Journal of Archaeological Science: Reports 19 (2018) 352–356

Contents lists available at ScienceDirect

Journal of Archaeological Science: Reports

journal homepage: www.elsevier.com/locate/jasrep

Rate of natural population increase as a paleodemographic measure of growth☆

Clare McFadden, Marc F. Oxenham*

School of Archaeology and Anthropology, Australian National University, Canberra, ACT 2601, Australia

ARTICLE INFO

Keywords:
Paleodemography
Population growth
Rate of natural increase
Demographic transition
Agricultural transition

ABSTRACT

The aim of this study was to provide a verifiable measure of population increase from age-at-death data. It was anticipated that the D0-14/D ratio would be a good predictor of the rate of natural increase (births minus deaths) due to its strong relationship with the total fertility rate. United Nations age-at-death data for 58 countries was used to calculate the rate of natural population increase and evaluate its relationship to the D0-14/D ratio. Additionally, the impact of migration on both the rate and the ratio was measured. A correlation of $r = 0.863$ (95% CI 0.777–0.917) between the D0-14/D ratio and rate of natural population increase was found. Linear regression provided a simple equation for calculating the rate of population increase. The rate of natural population increase accounts for the disparity (or lack of) between births and deaths, and provides a valuable measure for evaluating ancient population variability. While the rate does not factor in migration, we believe migration should be measured independently as it is not always of interest to bioarcheological research questions and has a negligible impact on the rate of natural increase and the D0-14/D ratio. Estimating the rate of natural population increase has the potential to provide significant insights into past populations and the human response to change.

Population growth is a demographic measure which estimates the contribution of births, deaths and migration to population size over time. In the study of ancient populations, changes in population size can tell us a great deal about the health of a population and its response to change. An example of this is the Neolithic Demographic Transition (NDT), considered to be one of the most significant events in the history of modern humans, and is variously associated with increasing social complexity, population size, and territorial pressure (Bocquet-Appel, 2008). Measuring the impacts of the NDT across the globe has been an area of significant interest to date (Armelagos et al., 1991; Bellwood and Oxenham, 2008; Bocquet-Appel and Naji, 2006; Buikstra et al., 1986; Cowgill, 1975; Eshed et al., 2004; Gage and Dewitte, 2009; Hassan and Sengel, 1973; Johansson and Horowitz, 1986; Kohler and Reese, 2014; Kuijt, 2008; Papathanasiou, 2005; Shennan, 2009; Woodbridge et al., 2014), yet a reliable way in which to estimate the rate of population increase from skeletal remains has continued to elude researchers.

Previous attempts to estimate population growth are highly diverse and include demographic (Cowgill, 1975) and paleodemographic modelling (Bocquet-Appel, 2002; Schindler et al., 2012), ethnographic and paleoclimate analyses (Tallavaara et al., 2015), spatiotemporal radiocarbon date approaches (Chaput and Gajewski, 2016; Crema et al., 2016; Delgado et al., 2015; Downey et al., 2014; Rick, 1987; Zahid et al., 2016), zooarchaeological evidence of increased animal consumption (Stiner et al., 1999), and mitochondrial DNA analyses (Harpending, 1994; Excoffier and Schneider, 1999). These approaches have achieved some success, but are underpinned by several practical issues, such as unavailability of the desired data for modelling in the bioarcheological record, the requirement for two or more distinct temporal points for estimates of relative change, the difficulty of standardizing archaeological, zooarchaeological and DNA data, and lack of verifiability of such methods.

The rate of natural increase is a relatively simple demographic measure: the birth rate (births per 1000) minus the mortality rate (deaths per 1000) for a period or point in time, divided by 10 to convert it to a percentage (Population Reference Bureau, 2017). Its value as a paleodemographic measure has previously been noted by paleodemographers (Angel, 1969; Bocquet-Appel and Naji, 2006). The relationship between juvenile to adult ratios and total fertility rate suggests that an estimate of birth rate can be reasonably obtained (Bocquet-Appel and Masset, 1982; McFadden and Oxenham, 2017), however, the mortality rate is somewhat more complex (Gage and Dewitte, 2009; Wood et al.,

☆ The authors declare that they have no competing interests.

