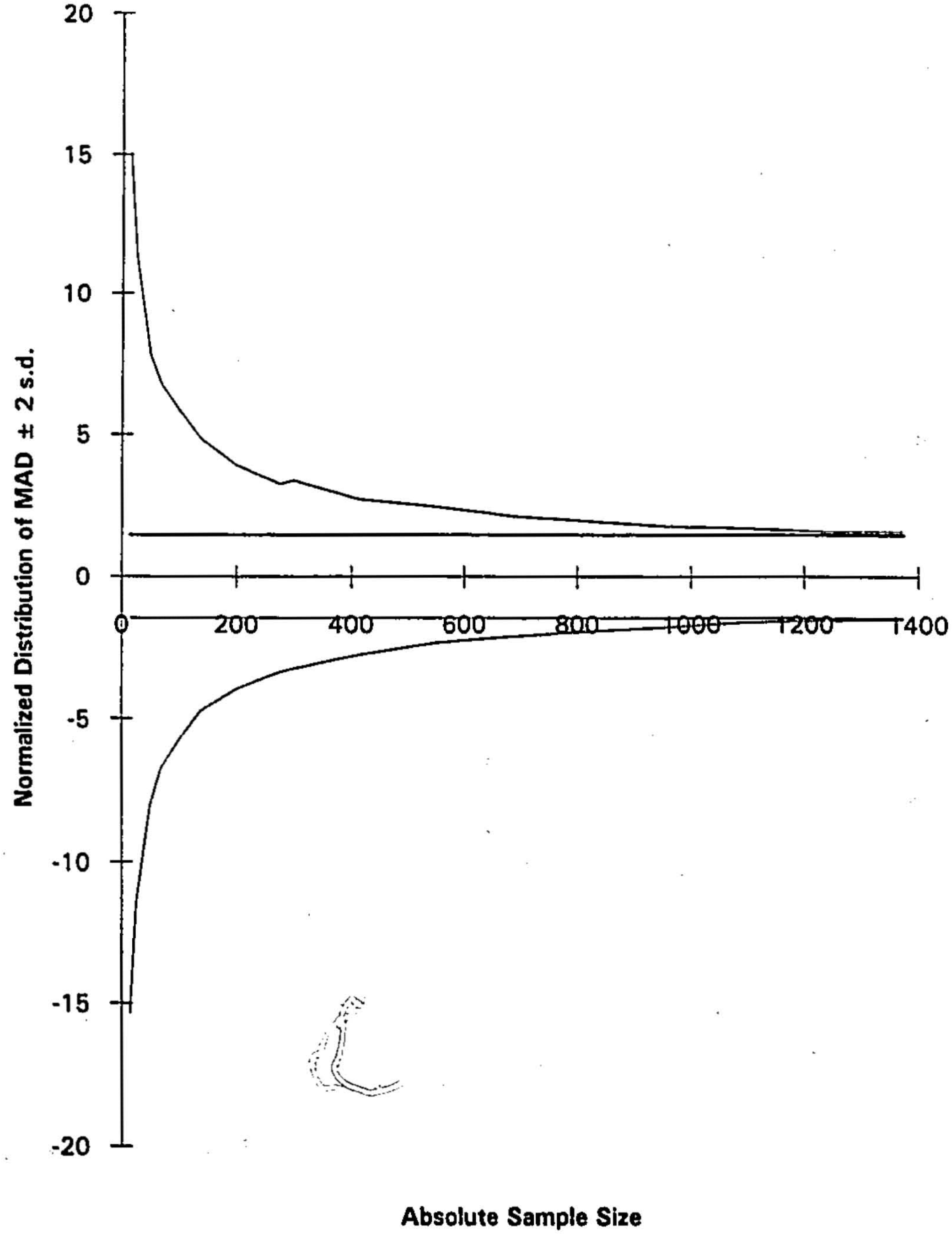

FIGURE 5.16B: Resampling distribution of MAD (mean ± 2 s.d.) for decreasing samples in absolute numbers. The two horizontal lines represent the upper and lower boundaries of the 95% confidence interval for the Union cemetery population mean

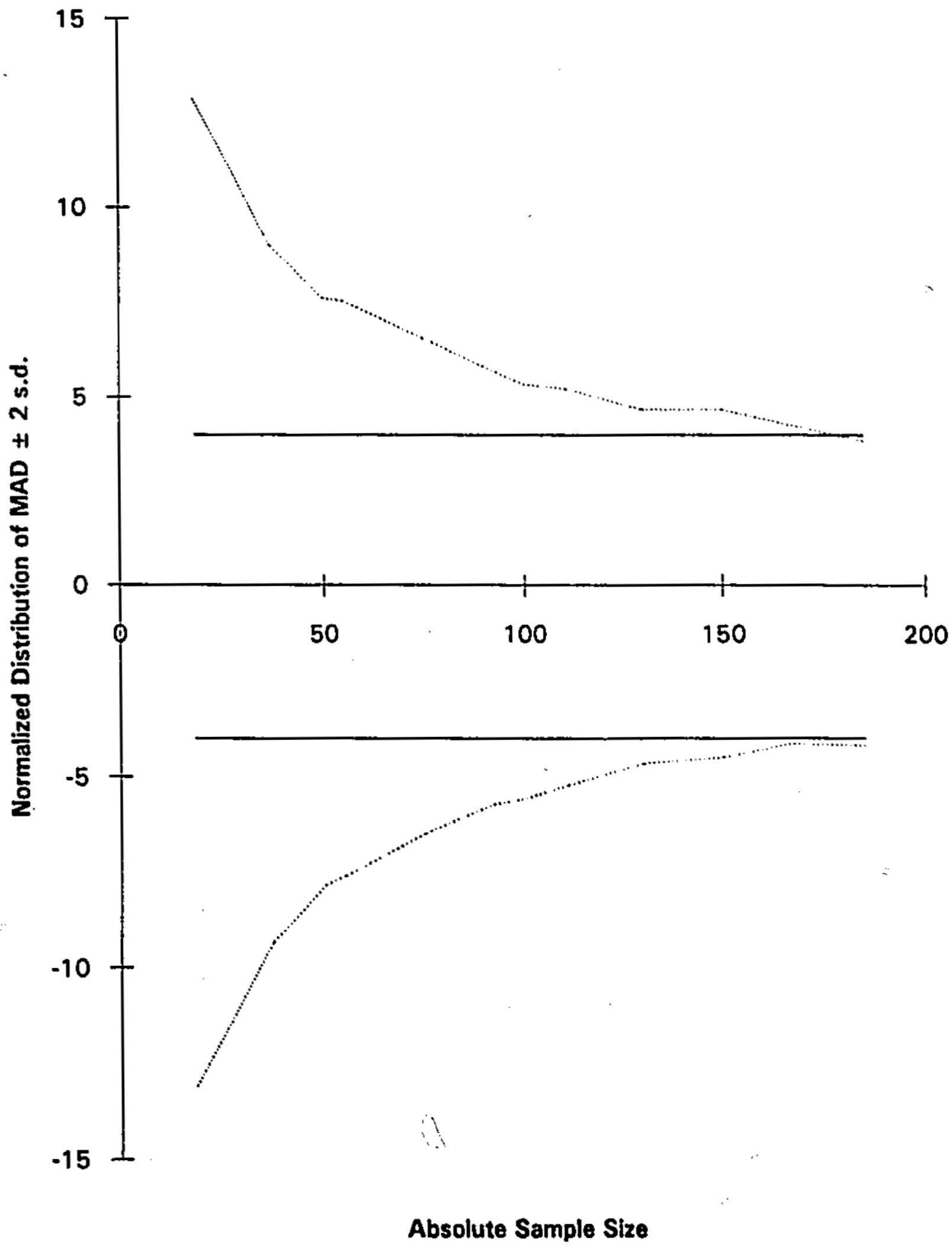

FIGURE 5.16C: Resampling distribution of MAD (mean ± 2 s.d.) for decreasing samples in absolute numbers. The two horizontal lines represent the upper and lower boundaries of the 95% confidence interval for the St. Luke's cemetery population mean

MAD begin with samples sizes of N=500 and quickly increase in samples of fewer individuals[13].

### *Age Bias*

Beyond simple sample size, the present study also examined the effects of age-bias in representation within a skeletal sample. For example, the under-representation of infants in many skeletal samples has long been an issue of contention. While it has been argued that infant bones are more susceptible to decay, it may be the lack of experience of the excavator in recognizing the small fragments of infant skeletons that results in the reduced recovery (Paine 1992; Saunders 1992; Storey 1992). Nevertheless, several methods of 'correcting' infant and juvenile proportions have been proposed.

The general effects of underrepresentation of infants, children and adults on a sample MAD are illustrated in Figures 5.17 through 5.19 for the St. Thomas' sample. Again, the patterning is the same for all three cemetery populations. Figure 5.17 again illustrates the potential deviance between a sample and cemetery MAD with a decreasing percentage representation within the sample. In Figure 5.18 we observe that while infant under-representation can affect the mean age-at-death within a sample, it is clearly much less significant than adult underrepresentation. While the difference between the sample and population MAD for infant under-representation follows a consistent trend toward under-estimation of the population MAD, it is never greater than about one year; and does not fall

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[13] This is of course not unexpected and there is a simple calculation which can be used to calculate the required sample size to fall within the 95 percent confidence interval of a population mean with a known level of variance, s, and a given level of tolerance, d: $n=(Z_{\alpha}\times\frac{s}{d})^2$ (Brown and Rothery 1993). For example, for a 95% confidence interval ($\alpha$=0.05), Z=1.96, and an estimated standard deviation of 8, with a tolerance say ±2, then $n=(1.96\cdot\frac{8}{2})^2=62$ .

