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0521800633 - Paleodemography: Age Distributions from Skeletal Samples

Edited by Robert D. Hoppa and James W. Vaupel

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1 *The Rostock Manifesto for paleodemography: the way from stage to age*

ROBERT D. HOPPA AND JAMES W. VAUPEL

Introduction

In June 1999, the Laboratory of Survival and Longevity at the Max Planck Institute for Demographic Research in Rostock, Germany, hosted a three-day workshop entitled “Mathematical Modelling for Palaeodemography: Coming to Consensus”. The title chosen reflected two issues the workshop was meant to deal with. First, the use of biostatistical methods as a means for estimating demographic profiles from skeletal data was clearly emerging as the right direction for the future. A number of individuals were invited who had published such techniques. Second, coming to consensus was a play on words for evaluating and finding a methodological approach that best did the job for paleodemography.

The initial workshop focused specifically on adult aging techniques. This was partly a reflection of the need to find methods that could capture the right-most tail of the age distribution in archaeological populations – the oldest old. Although nonadult aging techniques have increased levels of accuracy and precision, assessing the complete age structure of the population is absolutely imperative. The statistical approaches presented in this volume, while presented in the context of adult age estimation, are more broadly applicable to age indicator methods for any group (see e.g., Konigsberg and Holman 1999).

The purpose of the workshop was to provide individuals with an identical dataset on which to test their techniques. Thus everyone would be able to use their methods to estimate the demographic profile for a real target sample using a series of skeletal age indicator stages for which known-age data were associated, but not revealed. The assumption here was that, for the first time, the presentation of these newly emerging statistical techniques could be evaluated in terms of their accuracy and reliability in estimating age profiles on a level playing field – comparing apples with apples, if you will.

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As it turns out, the outcome of the workshop resulted in a realization that statistical methods might vary, but it was the theoretical framework in which such methods were placed that was critical. Thus, on conclusion of the workshop, there was unanimous acceptance of a theoretical approach – what became known amongst attendees as the “Rostock Manifesto”, a collegial call for new directions in paleodemographic research. While this theoretical framework represents the primary basis for which this project was developed, we nevertheless recognized that there are several interconnected issues in the reconstruction of population parameters from skeletal samples that should be addressed. Subsequently, in August 2000, a follow-up workshop was held in Rostock, in which attendees presented and discussed a variety of issues directly relevant to the field of paleodemography. This book represents the cumulative efforts of those who participated in these meetings.

The Rostock Manifesto has four major elements:

1. Working more meticulously with existing and new reference collections of skeletons of known age, osteologists must develop more reliable and more vigorously validated age indicator stages or categories that relate skeletal morphology to known chronological age.
2. Using these osteological data, anthropologists, demographers and statisticians must develop models and methods to estimate $\Pr(c|a)$, the probability of observing a suite of skeletal characteristics c , given known age a .
3. Osteologists must recognize that what is of interest in paleodemographic research is $\Pr(a|c)$, the probability that the skeletal remains are from a person who died at age a , given the evidence concerning c , the characteristics of the skeletal remains. This probability, $\Pr(a|c)$, is NOT equal to $\Pr(c|a)$, the latter being known from reference samples. Rather $\Pr(a|c)$ must be calculated from $\Pr(c|a)$ using Bayes' theorem. Even the most experienced and intelligent osteologists cannot make this calculation in their heads. Pencil and paper or a computer is required, as well as information concerning $f(a)$, the probability distribution of ages-at-death (i.e., lifespan) in the target population of interest.
4. This means that $f(a)$ must be estimated *before* $\Pr(a|c)$ can be assessed. That is to say, to calculate $\Pr(a|c)$ it is necessary to first estimate $f(a)$, the probability distribution of lifespans in the target population. To

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estimate $f(a)$ a model is needed of how the chance of death varies with age. Furthermore a method is needed to relate empirical observations of skeletal characteristics in the target population to the probability of observing the skeletal characteristics in this population. The empirical observations generally will be counts of how many skeletons are classified into each of the stages or categories c . The probability of these characteristics, $\text{Pr}(c)$, is given by

$$\text{Pr}(c) = \int_0^{\omega} \text{Pr}(c|a)f(a)da, \quad (1.1)$$

where ω is the upper limit of the human lifespan. The basic strategy is to choose the parameters of the model of the lifespan distribution $f(a)$, or the levels of mortality in various age categories in a nonparametric model, to maximize the “fit” between the observed frequencies of the morphological characteristics and the underlying probabilities of these characteristics.