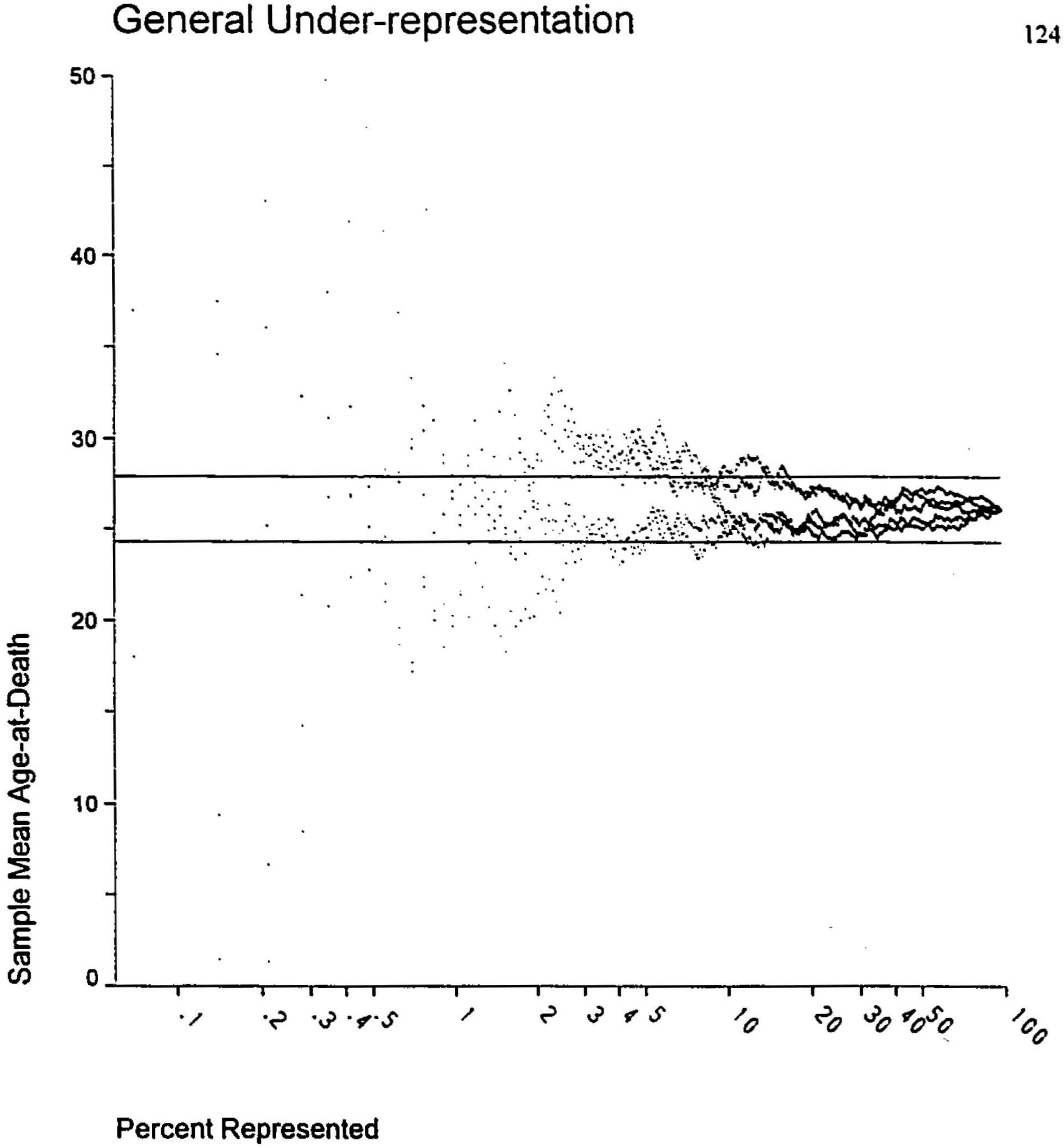

FIGURE 5.17: Sampling distribution of MAD showing the increased variability of the sample MAD as total representativeness (%) decreases. The two horizontal lines represent the upper and lower boundaries of the 99% confidence interval for the St. Thomas' cemetery population mean

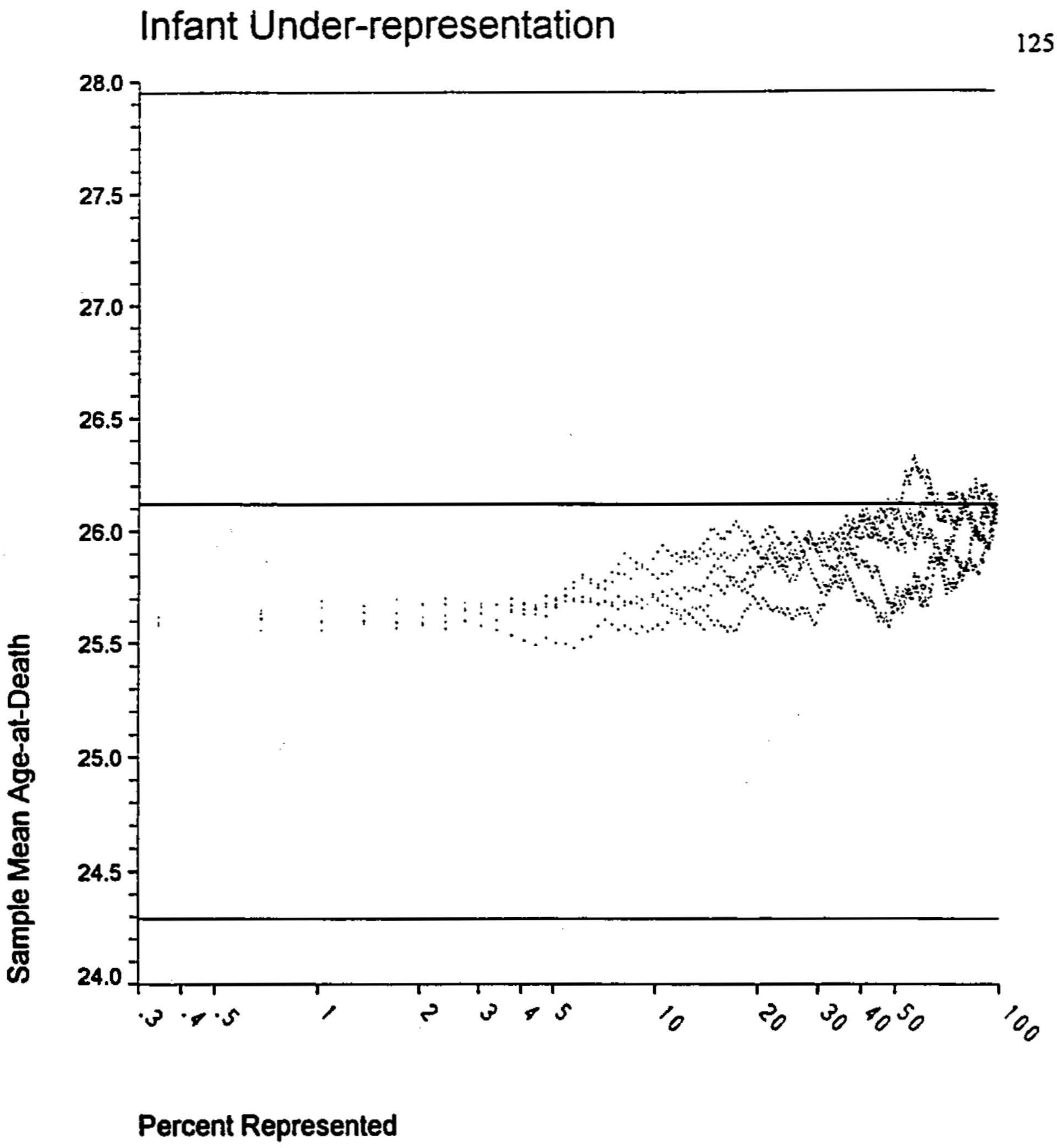

**FIGURE 5.18:** Sampling distribution of MAD showing the increased under-estimation of the sample MAD as infant representativeness (%) decreases. The bold horizontal line is the St. Thomas' cemetery population mean and the two light horizontal lines represent the upper and lower boundaries of the 99% confidence interval for the mean

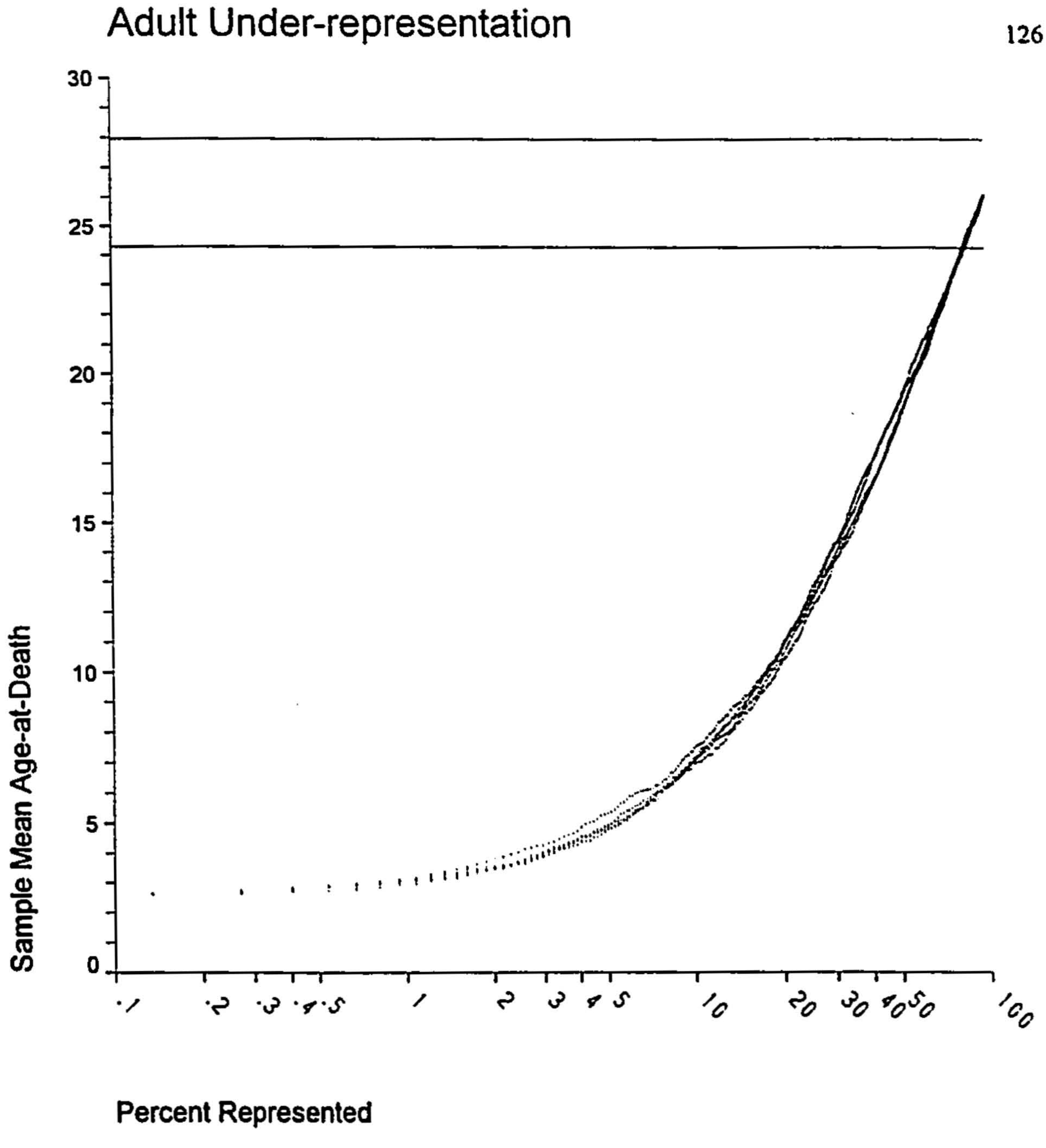

FIGURE 5.19: Sampling distribution of MAD showing the rapidly increasing under-estimation of the sample MAD as adult representativeness (%) decreases. The two horizontal lines represent the upper and lower boundaries of the 99% confidence interval for the St. Thomas' cemetery population mean

outside of the 99% confidence interval for the population's mean age-at-death. In contrast, the deviation between the sample and population MAD's drastically increases with only minimal adult under-representation, as shown in Figure 5.19. As Jackes (1992) notes, it is the under-representation of adults in a sample, that has a more dramatic effect on palaeodemographic statistics such as mean age-at-death, since adults contribute more to the population mean than do children or infants. This is clearly illustrated in Figures 5.17-5.19. Larsen et al. (1995) recognized this effect in their study, noting that clearly all the adults from the family were not included in the cemetery since calculated life expectancies were unrealistically low. Thus, adult under-representation forms a significant problem for studies This is particularly true when the population has a greater life expectancy since the absence of older adults will dramatically reduce the sample MAD. Hence, not only is there a relationship between adult representativeness and the accuracy of MAD estimates, but there is also a relationship between life expectancy and MAD.

There are further implications for adult under-representation in the calculation of various population ratios, some of which are used to estimate fertility (cf Table 2.2). As Jackes (1992) notes, most of the ratios proposed by physical anthropologists are intended to ignore the infant cohort — it is assumed that infants will be under-represented and thus infant mortality rates are inaccurate. While methodological biases in adult demography are minimized by these ratios[14], the absence of adults due to other biases will significantly affect these ratios.

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[14] Because most ratios are examining a broad adult age group (eg 20+) the imprecision in the ageing of older adults and the qualitative ageing (as adult) of fragmentary remains have little effect on the estimates.

### *Sex Bias*

Statistics on sex are perhaps the least subject to error, with the only serious consideration being accurate representation of the sexes when enumerated. Sex ratios for any population are affected by its past fertility, mortality and migration (Petersen 1975b). Petersen notes that one important reason for studying sex ratio is its importance to family formation, marriage patterns and other factors that can directly affect fertility rates within a population. Minimal error is introduced in contemporary or historical demographic studies and determination of sex in skeletal remains associated with past populations is reasonably accurate for adults. The relationship in a population between males and females can be presented in terms of an excess, proportion or ratio (Petersen 1975b). Whether the sex ratio implied from cemetery data is an accurate reflection of living sex ratios is questionable, however. When differences in mortality rates between males and females are relatively small, it is suggested that the sex ratio observed in the mortality sample is a suitable estimate of the living sex ratio. However, when male and female mortality rates are substantially different, whether the result of biological or socio-cultural factors, the ratio of males to females within the cemetery fail to accurately represent the living sex ratios. This is particularly relevant given the possible differences observed between male and female MAD's even in samples as large as 250 individuals.

To illustrate the differences between male and female MAD's, 1000 random samples of size n= 250, 100, and 50 drawn from the Union cemetery population, are presented in Figure 5.20. Comparisons of the distributions for the runs of each sample size demonstrates that the potential differences between male and female MAD's can be quite large. While

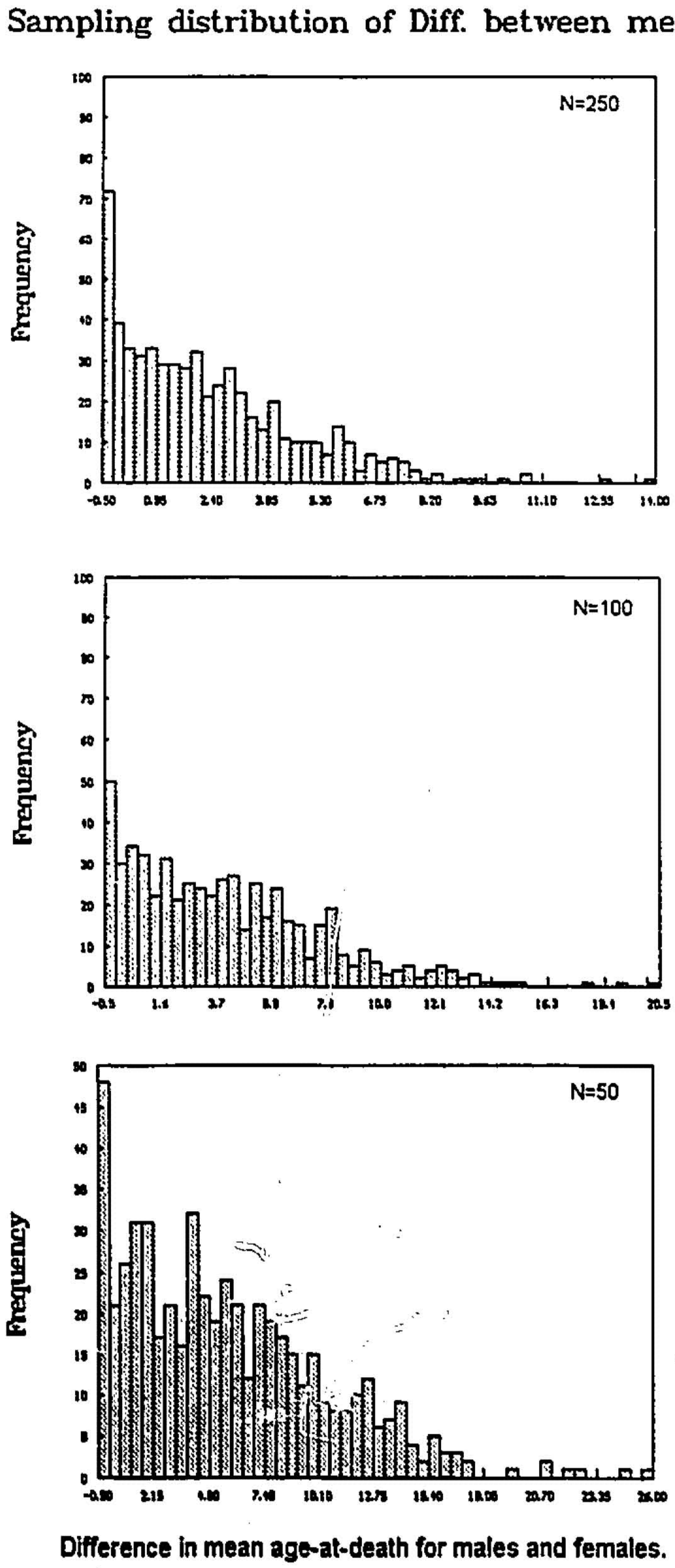

FIGURE 5.20: Sampling distributions of the difference between male and female MAD's (in years) for sample sizes of N=250, 100 and 50. The figures represent distributions based on 1000 random draws from the Union cemetery population, for which no statistical difference between the male and female MAD's was observed

samples of 250 are unlikely to show differences of much more than five years, samples of 100 or 50 can deviate from the true pattern within the parent cemetery population by as much as fifteen years. Given that this example is drawn from the Union cemetery distribution which observed no significant differences in survivorship between the sexes, the potential magnitude of differences observed here is quite alarming. For basic palaeodemographic analyses of life expectancy, these differences have little effect. But for interpretations regarding past populations that depend upon the ratio of males to females or the differences in their age-at-death structures, these differences are substantial. Particularly alarming is the fact that, again, these differences were generated using random sampling techniques, but produce results that could easily be interpreted as cultural differences in health or socio-economics between the sexes. A variety of biological and environmental factors from birth order, age difference in marriage, social class and occupation are known to influence the secondary sex ratio in populations (Beiles 1974; James 1987; Ulizzi and Zonta 1995). In northern Aboriginal communities, for example, we might expect to find significant differences in mortality between the sexes due to high mortality from drowning and related hunting accidents (Lancaster 1990). False differences in mortality because of sampling bias might lead to other conclusions related to occupation in agricultural communities, for example. Conversely, when differences are in fact present, sampling bias may hide them and prevent further exploration of the factors thought to be associated with the mortality differential (e.g. hunting, warfare, drowning, differential access to food). The potential for this kind of error in the literature is evident with studies like that of Benfer (1984) who presents an argument for female infanticide based on a sample of 145 subdivided by sex and into three separate temporal layers (n=35, 62 and 48).

The study suggests the observed differences in mortality patterns between males and females may reflect marriage patterns. Benfer notes that:

> The Paloma [mortality] pattern is the reverse, with 19 males and 11 females dying in their 20's, while 11 males and 18 females died in their 30's....delayed marriage is suggested, as is commonly found where infanticide is practiced (Benfer 1984:538).

Similarly, Rathbun (1982, 1984) observed significant differences in mortality between males and females for aggregate samples of less than 100 individuals, which he attributed to "population variation by gender and differential migration" (Rathbun 1984:142).

### *Bias in Population Ratios*

The relationship between sample size, mean age-at-death and two population ratios (juvenile/adult ratio and 30+/5+) are illustrated for the St. Thomas' cemetery population in Figures 5.21 and 5.22. Both of these figures depict the MAD and ratio for several hundred samples (ranging from N=500 to N=25). In both cases, substantial deviations from the population values occur for samples under approximately 250 individuals. Ignoring the issue of sample size, Figure 5.23 illustrates the general trend for overestimations in MAD to result in underestimations of the JA ratio, as one would expect. A higher mean age-at-death is suggestive of a greater number of adults (or fewer children) with or without an associated increase in the mean adult age. Thus, for a sample in which the MAD is high, any ratio of children to adults such as the JA ratio, will necessarily be smaller because there are more adults and because of the larger denominator in the ratio. The cemetery population MAD and JA ratio are noted by a reference line on the x- and y-axis respectively. From Figure 5.23 the relationship between the two variables can be observed with the greater the difference

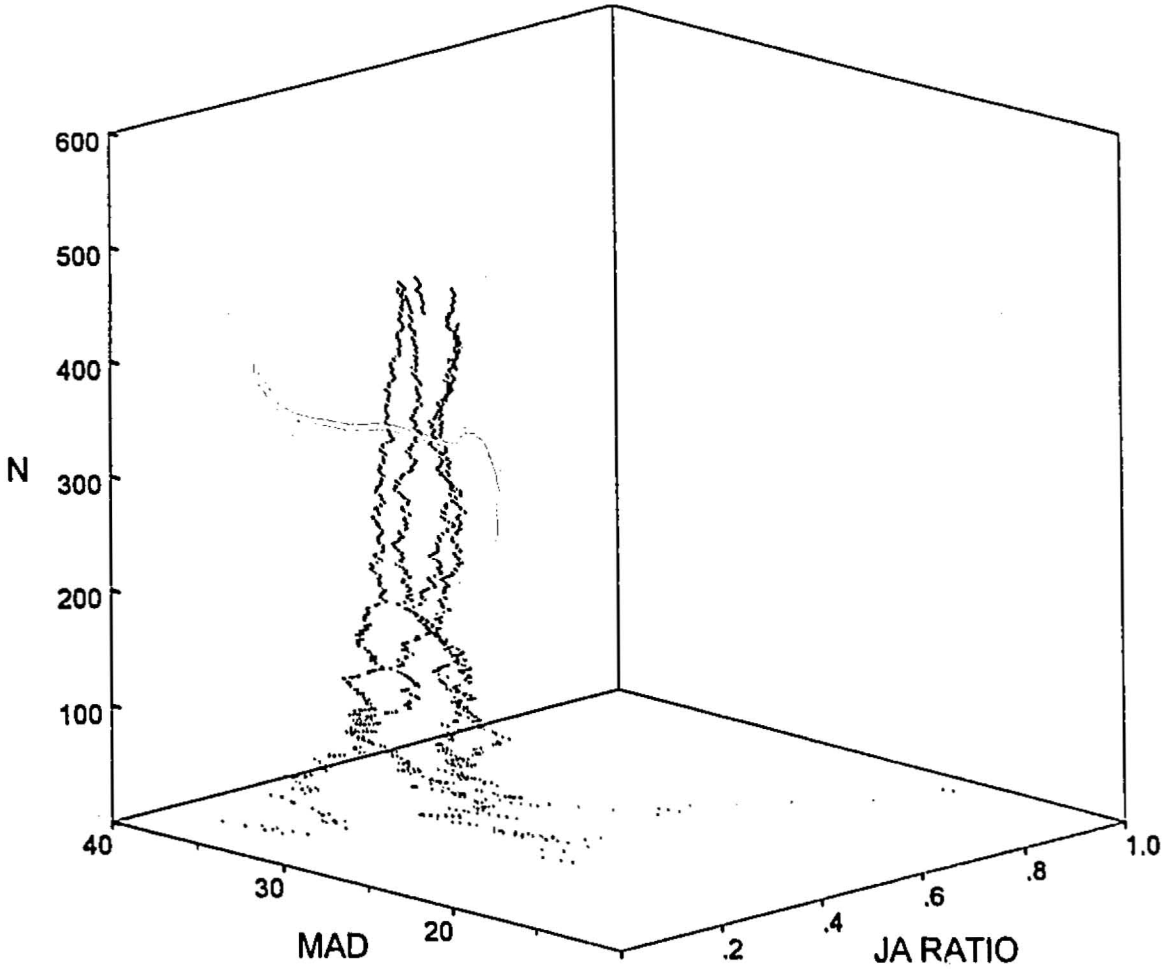

FIGURE 5.21: Scattergram illustrating the relationship between sample size (N), mean age-at-death (MAD) and the juvenile/adult ratio. For this figure, a series of random samples of varying sizes were drawn (without replacement)