The various chapters of this book pertain to these four precepts. In the following discussion we explain each of the dictums in more detail and adumbrate how the chapters relate to them.

The need for better osteological methods

Paleodemographic reconstructions of past populations depend on accurate determination of age-at-death distributions, sorted by sex, within skeletal samples. The accuracy and reliability of age estimation techniques have been central concerns in critiques of paleodemography. In particular, the underestimation of ages for older adults and age mimicry have invited strong criticism (Bocquet-Appel and Masset 1982, 1985, 1996; Sattenspiel and Harpending 1983; Van Gerven and Armelagos 1983; Buikstra and Konigsberg 1985; Masset and Parzys 1985; Bocquet-Appel 1986; Greene *et al.* 1986; Wittwer-Backofen 1987; Horowitz *et al.* 1988; Konigsberg and Frankenberg 1992, 2001). While there are a variety of methodological approaches to scoring age-related changes in the skeleton, many (although not all) commonly employed methods are based on an osteological age indicator staging system where the stages serve as proxies for age. In Chapter 4, Kemkes-Grottenthaler provides an excellent historical overview of age indicator methods for assessing age-at-death in the skeleton, contrasting the historical division between European and North American methods, and the need for true multivariate techniques. Such methods are used both in forensic investigations where the age of an individual is of

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primary interest, and in paleodemographic investigations where the mortality schedule of a population is of interest. The subsequent two chapters present two new osteological techniques relevant to estimating age-at-death from the skeleton. In Chapter 5, Boldsen and colleagues present a new multivariate method that incorporates morphological assessments of the pubic symphysis, auricular surface, and cranial suture closures. Estimating age for an individual requires, as noted above, information about the population mortality schedule. Different statistical approaches to estimating this schedule may be appropriate when the number of individuals to be aged is a handful or less or thousands or more. Chapter 5 by Boldsen and colleagues demonstrates the applicability of transition analysis for estimating age in a single individual or a small sample for which estimating of age structures from the target sample is impossible. In Chapter 6, Wittwer-Backofen and Buba present the preliminary results of a validation study of a refined method for estimating age-at-death directly from teeth, using cementum annulation.

The need for better reference samples

As noted above, the information that osteologists have regarding age and stages pertains to the probability of being in a specific stage given age, $\Pr(c|a)$. This is based on comparisons of stage and age in documentary reference samples. It is important that the reported ages in such reference samples be carefully validated. Age misreporting is common, so care must be taken to document and verify ages. This is particularly important when a person's age is given by a proxy source (because, e.g., the person has died). The reference collection used in Chapter 5 by Boldsen and coworkers includes three black females who are reported to have reached their 90s. They almost certainly died at younger ages and either their reported ages should be checked or they should be excluded from any future analysis. For further discussion of age validation, see Jeune and Vaupel (1999).

It became abundantly clear both from discussions that developed during the workshops and from the practical difficulties in providing attendees with real data on which to test their methods – specifically the paucity of published reference sample data – that there was a need to explore the existence of known-age skeletal samples for which methods have and can be developed and/or tested. Usher addresses this issue in Chapter 3, where she provides an overview of the use of known-age reference samples as a means for developing osteological aging techniques, and a general assessment of those collections that are known to exist.

The need to use Bayes’ theorem

The concept of estimating age from a skeleton is fundamental to any skeletal biologist. Training in osteology means learning rigorously how to “read” biological information from the skeleton related to age, sex, pathology, and personal identification. The specific means of any one study will be tied to the questions being asked, but ultimately age and sex have formed a fundamental first step for any anthropologist examining a series of skeletons. Because these two features are so important to further analyses, and to some extent codependent on one another (many aging criteria are sex specific), they have formed an intrinsic expertise for all experienced researchers.