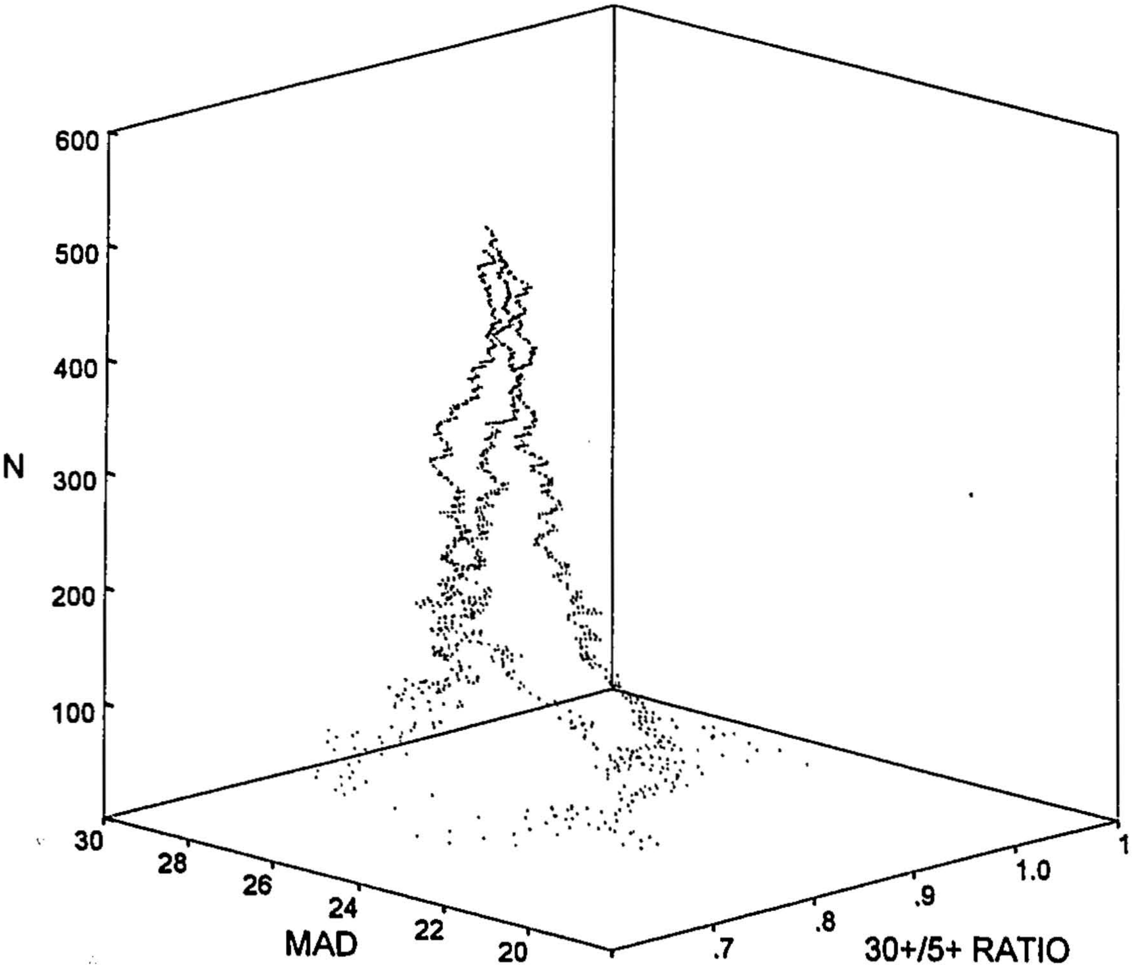

FIGURE 5.22: Scattergram illustrating the relationship between sample size (N), mean age-at-death (MAD) and the 30+/5+ ratio. For this figure, a series of random samples of varying sizes were drawn (without replacement)

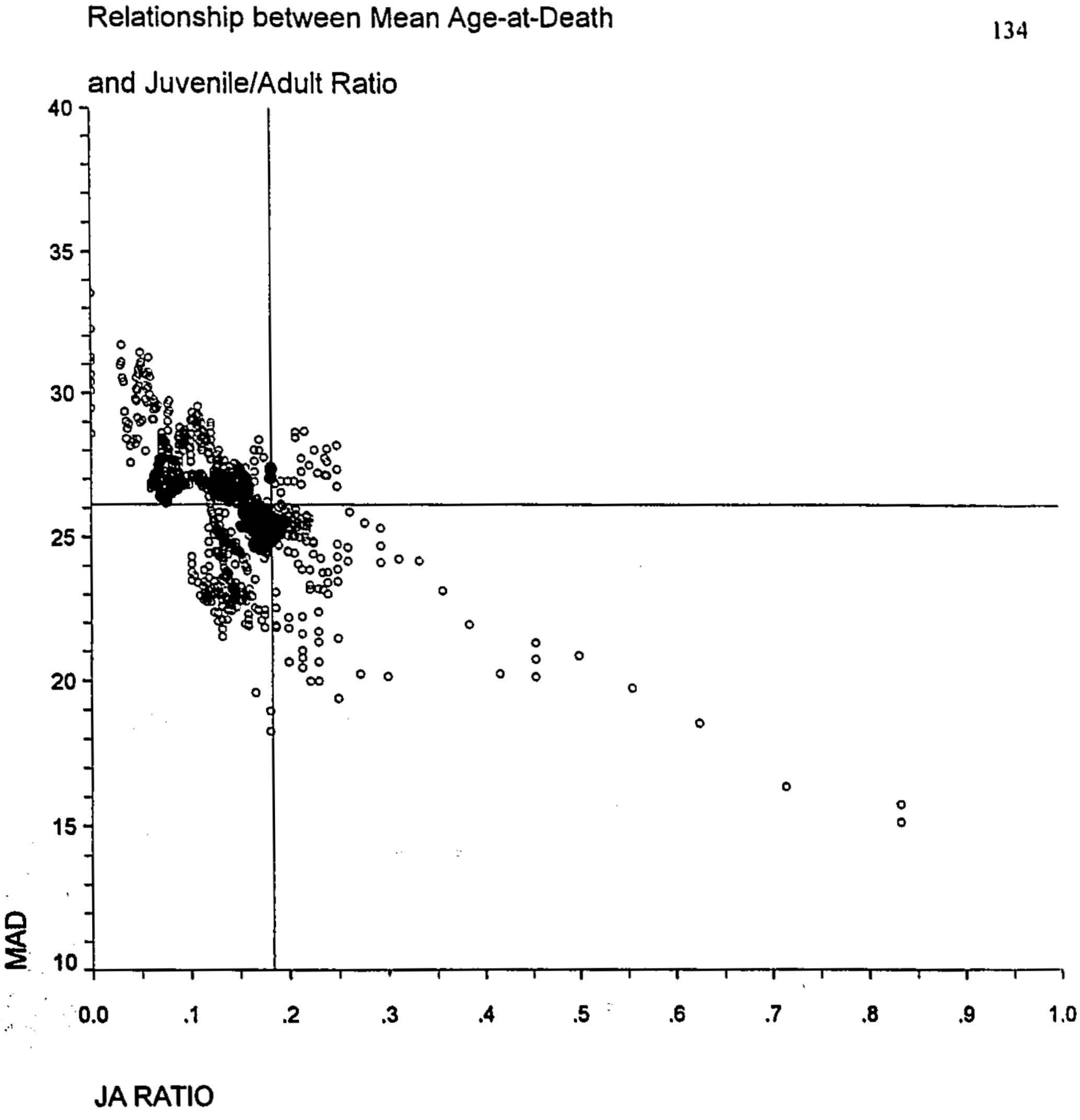

FIGURE 5.23: Scattergram illustrating the relationship between mean age-at-death (MAD) and the juvenile/adult ratio. Each data point represents a sample MAD and JA ratio. The horizontal line marks the population MAD and the vertical line marks the population JA ratio

between the sample and population MAD, the more likely that difference between the sample and population JA ratio is also substantial. However, there is also a somewhat disconcerting scatter of MAD-JA ratio patterns observable. It is apparent from this illustration that we cannot readily anticipate how the JA ratio has been affected by sample bias even if we can determine or estimate the magnitude and direction of error in the sample MAD. Given the argument that MAD is affected mainly by changes in fertility (Konigsberg and Frankenberg 1994; Milner et al. 1989; Sattenspiel and Harpending 1983; Wood et al. 1992) and that the juvenile adult ratio is a reasonably accurate estimator of fertility (Jackes 1992), the problems of making interpretations from skeletal samples are compounded when two related statistics can vary somewhat independently of one another. Figure 5.24 similarly plots a distribution of mean age-at-death against mean childhood mortality for samples from n=500 to n=25. The relationship between mean childhood mortality and mean age-at-death is similar to that observed for the JA ratio, although the spread in MCM values is much tighter. Both the JA ratio and mean childhood mortality are only dependent upon an accurate proportion of children under 15 years of age to adults over 15 years of age in the sample, and are not as strongly influenced by the actual age distribution *per se*. Thus, even when adult ages are indeterminate or unreliable, these calculations will remain unbiased. This is also useful when new ageing methods are re-applied to old data resulting in a shift in mean ages-at-death among the adults but without any change to the proportions in the sample.

### *Aggregate Bias: Time and Space*

The effects of temporal biases are most interesting because they represent a factor which researchers inherently wish to examine, but for which palaeodemographic data, for the

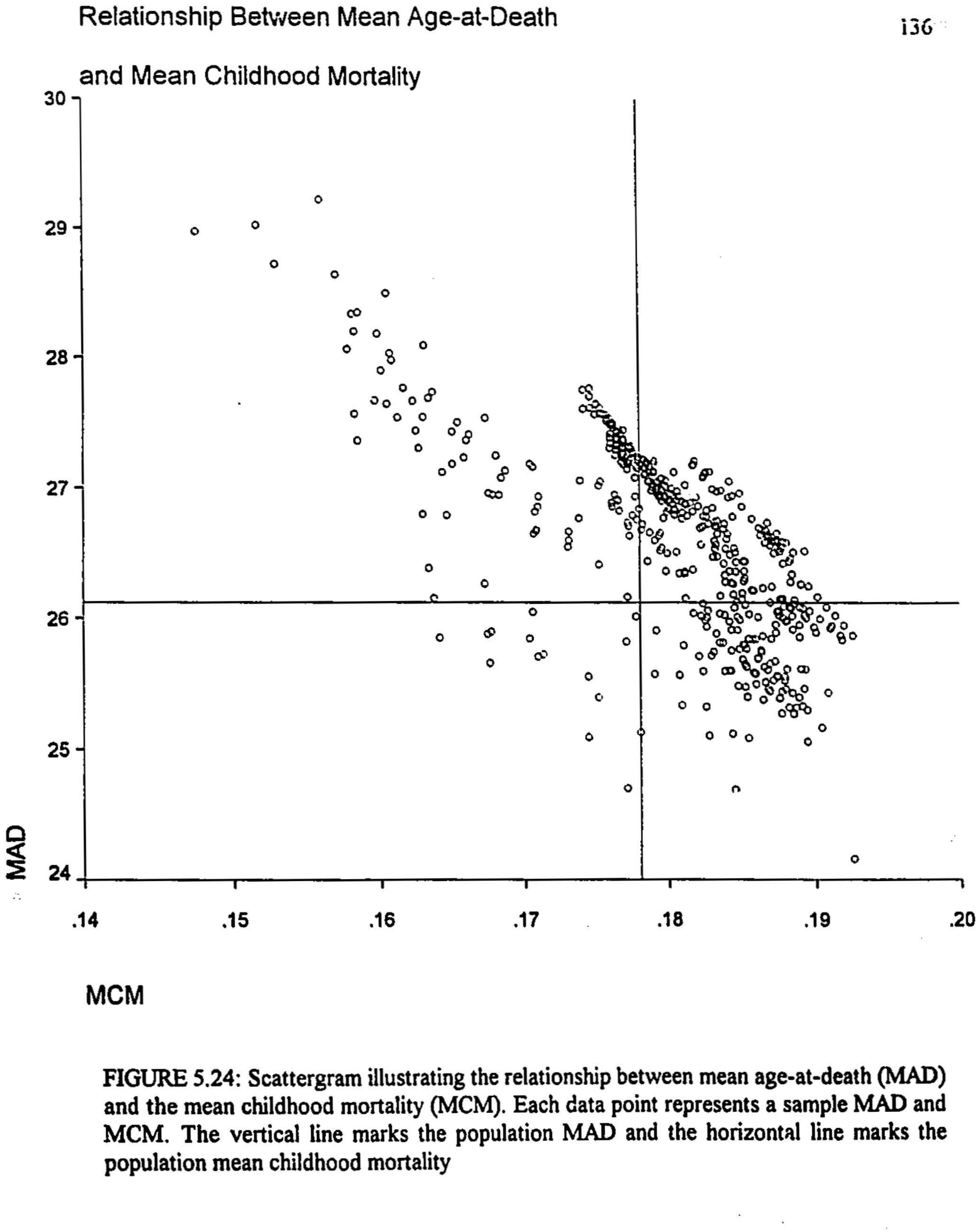

FIGURE 5.24: Scattergram illustrating the relationship between mean age-at-death (MAD) and the mean childhood mortality (MCM). Each data point represents a sample MAD and MCM. The vertical line marks the population MAD and the horizontal line marks the population mean childhood mortality

most part, cannot distinguish. While there are some exceptions, such as historically documented samples with personally identified graves, most skeletal researchers can do little more than simply divide their sample into a handful of archaeologically defined time periods. It is known that changes in mortality profiles and their associated mean age-at-death are further complicated by differing cohort sizes (Konigsberg and Frankenberg 1994). The distribution of ages-at-death by birth cohort and burial cohort for each of the three cemetery populations has been discussed earlier (see Figures 5.3-5.8, pp. 102). Comparisons of the survivorship curves by birth and death cohorts revealed some differences between the cemetery populations. All three cemetery populations showed significantly different survival distributions by birth cohort, but only the Union cemetery population showed significant differences between death cohorts ($p<0.001$).

The relationship between population mean age-at-death and the temporal sampling span was explored by sampling the cemetery populations for intervals of various length. The absolute difference between the sample MAD and cemetery MAD was calculated. There is a strong negative correlation between the duration of the interval sampled (e.g. 5 years, 10 years or 25 years), i) the beginning date of the interval, and ii) the ending date of the interval with iii) the observed difference between the sample MAD for an interval and the population MAD ($p<0.001$ for all three pairs of Pearson's correlation coefficients). Thus, the smaller the interval or the more removed it is from the middle of the cemetery's duration, the greater the difference in MAD between sample and population. This is of importance because it leads one to question whether palaeodemographic analyses of skeletal samples from substantially different time spans are directly comparable. This may be partially related to greater sample sizes in longer duration series, since as sample sizes increase there is a greater potential for outliers in the age-at-death distribution to occur, and thus small samples are unlikely to produce individuals of great age (Konigsberg and Frankenberg 1994). While Konigsberg and Frankenberg have made this comment in reference to the investigation of the human life-span, its implications for comparative palaeodemographic studies is clear, particularly given the importance of adult enumeration for accurate estimation of mean age-at-death within a population. Further, given that estimated life expectancy is related to mean age-at-death within a sample, one must then question if observed differences are a result of one series representing a longer duration within the population. This does make some intuitive sense, since samples which cover more than 60-80 years (one human lifespan) will better reflect life expectancy within the population as at least some of the individuals within the cemetery would have been at risk of dying throughout the entire period the cemetery was in use. In contrast, a cemetery of relatively short duration is more likely to under-estimate life expectancy, since fewer cohorts are at risk of dying during its use. This is equally true for samples that, for whatever reason, are drawn from a more restricted time interval even though the cemetery as a whole may represent several centuries of burials.

That we cannot evaluate skeletal samples in a temporal framework is perhaps the greatest weakness of palaeodemographic studies. The impact of this conclusion is significant with the analyses of skeletal samples being seriously limited in the types of questions that can be explored. Unlike modern or even historical demography where mortality data is associated with sequential time intervals (eg. years, decades etc), palaeodemographic analyses are necessarily forced to examine longitudinal data in a cross-sectional format. A time frame of perhaps one to two centuries is the smallest level of precision for which archaeological samples can be dated with some obvious exceptions such as plague pits, crypt burials or battle cemeteries (Waldron 1994). The problem for palaeodemography is that, unlike modern demography, a population at risk is not known. Thus, the skeletal sample is not known to be reflective of short-term or long-term mortality from a small or large population. Such information is clearly important for the estimation of life expectancy from a mortality sample. Ironically, it is this kind of information that is absent from palaeodemographic studies which present and often compare life expectancies estimated using the cohort method As a result, there are differing implications for samples which span a long period versus a short period of time. The most obvious of these is that cemeteries of relatively short duration will more closely reflect the underlying patterns of mortality within the living population. In contrast, cemeteries of longer duration will have mortality profiles that are more likely to be smoothed out. This was illustrated in Figure 2.2 (pp. 23) which plots the frequency of deaths per year in the St. Thomas' cemetery population. For this cemetery population an increasing trend over time can be observed with three distinct peaks in mortality. However, without the benefit of a temporal framework, these features are essentially smoothed out, and only a mean number of burials per year can be calculated.

The smoothing effect on factors of interest for palaeodemography can also occur in studies which aggregate data from many small samples into one single sample. The use of aggregate data has been quite common in palaeodemography (e.g. Angel 1969; Blakely 1971; Owsley and Bass 1979), given the often poor sample sizes from many archaeological sites. Perhaps the most extreme example of this practice is in palaeodemographic studies of hominid and early human populations (Mann 1975; McKinley 1971; Vallois 1937). Trinkaus (1995) for example, has recently re-examined the question of Neandertal mortality, summarizing the age patterns of 206 individuals from 77 sites (46 of which provided only one individual to the combined sample). Trinkaus, in fact, depends upon the effect of this imposed cross-sectional sample (across both time and space) stating that "since these samples are used here to provide a pattern against which to compare the Neanderthal mortality profiles, any such biases should have little effect on overall patterns across the samples" (Trinkaus 1995:124). Nevertheless, site frequencies were weighted for possible differences in preservation, and infant frequencies *corrected* to expected neonatal values for more recent populations. It is not surprising then, that the study observed a 'similar range of neonatal mortality' between the recent ethnographic demography and the palaeodemographic assessment of Neandertal mortality. Trinkaus recognizes that this type of aggregate analysis "represents nothing resembling a population on which one can do demographic analysis" (1995:137) but continues by noting that effects of pooling specimens across sites and through time may tell us something about Neandertal population dynamics even though they do not permit a proper palaeodemographic analysis (ie life tables). Given the wide range of variation that would have been affecting the recovery of any one specimen, I find it doubtful that anything can be said regarding Neandertal population structure beyond a simple descriptive analysis of individual mortality. Without the cohesion of a common temporal period or specific geographic area it is difficult to accept any interpretations of hominid life based on such data.

### *II: The St. Thomas' Skeletal Sample*

An analysis of the excavated St. Thomas' skeletal sample provided the opportunity to further examine the issue of representativeness between an existing skeletal sample and its known cemetery population. For this study, the issue of preservation of the skeletal sample was explored.

As noted earlier, in order to assess the relative degree of preservation within the St. Thomas' skeletal sample, an index of measurable infracranial elements was calculated (see pp. 86 for definition). Figure 5.25 illustrates the distribution of values for the index. Based on this figure, the preservation of St. Thomas' skeletal sample is high, with a strongly skewed distribution. The mean for the index of preservation was 0.763, implying that individual skeletons were on average about 76% complete. Comparisons of the preservation index between sides (paired samples t-tests) and sex (independent samples t-test) are presented in Table 5.11. As well, individuals were grouped into ageable and unageable categories dependant upon a estimate of age by Rogers (1991). An independent t-test to compare the means between ageable and unageable individuals demonstrated a significant difference between the two groups (Table 5.11). Differences between sides were not significant ($p>0.10$). The independent samples t-test for sex and ageable cases both showed significant differences in mean preservation. In general, males are better preserved than females ($p=0.042$), in contradiction to other studies (eg. Nawrocki 1995; Walker et al. 1988) which observed no sex-related differences in preservation, although both sexes have a relatively high degree of preservation within this sample. An ANOVA on the index of preservation, considering sex as a factor and age as a covariate (Table 5.12) shows that sex is, in fact, not a significant factor for individual preservation while age is. This suggests that the observed differences in preservation between the sexes is a result of the differing age structure of the