The concept of age estimation has, despite a variety of possible techniques, followed the same series of short steps: (a) assess skeletal morphology, (b) link skeletal morphology to chronological age through a reference collection, and (c) estimate age. While in principle these steps are correct, there is some issue over how the second step is executed. The second step is tied critically to the reference population on which a method, or series of methods, has been developed. In this step, morphological aging criteria are established, given known age in the reference sample. Thus we have some understanding of the probability of what stage a skeleton should be, conditional on age, or in mathematical notation $\Pr(c|a)$, where c represents the morphological age indicator stage or category, and a represents chronological age-at-death. However, the ultimate goal of using this relationship is to estimate the age of an individual or group of individuals within an archaeological sample: that is to say, to estimate the probability of age conditional on stage, or $\Pr(a|c)$. This probability is not equivalent to $\Pr(c|a)$ but can be solved using Bayes’ theorem as follows:

$$\Pr(a|c) = \frac{\Pr(c|a)f(a)}{\int_0^{\omega} \Pr(c|a)f(a)da} \tag{1.2}$$

As noted by Konigsberg and Frankenberg (1994), it is a paradox that the very distribution that one is trying to estimate, $f(a)$, is required before individual age estimation can proceed. This seems counterintuitive to osteological training – how can one estimate a population structure before knowing the age of the individuals? But again, the problem is based, in part, on the notion that we can easily invert the relationship between stage and age, which is not correct. The question then arises as to how to make use of information in the reference sample without biasing our estimates of the age distribution or making faulty assumptions.

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While, ultimately, the goal would be to proceed without the need to impose any predefined patterns of mortality, currently the kinds of osteological data available are not adequate to allow for nonparametric approaches, at least for intervals of reasonable length. As a result, there is a need to incorporate parametric models of mortality into paleodemographic reconstructions. Given the limited information available from current skeletal age indicator methods and relatively small target samples sizes, only a handful of parameters can reasonably be estimated. As Konigsberg and Frankenberg (2001) note, this has plagued a variety of statistical exercises that have attempted to estimate more age intervals than age indicator categories, resulting in negative degrees of freedom in their models.

Chapters 7 (Wood *et al.*) and 8 (Paine and Boldsen) both deal with the process of modeling population dynamics in paleodemography. First, Wood and colleagues summarize for the reader various models that can be used to fit to paleodemographic data, and the advantages and disadvantages of differing approaches. In Chapter 8, Paine and Boldsen illustrate how one can link the mortality patterns in paleodemographic analyses to the broader questions of population processes, including disease, migration, and fertility.

The need to assess the distribution of lifespans in the target population

There are four approaches to estimating $f(a)$, the probability distribution of ages at death (i.e., lifespan) in the target population of interest. First, the distribution can be specified based on some convenient assumption, such as the assumption that all lifespans between age 20 years, say, and age 100 years, say, are equally likely. Second, the distribution can be assessed using the subjective judgments of experts who have ancillary knowledge. Third, a known distribution of lifespans, from some population assumed to be similar to the target population of interest, can be appropriated. Fourth, empirical data on the frequency of characteristics c in the skeletons of the target population together with information about $\Pr(c|a)$ from the reference population can be used in a mortality model to estimate the parameters or values of $f(a)$. The first three of these approaches are discussed briefly in Chapter 5, where Boldsen and colleagues argue that, when a flat or uniform prior is assumed, $\Pr(a|c)$ is related proportionally to $\Pr(c|a)$ and can be estimated relatively easily. However, a uniform prior is not reflective of real mortality distributions. The last, and most appealing, approach is discussed in Chapters 9 to 12.

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First, Love and Müller (Chapter 9) use a semiparametric approach and estimate weight functions in order to estimate age structure from age indicator data in the target sample. The next two chapters present parametric approaches to estimating age profiles – Holman and colleagues (Chapter 10) use a logit and Konigsberg and Herrman (Chapter 11) a probit approach. An example of how these methods can be applied to archaeological data follows with Herrmann and Konigsberg (Chapter 12) re-examining the Indian Knoll site, using the statistical approach outlined in Chapter 11 to make new inferences about this Archaic population.