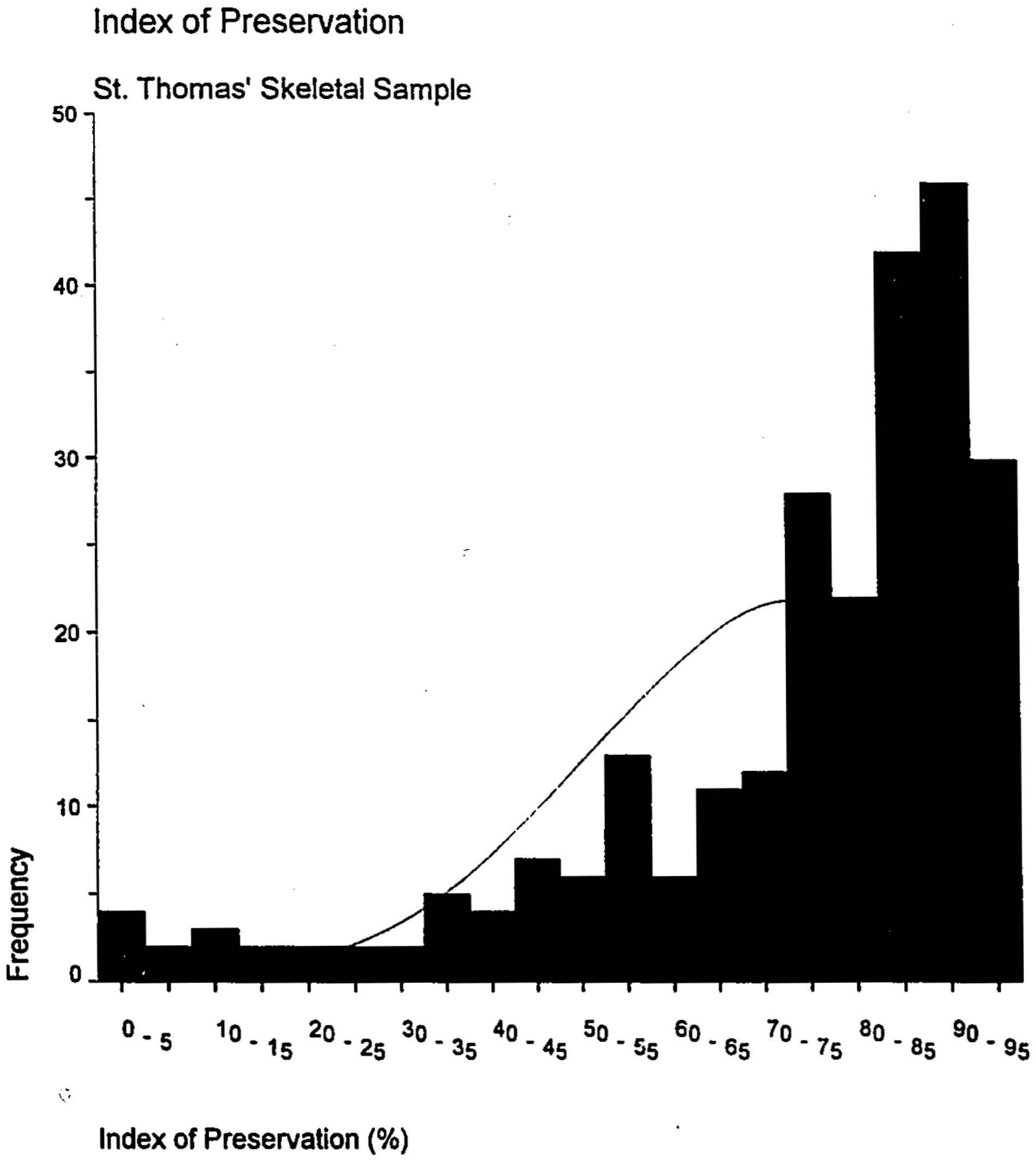

FIGURE 5.25: Histo-gram illustrating the distribution of the index of preservation for the St. Thomas' skeletal sample based on infracranial measures, with a normal curve overlaid. The mean preservation index in the sample is 76.3 percent

TABLE 5.11: Paired and Independent samples t-tests for differences in preservation between sides and sex.

| *Sides* | No. Pairs | R | 2-tail Sig. | Mean Diff. | t-value | df | 2-tail Sig. |
|---|---|---|---|---|---|---|---|
| | 249 | .820 | <0.001 | -0.0147 | -1.62 | 248 | 0.106 |

Sides combined

| Sex | No. Cases | Mean | Levene's F | Levene's p | Mean Diff. | t-value | df | 2-tail. Sig. |
|---|---|---|---|---|---|---|---|---|
| Male | 139 | .7898 | | | | | | |
| Female | 110 | .7300 | 4.370 | .038 | .0598 | 2.04 | 213.92 | 0.042 |
| Unageable | 12 | .4417 | 6.023 | .015 | -.3380 | -3.64 | 11.49 | 0.004 |
| Ageable | 237 | .7797 | | | | | | |

TABLE 5.12: General factorial ANOVA for the index of preservation for the St. Thomas' skeletal sample with sex as a factor and age as a covariate.

Tests of Significance for INDEX OF PRESERVATION using UNIQUE sum of squares.

| Sources of Variation | SS | DF | MS | F | Sig. of F |
|---|---|---|---|---|---|
| WITHIN+RESIDUAL | 9.86 | 234 | .04 | | |
| REGRESSION | .38 | 1 | .38 | 9.03 | .003 |
| SEX | .08 | 1 | .08 | 1.96 | .162 |
| (Model) | .46 | 2 | .23 | 5.43 | .005 |
| (Total) | 10.32 | 236 | .04 | | |

R-Squared = .044
Adjusted R-Squared = .036

Regression analysis for WITHIN+RESIDUAL error term.
Individual univariate .9500 confidence intervals
Dependent variable . . . INDEX OF PRESERVATION

| COVARIATE | B | Beta | Std. Err. | t-value | Sig of t |
|---|---|---|---|---|---|
| AGE | -.0033950436 | -.1920559761 | .00113 | -3.00482 | .003 |

two groups. In this case, the difference in age structure between adult males and females is not significant. Sexual dimorphism may also play a role with larger or more massive bones being more apt to survive post-depositional changes. A further examination of correlations between size and preservation could be assessed by using for example, maximum femur length, as an estimate of relative size. Correlations between bone size and the index of preservation were not significant. Nawrocki (1995) similarly observed no influence from size on the relative degree of preservation among Oneida burials. However, such comparisons would already be slightly skewed by the fact that those individuals who have a maximum femur length measurable (or any other measure included when calculating the index) are already better preserved. The observed difference between ageable and unageable (p=0.004) is not unexpected since the lack of ageable traits already suggests a relatively poor state of preservation for the individual. As such, a simple proportion of ageable to unageable cases will provide a rough guide of relative preservation for a sample.

Figure 5.26 plots the preservation index against estimated age-at-death with a linear regression line demonstrating a slight negative correlation with increased age (p=.003). This analysis suggests that in general older individuals have a reduced level of preservation. Of course, this relationship is biased itself as it does not account for those individuals who were unageable, most likely as a result of poor preservation. In addition, the cluster of poorly preserved young adults suggests that other factors are also playing a role in the preservation of skeletal remains. Partial excavation of certain graves would obviously bias the index, but other factors such a burial below ground or the presence of a coffin can be examined from the archaeological recording forms for the sample.

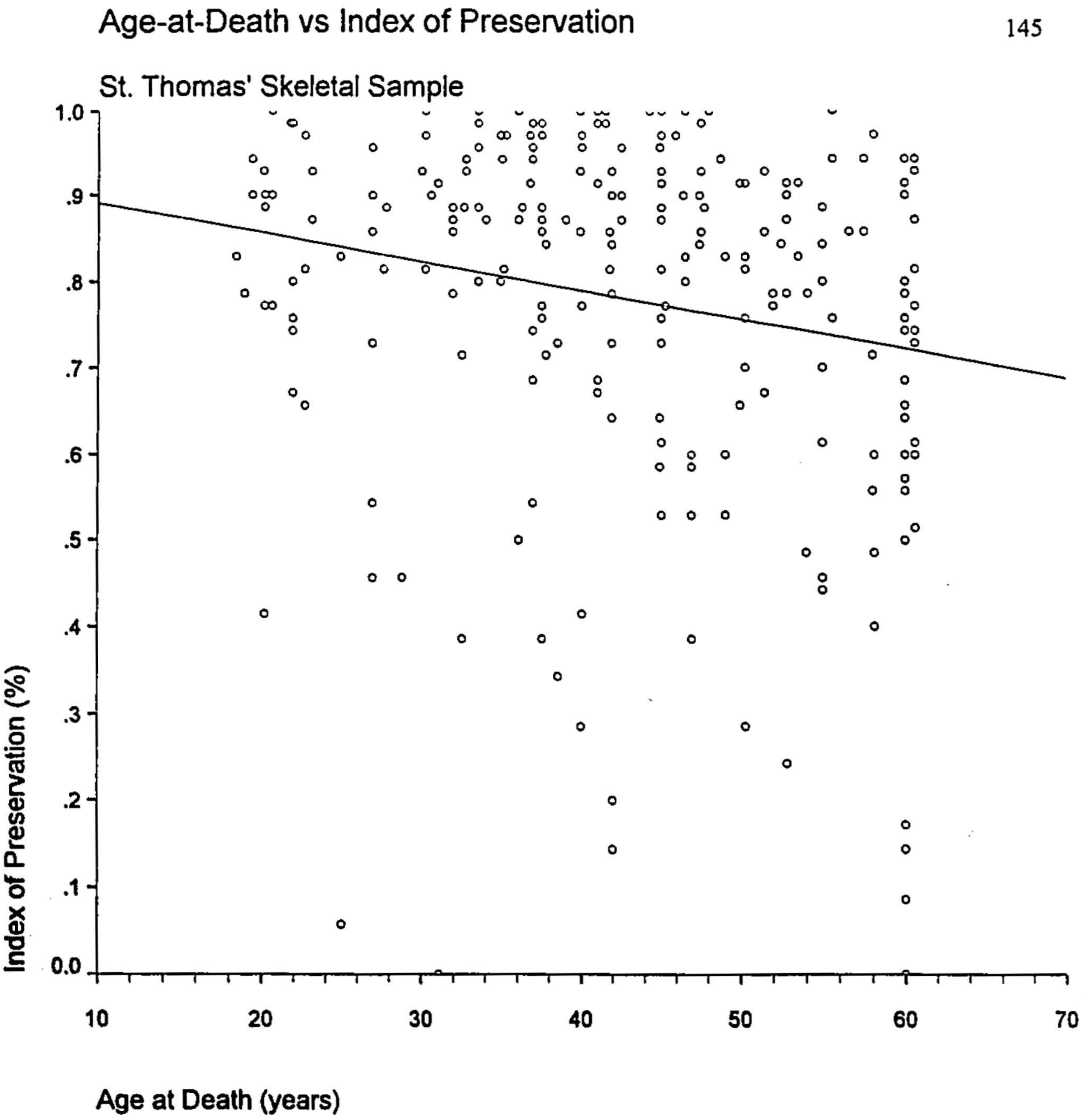

FIGURE 5.26: Scattergram plotting skeletal age-at-death against the index of preservation for the St. Thomas' skeletal sample. A linear regression line illustrates a slight, but not significant, negative trend between preservation and age

For the St. Thomas' burials, the depth an individual was buried below the ground (measured to the floor of the coffin) was as much as 1.85 metres, with a mean depth of 0.68m (s.d.=0.30). Correlations between the recorded depth and preservation were not significant. In addition the recorded presence or absence of a coffin showed no significant correlation with the degree of preservation. Two factors may contribute to these observations. First, the depth to the floor of the coffin was measured relative to a stationary datum point. As such, the relative depth inferred from these values may be a reflection of changes in ground level over the entire cemetery. Further, the recorded absence of a coffin in the archaeological record means the absence of any material remains of the coffin. It is assumed that a coffin existed for all individuals and that its absence is a reflection of environmental conditions affecting the preservation of the burial as a whole.

Nawrocki (1995) observed a significant correlation between the relative preservation of skeletons and the depth of burial below the surface ($p<0.001$) for the Oneida. He developed least squares linear regression equations to predict preservation based on depth of burial, and although the model coefficients are significantly different from zero ($p<0.007$), the variation explained from the model is low ($r^2=0.125$). Removal of outliers in the assemblage increases the variance explained by depth to 28 percent.

### *Summary*

The purpose of this study has been to explore the issue of representativeness and its implications for palaeodemographic reconstructions from skeletal samples. To this end, a number of simulated samples were generated from three separate mortality populations. Comparisons of the age-at-death distributions of these samples to the parent populations were then made to assess the relative magnitude of deviation associated with different types of bias. The damaging effects of a variety of biases (age, sex, population ratios, temporal bias) regardless of the cause, for palaeodemographic estimators is clear. If these biases are not recognized, then interpretation of past health based on palaeodemographic parameters are unlikely to be an accurate reflection of the living population. In addition, a retrospective analysis of preservation on the St. Thomas' skeletal sample was conducted to examine the effects of an environmental filter acting on an archaeologically excavated skeletal series.

This research has employed the same principles that Lovejoy (1971) originally applied to the problem of bias in skeletal series. He applied a modern demographic technique to detect census error between the core and periphery segments of the skeletal sample — "...the core population may be considered as the 'ideal' census. This can then be compared with the census of the peripheral population in order to determine probable census error" (1971: 102). Here, the same principal is applied to test representativeness but with the cemetery population considered the core and the skeletal sample the peripheral population. Through a series of random sampling experiments, the issue of representativeness has been examined more directly. Preservation, as an example of recognizable bias within skeletal samples was briefly explored in this study. While the general level of preservation within the St. Thomas' skeletal sample was considered very good, a more critical examination of its potential effects served to reinforce the assumption that there is not significant bias associated with preservation in the St. Thomas' sample.

Given that sample size is a considerable problem for many osteological studies, it seemed warranted that a basic examination of representativeness with decreasing sample size be made without the more complex sources of biases. Further, recognizing the complexities caused by the non-random nature of skeletal samples one can begin to examine the problem of representativeness at its most fundamental level — that is, when variation between sample and cemetery are the result of purely random factors. The basis for doing so was that to completely understand the biasing effects of various non-random factors which influence the development of a cemetery, the level of bias created within a purely random framework should first be examined.

Clearly, from the examples presented, variability in age-at-death distribution is high in samples of less than 100. It is also clear that it is not the percentage of the total cemetery represented in a skeletal sample that is important, but rather the absolute numbers of individuals available to be included in the palaeodemographic reconstruction. This is not to suggest that a sample of 100 will always result in a representative demographic distribution of the cemetery. Rather it is meant as a guideline, suggesting that for samples of less than 100 individuals, it is highly probable (although not definite) that the mortality profiles constructed are not a reflection of the cemetery. Of course the simulated skeletal samples presented in this study do not account for methodological or environmental biases at the excavation-analyzable sample transition. As such, a required minimum of 100 *analyzable* individuals would suggest an overall sample of possibly greater numbers depending on the relative degree of preservation within the sample.

# CHAPTER 6

## CONCLUSIONS

### *Introduction*

It is clear that palaeodemography has been and will continue to be an integral part of osteological analysis. It is less clear what form future palaeodemographic studies will take.

> Palaeodemography... presupposes that direct relationships exist between statistics calculated from archaeological skeletal series (eg. skeletal lesion frequencies and mean age at death) and the health status of the past populations that gave rise to the series (Wood et al. 1992:343).

There is some consensus that mean age-at-death profiles derived from cemetery populations are in fact related to population fertility, an observation that is not necessarily intuitive. While current literature seems to suggest that changes in mean age-at-death are a reflection of changes in fertility rather than mortality, I would argue that it is irrelevant what mean age-at-death reflects if we cannot establish the relative representativeness of the skeletal sample to the once living past population or at the very least, to the cemetery. If valid statistical manipulation and comparison of skeletal data are to be undertaken, collections of sufficient size representative of the true age and sex distributions must be available (Rathbun 1984). Researchers have argued that for cemeteries of relatively short duration, with reasonably large, well preserved skeletal samples, age and sex distributions of the skeletal sample can represent the demographic parameters of the cemetery as a whole (VanGerven and Armelagos, 1983; Buikstra and Konigsberg, 1985; Herring et al. 1992; Lamphear, 1989; Saunders, Herring and Boyce, 1991). Unfortunately such samples are the exception rather than the rule in osteology. For those investigators who have the luxury of a parent population associated with a skeletal sample, a variety of statistical techniques can be employed to test whether or not there are significant differences between the sample and population. Such tests determine, with varying degrees of success, whether the observed variation within a sample is greater than would be expected from random chance alone. However, statistical significance or lack thereof should not be confused with biological or demographic significance (Brown and Rothery 1993). However,

> It is necessary to remember when drawing inferences from the demography of a palaeopathological population that the comparison is with a dead and not a living population and that although it is, of course, related to the living population from which it was drawn, since the form of the relationship is not known *it will not be possible to reconstruct the demography of the living population* (Waldron 1994:20, emphasis added)

Konigsberg and Frankenberg (1994) recognize that this is problematic, noting that the mean age-at-death will almost always be less than the mean age in the living population. Some might argue that palaeodemography need not necessarily be attempting to reconstruct the living age-structure, but rather make inferences about health from the age-structure of the dead. And while this may be true, we must also recognize that many of the inferences regarding palaeodemographic estimators such as fertility, must assume that the age structure of the mortality sample *is* a reflection of the age structure within the living population. This is often forgotten or ignored despite the intuitive logic behind the argument.

## *Conclusions*

It is clear from the various examples presented here that random variation can, for palaeodemography produce a substantial range of variation whose magnitude, even when not statistically different from a population, is of great importance for interpreting palaeodemographic data. From this exploration a number of basic conclusions can be drawn.

> 1) Palaeodemographic reconstructions from samples of less than 100 analyzable individuals, are unlikely to provide accurate interpretations regarding mortality and population structure.
>
> 2) The under-representation of adults, whether through cultural, environmental or methodological bias can serve to make interpretations based on mean age-at-death inaccurate.
>
> 3) Sampling biases related to temporal factors will directly affect estimates of palaeodemographic parameters such as life expectancy.
>
> 4) Given that most samples will be subject, differentially, to biases at a variety of levels, comparative studies based on palaeodemographic data cannot realistically be considered reliable ***without careful control for those biases***.

## *Recommendations for the Future*

Palaeodemographic studies have the potential to provide important information regarding past population dynamics. However, without careful consideration of what or who exactly is represented by skeletal samples, palaeodemographic analyses shed little light on the realities of past life. Konigsberg and Frankenberg (1994) suggest that it is time to move beyond the methodological criticisms of palaeodemography and start exploring the broader questions regarding human prehistory. While I agree that the specific problems of methodologies related to ageing for example, can and are being dealt with (eg. Lucy et al. *submitted*; Konigsberg and Frankenberg 1992; Bocquet-Appel and Masset 1996) it is imperative that we re-examine the theoretical basis on which these studies are made. If representativeness is, as I would suggest, the primary theoretical obstacle for researchers to overcome, then it is necessary to shift our focus to rigorously exploring those factors that bias our samples. This should be done at both the practical level (examining factors within excavated samples) and at the theoretical level through experimental methodologies and computer simulations. While the latter has begun (eg. Saunders and Hoppa 1993, Wood et al. 1992), few studies have examined issues of representativeness, beyond preservation, directly for their samples.

# APPENDIX I

**St. Thomas' Cemetery Population**
Year of Death

| Year | N | % | Valid % | Cum % |
|---|---|---|---|---|
| 1821 | 4 | .3 | .3 | .3 |
| 1822 | 2 | .1 | .1 | .4 |
| 1823 | 8 | .5 | .5 | .9 |
| 1824 | 7 | .4 | .5 | 1.4 |
| 1825 | 11 | .7 | .7 | 2.1 |
| 1826 | 12 | .8 | .8 | 2.8 |
| 1827 | 9 | .6 | .6 | 3.4 |
| 1828 | 19 | 1.2 | 1.2 | 4.6 |
| 1829 | 11 | .7 | .7 | 5.4 |
| 1830 | 11 | .7 | .7 | 6.1 |
| 1831 | 9 | .6 | .6 | 6.6 |
| 1832 | 11 | .7 | .7 | 7.4 |
| 1833 | 23 | 1.5 | 1.5 | 8.8 |
| 1834 | 16 | 1.0 | 1.0 | 9.9 |
| 1835 | 14 | .9 | .9 | 10.8 |
| 1836 | 18 | 1.2 | 1.2 | 11.9 |
| 1837 | 16 | 1.0 | 1.0 | 13.0 |
| 1838 | 18 | 1.2 | 1.2 | 14.1 |
| 1839 | 17 | 1.1 | 1.1 | 15.2 |
| 1840 | 19 | 1.2 | 1.2 | 16.5 |
| 1841 | 30 | 1.9 | 1.9 | 18.4 |
| 1842 | 17 | 1.1 | 1.1 | 19.5 |
| 1843 | 28 | 1.8 | 1.8 | 21.3 |
| 1844 | 20 | 1.3 | 1.3 | 22.6 |
| 1845 | 14 | .9 | .9 | 23.5 |
| 1846 | 28 | 1.8 | 1.8 | 25.3 |
| 1847 | 46 | 2.9 | 3.0 | 28.3 |
| 1848 | 39 | 2.5 | 2.5 | 30.8 |
| 1849 | 34 | 2.2 | 2.2 | 33.0 |
| 1850 | 34 | 2.2 | 2.2 | 35.2 |
| 1851 | 33 | 2.1 | 2.1 | 37.3 |
| 1852 | 43 | 2.7 | 2.8 | 40.1 |
| 1853 | 49 | 3.1 | 3.2 | 43.3 |
| 1854 | 78 | 5.0 | 5.0 | 48.3 |
| 1855 | 48 | 3.1 | 3.1 | 51.4 |
| 1856 | 28 | 1.8 | 1.8 | 53.2 |
| 1857 | 38 | 2.4 | 2.5 | 55.6 |
| 1858 | 31 | 2.0 | 2.0 | 57.7 |
| 1859 | 37 | 2.4 | 2.4 | 60.0 |
| 1860 | 25 | 1.6 | 1.6 | 61.7 |
| 1861 | 37 | 2.4 | 2.4 | 64.0 |
| 1862 | 55 | 3.5 | 3.6 | 67.6 |
| 1863 | 70 | 4.5 | 4.5 | 72.1 |
| 1864 | 47 | 3.0 | 3.0 | 75.1 |
| 1865 | 48 | 3.1 | 3.1 | 78.2 |
| 1866 | 25 | 1.6 | 1.6 | 79.9 |
| 1867 | 39 | 2.5 | 2.5 | 82.4 |
| 1868 | 47 | 3.0 | 3.0 | 85.4 |
| 1869 | 48 | 3.1 | 3.1 | 88.5 |
| 1870 | 50 | 3.2 | 3.2 | 91.7 |
| 1871 | 60 | 3.8 | 3.9 | 95.6 |
| 1872 | 35 | 2.2 | 2.3 | 97.9 |
| 1873 | 27 | 1.7 | 1.7 | 99.6 |
| 1874 | 6 | .4 | .4 | 100.0 |
| . | 151.0 | Missing | | |
| Total | 1564 | 100.0 | 100.0 | |