Paleodemographic studies have the potential to provide important information regarding past population dynamics. However, the tools with which this task has been traditionally undertaken have not been sufficient. If we are interested in understanding demographic processes in archaeological populations, it is necessary to adopt a new framework in which to estimate age distributions from skeletal samples. It was once argued that, to be successful, paleodemographers should work more closely with researchers in the field of demography (Petersen 1975). This book answers that challenge, bringing together physical anthropologists, demographers, and statisticians to tackle theoretical and methodological issues related to reconstructing demographic structure from skeletal samples.

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2 *Paleodemography: looking back and thinking ahead*

ROBERT D. HOPPA

Introduction

Paleodemography is the field of inquiry that attempts to identify demographic parameters from past populations derived from archaeological contexts. Questions have been explored primarily by physical anthropologists through the analysis of skeletal remains, although such information can be augmented with associated documentary information available from epigraphy, census and parish records, or, sometimes, 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). However, paleodemographic theory relies upon several assumptions that cannot be readily validated by the researcher. The primary assumption of paleodemographic 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).

Historical perspectives

By 1950, the subject of human longevity in the past had been tackled by the occasional inquiry (e.g., Lankester 1870; Pearson 1902; MacDonnell 1913; Hooton 1930; Vallois, 1937; Willcox 1938; Weidenreich 1939; Senyürek 1947). However, it was the writings of J. Lawrence Angel, in the mid 20th century, on life expectancy in ancient Greece (e.g., Angel 1947, 1954) that many cite as the beginnings of paleodemography as an emerging area of specialization within physical anthropology (for a more detailed overview of the history of the field, see Konigsberg and Frankenberg 2001).

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Following Angel's early papers, paleodemography became standard practice in physical anthropological studies of human skeletal samples from the archaeological record. Initially, such studies made use of the abridged life table as a tool for interpreting age-at-death profiles in ancient populations (e.g. Vallois 1960; Kobayashi 1967; Angel 1968, 1969a,b, 1972, 1975; Kennedy 1969; Swedlund and Armelagos 1969; Acsádi and Nemeskéri 1970; Blakely 1971, 1977; Brothwell 1971; Lovejoy 1971; McKinley 1971; Bennet 1973; Masset 1973; Weiss 1973, 1975; Ubelaker 1974; Moore *et al.* 1975; Piasecki 1975; Plog 1975; Asch 1976; Armelagos and Medina 1977; Bocquet-Appel 1977, 1978, 1979; Bocquet-Appel and Masset 1977; Clarke 1977; Henneberg 1977; Lovejoy *et al.* 1977; Passarelli 1977; Pal-kovich 1978; Owsley and Bass 1979; Piontek 1979; Welinder 1979; Hassan 1981; Piontek and Henneberg 1981; Van Gerven *et al.* 1981; Pardini *et al.* 1983). Using osteological age indicator methods, individuals were assigned to age groups and distributed into an abridged life table. That is to say, individual ages were estimated first and those estimates were aggregated for demographic analysis. Because of the differences in precision for differing ages, and the desire to try to standardize the demographic data into five-year cohorts, individuals were often redistributed across multiple cohorts within the life table.

In the mid 1970s Howell (1976) noted that demographic analyses of past populations rely on the assumption of biological uniformitarianism. 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). The law of uniformitarianism is a fundamental assumption made by biologists working on skeletons at a variety of analytical levels. Estimates of demographic parameters in past populations necessarily assume that the biological processes related to mortality and fertility in humans were the same in the past as they are in the present (Weiss 1973, 1975; Howell 1976; see also Paine 1997). However, it is not only the broader issues of demographic structure that must conform to this assumption. Techniques for assessing age from skeletal remains must also assume uniformitarianism in the use of biological aging criteria, such that the pattern of age-progressive changes observed in modern reference populations is not significantly different from the pattern observed in past populations.

This assumption has implications at two levels for paleodemography. The first issue relates to application of this theory to biological processes, particularly those relevant to population structure, and assumes that humans have not changed over time with respect to their biological responses