| | |
|---|---|
| Valid cases | 1549 |
| Missing cases | 15 |

**Union Cemetery Population**
Year of Death

| Year | N | % | Valid % | Cum % |
|---|---|---|---|---|
| 1810 | 1 | .1 | .1 | .1 |
| 1815 | 1 | .1 | .1 | .1 |
| 1830 | 1 | .1 | .1 | .2 |
| 1833 | 1 | .1 | .1 | .3 |
| 1834 | 1 | .1 | .1 | .4 |
| 1840 | 1 | .1 | .1 | .4 |
| 1841 | 2 | .1 | .1 | .6 |
| 1843 | 1 | .1 | .1 | .6 |
| 1844 | 1 | .1 | .1 | .7 |
| 1845 | 2 | .1 | .1 | .8 |
| 1846 | 4 | .3 | .3 | 1.1 |
| 1847 | 3 | .2 | .2 | 1.3 |
| 1848 | 7 | .5 | .5 | 1.8 |
| 1849 | 6 | .4 | .4 | 2.3 |
| 1850 | 7 | .5 | .5 | 2.7 |
| 1851 | 4 | .3 | .3 | 3.0 |

| Year | N | % | Valid % | Cum % |
|---|---|---|---|---|
| 1852 | 4 | .3 | .3 | 3.3 |
| 1854 | 3 | .2 | .2 | 3.5 |
| 1855 | 5 | .3 | .4 | 3.9 |
| 1856 | 1 | .1 | .1 | 3.9 |
| 1857 | 3 | .2 | .2 | 4.2 |
| 1858 | 3 | .2 | .2 | 4.4 |
| 1859 | 1 | .1 | .1 | 4.4 |
| 1860 | 4 | .3 | .3 | 4.7 |
| 1861 | 6 | .4 | .4 | 5.1 |
| 1862 | 4 | .3 | .3 | 5.4 |
| 1863 | 8 | .6 | .6 | 6.0 |
| 1864 | 7 | .5 | .5 | 6.5 |
| 1865 | 6 | .4 | .4 | 6.9 |
| 1866 | 5 | .3 | .4 | 7.3 |
| 1867 | 11 | .8 | .8 | 8.0 |
| 1868 | 4 | .3 | .3 | 8.3 |
| 1869 | 6 | .4 | .4 | 8.7 |
| 1870 | 5 | .3 | .4 | 9.1 |
| 1871 | 9 | .6 | .6 | 9.7 |
| 1872 | 9 | .6 | .6 | 10.4 |
| 1873 | 3 | .2 | .2 | 10.6 |
| 1874 | 5 | .3 | .4 | 10.9 |
| 1875 | 7 | .5 | .5 | 11.4 |
| 1876 | 5 | .3 | .4 | 11.8 |
| 1877 | 5 | .3 | .4 | 12.1 |
| 1878 | 6 | .4 | .4 | 12.5 |
| 1879 | 11 | .8 | .8 | 13.3 |
| 1880 | 10 | .7 | .7 | 14.0 |
| 1881 | 10 | .7 | .7 | 14.7 |
| 1882 | 12 | .8 | .8 | 15.6 |
| 1883 | 6 | .4 | .4 | 16.0 |
| 1884 | 9 | .6 | .6 | 16.6 |
| 1885 | 6 | .4 | .4 | 17.0 |
| 1886 | 12 | .8 | .8 | 17.9 |
| 1887 | 7 | .5 | .5 | 18.4 |
| 1888 | 16 | 1.1 | 1.1 | 19.5 |
| 1889 | 7 | .5 | .5 | 20.0 |
| 1890 | 10 | .7 | .7 | 20.7 |
| 1891 | 6 | .4 | .4 | 21.1 |
| 1892 | 13 | .9 | .9 | 22.0 |
| 1893 | 2 | .1 | .1 | 22.2 |
| 1894 | 10 | .7 | .7 | 22.9 |
| 1895 | 11 | .8 | .8 | 23.7 |
| 1896 | 9 | .6 | .6 | 24.3 |
| 1897 | 9 | .6 | .6 | 24.9 |
| 1898 | 6 | .4 | .4 | 25.4 |
| 1899 | 13 | .9 | .9 | 26.3 |
| 1900 | 4 | .3 | .3 | 26.5 |
| 1901 | 9 | .6 | .6 | 27.2 |
| 1902 | 8 | .6 | .6 | 27.7 |
| 1903 | 12 | .8 | .8 | 28.6 |
| 1904 | 11 | .8 | .8 | 29.4 |
| 1905 | 5 | .3 | .4 | 29.7 |
| 1906 | 16 | 1.1 | 1.1 | 30.8 |
| 1907 | 12 | .8 | .8 | 31.7 |
| 1908 | 18 | 1.3 | 1.3 | 33.0 |
| 1909 | 9 | .6 | .6 | 33.6 |
| 1910 | 12 | .8 | .8 | 34.4 |
| 1911 | 5 | .3 | .4 | 34.8 |
| 1912 | 13 | .9 | .9 | 35.7 |
| 1913 | 5 | .3 | .4 | 36.1 |
| 1914 | 10 | .7 | .7 | 36.8 |
| 1915 | 13 | .9 | .9 | 37.7 |
| 1916 | 6 | .4 | .4 | 38.1 |
| 1917 | 13 | .9 | .9 | 39.0 |
| 1918 | 15 | 1.0 | 1.1 | 40.1 |
| 1919 | 10 | .7 | .7 | 40.8 |
| 1920 | 8 | .6 | .6 | 41.3 |
| 1921 | 14 | 1.0 | 1.0 | 42.3 |
| 1922 | 11 | .8 | .8 | 43.1 |
| 1923 | 14 | 1.0 | 1.0 | 44.1 |
| 1924 | 10 | .7 | .7 | 44.8 |
| 1925 | 10 | .7 | .7 | 45.5 |
| 1926 | 15 | 1.0 | 1.1 | 46.5 |
| 1927 | 13 | .9 | .9 | 47.5 |
| 1928 | 13 | .9 | .9 | 48.4 |
| 1929 | 8 | .6 | .6 | 48.9 |
| 1930 | 11 | .8 | .8 | 49.7 |
| 1931 | 11 | .8 | .8 | 50.5 |
| 1932 | 9 | .6 | .6 | 51.1 |
| 1933 | 12 | .8 | .8 | 52.0 |
| 1934 | 17 | 1.2 | 1.2 | 53.2 |
| 1935 | 13 | .9 | .9 | 54.1 |
| 1936 | 10 | .7 | .7 | 54.8 |
| 1937 | 12 | .8 | .8 | 55.6 |
| 1938 | 7 | .5 | .5 | 56.1 |
| 1939 | 14 | 1.0 | 1.0 | 57.1 |
| 1940 | 20 | 1.4 | 1.4 | 58.5 |
| 1941 | 8 | .6 | .6 | 59.1 |
| 1942 | 7 | .5 | .5 | 59.6 |
| 1943 | 23 | 1.6 | 1.6 | 61.2 |
| 1944 | 10 | .7 | .7 | 61.9 |
| 1945 | 11 | .8 | .8 | 62.7 |
| 1946 | 15 | 1.0 | 1.1 | 63.7 |
| 1947 | 16 | 1.1 | 1.1 | 64.9 |
| 1948 | 11 | .8 | .8 | 65.6 |
| 1949 | 17 | 1.2 | 1.2 | 66.8 |
| 1950 | 18 | 1.3 | 1.3 | 68.1 |
| 1951 | 12 | .8 | .8 | 68.9 |
| 1952 | 13 | .9 | .9 | 69.9 |

Year of Death

| Year | N | % | Valid<br>% | Cum<br>% |
|---|---|---|---|---|
| 1953 | 19 | 1.3 | 1.3 | 71.2 |
| 1954 | 19 | 1.3 | 1.3 | 72.5 |
| 1955 | 18 | 1.3 | 1.3 | 73.8 |
| 1956 | 19 | 1.3 | 1.3 | 75.1 |
| 1957 | 18 | 1.3 | 1.3 | 76.4 |
| 1958 | 13 | .9 | .9 | 77.3 |
| 1959 | 22 | 1.5 | 1.5 | 78.9 |
| 1960 | 20 | 1.4 | 1.4 | 80.3 |
| 1961 | 20 | 1.4 | 1.4 | 81.7 |
| 1962 | 24 | 1.7 | 1.7 | 83.4 |
| 1963 | 20 | 1.4 | 1.4 | 84.8 |
| 1964 | 14 | 1.0 | 1.0 | 85.8 |
| 1965 | 15 | 1.0 | 1.1 | 86.8 |
| 1966 | 22 | 1.5 | 1.5 | 88.4 |
| 1967 | 15 | 1.0 | 1.1 | 89.4 |
| 1968 | 10 | .7 | .7 | 90.1 |
| 1969 | 13 | .9 | .9 | 91.1 |
| 1970 | 21 | 1.5 | 1.5 | 92.5 |
| 1971 | 14 | 1.0 | 1.0 | 93.5 |
| 1972 | 18 | 1.3 | 1.3 | 94.8 |
| 1973 | 16 | 1.1 | 1.1 | 95.9 |
| 1974 | 13 | .9 | .9 | 96.8 |
| 1975 | 17 | 1.2 | 1.2 | 98.0 |
| 1976 | 16 | 1.1 | 1.1 | 99.2 |
| 1977 | 12 | .8 | .8 | 100.0 |
| . | 19 | 1.3 | Missing | |
| Total | 1439 | 100.0 | 100.0 | |

| | |
|---|---|
| Valid cases | 1420 |
| Missing cases | 19 |

**St. Luke's Cemetery Population**

Year of Event

| Year | Burials<br>N | Baptisms<br>N | Marriage<br>N | TOTAL<br>ENTRIES |
|---|---|---|---|---|
| 1835 | 0 | 9 | 1 | 10 |
| 1836 | 3 | 25 | 1 | 29 |
| 1837 | 0 | 2 | 0 | 2 |
| 1838 | 3 | 26 | 1 | 30 |
| 1839 | 2 | 59 | 3 | 64 |
| 1840 | 7 | 69 | 3 | 79 |
| 1841 | 22 | 90 | 5 | 117 |
| 1842 | 6 | 54 | 5 | 65 |
| 1843 | 10 | 90 | 5 | 105 |
| 1844 | 21 | 54 | 5 | 80 |
| 1845 | 11 | 30 | 13 | 54 |
| 1846 | 13 | 37 | 6 | 56 |

| Year | Burials<br>N | Baptisms<br>N | Marriage<br>N | TOTAL<br>ENTRIES |
|---|---|---|---|---|
| 1847 | 21 | 48 | 12 | 81 |
| 1848 | 30 | 47 | 7 | 84 |
| 1849 | 12 | 36 | 5 | 53 |
| 1850 | 9 | 21 | 6 | 36 |
| 1851 | 17 | 22 | 6 | 45 |
| 1852 | 15 | 49 | 12 | 76 |
| 1853 | 0 | 68 | 10 | 78 |
| 1854 | 0 | 33 | 11 | 44 |
| 1855 | 0 | 29 | 6 | 35 |
| 1856 | 2 | 32 | 9 | 43 |
| 1857 | 1 | 4 | 2 | 7 |
| 1858 | 3 | 1 | 0 | 4 |
| 1859 | 3 | 2 | 9 | 14 |
| 1860 | 2 | 6 | 5 | 13 |
| 1861 | 1 | 4 | 6 | 11 |
| 1862 | 2 | 9 | 10 | 21 |
| 1863 | 0 | 3 | 12 | 15 |
| 1864 | 0 | 0 | 19 | 19 |
| 1865 | 0 | 2 | 4 | 6 |
| 1866 | 1 | 6 | 4 | 11 |
| 1867 | 8 | 10 | 7 | 25 |
| 1868 | 4 | 1 | 6 | 11 |

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