* Corresponding author at: A.D. Hope Building, 14 Ellery Crescent, Acton, ACT 2601, Australia.
E-mail address: Marc.oxenham@anu.edu.au (M.F. Oxenham).

https://doi.org/10.1016/j.jasrep.2018.03.012
Received 14 January 2018; Received in revised form 7 March 2018; Accepted 8 March 2018
2352-409X/

2002). The rate of natural population increase is population growth without migration though it should be noted that in demography, population growth is associated with further complexities. In contrast to fertility and birth rates, the rate of migration is very difficult to estimate and presents several theoretical and practical challenges (Clark, 1994; Burmeister, 2000). In the modern world, migration has a large impact on population growth (Zlotnik, 2004), however, its impact on the rate of natural increase is not so clear cut. Past populations may have experienced greater limits on migration due to lower population densities (Clark, 1994) and reduced mobility (Anthony, 1990), and with fewer limits on fertility, migration is anticipated to have had a relatively limited impact on the natural increase of past, in comparison to modern, populations. Further, in many cases, the aim of estimating population increase is to understand how a change in diet, economy, or lifestyle may have impacted on population health and size. In these circumstances, migration may still be of interest but as a separate research question, and therefore a somewhat different indicator may be more appropriate.

We propose that the rate of natural population increase is an optimal paleodemographic measure for questions relating to the impact of significant transitions and events with respect to the health and size of past populations. While excluding the potentially confounding factor of migration from the mix may initially appear to be an omission of valuable data, we believe that this is, in fact, of negligible impact and is indeed a practical improvement. The rate of natural increase avoids the complexities associated with measuring population growth and, when considered in the context of other archaeological evidence, may be equally valuable in cases where the extremes of little to no migration through to significant migration are indicated.

1. Materials and methods

This study aimed to evaluate the relationship between the rate of natural increase and an age-at-death ratio. Due to the strong correlation achieved by McFadden and Oxenham (2017) between total fertility rate and the D0-14/D ratio (or the ratio of subadults aged 0–14 years to the entire sample), it was anticipated that the D0-14/D ratio would also correlate with the birth rate; a major component of the rate of natural increase. Additionally, the magnitude of the impact migration has on the rate of natural increase and the age-at-death distribution was also of interest. The use of modern data is based on the uniformitarian theory of paleodemography proposed by Howell (1976) and the generalized pattern of human mortality summarized by Wood et al. (2002). Data for 58 countries (SI) from the United Nations Database (2017) for the year 1960 were used, being the earliest year for which the United Nations recorded the data of interest. Other reasons for targeting this period are that this year predates the widespread use of the contraceptive pill (Liao and Dollin, 2012) and represents a greater range of natural increase rates than many of the later years. The following data were extracted: birth rate, mortality rate, age-specific deaths and net migration rate. The rate of natural increase (%) was calculated by subtracting the mortality or death rate (D_r) from the birth rate (B_r) and dividing by 10:

$$\text{Rate of Natural Increase (\%)} = (B_r - D_r)/10$$

First-order correlation tests of the D0-14/D ratio to the calculated rate of natural increase and the net migration rate were performed, and the rate of natural increase to the net migration rate. Normal probability plots were used to identify potential outliers. It was expected that the relationship between the D0-14/D ratio and the rate of natural increase would be linear, as an increasing proportion of juvenile deaths was anticipated to predict an increased rate of natural increase. All statistics were calculated using StatsDirect 3 (2016). Rules for identifying outliers followed those of Pennsylvania State University (2017).

Table 1
Descriptive statistics and first-order correlations for the rate of natural increase, net migration rate, and D0-14/D ratio.

	Rate of natural increase	Net migration rate	D0-14/D Ratio
n=	57	57	57
Average	2.01	−2.04	0.26
Standard deviation	1.03	7.84	0.19
	Correlation with rate of natural increase	r = −0.158	r = 0.863
	95% confidence interval (CI)	−0.402–0.107	0.777–0.917
		Correlation with net migration rate	r = −0.232
		95% confidence interval (CI)	−0.465 to 0.030

2. Results

In the first instance, a correlation of $r = 0.835$ between the D0-14/D ratio and the rate of natural increase was observed. When residuals were plotted one outlier (Tonga) was identified from the normal distribution. In accordance with standard procedure (Pennsylvania State University, 2017), a normally distributed probability plot of residuals was observed with the removal of the outlier. This outlier was excluded from the remainder of analyses.

Descriptive results and first order correlations are provided in Table 1. With the outliers removed, a correlation of $r = 0.863$ (95% CI 0.777–0.917) was achieved between the rate of natural increase and the D0–14/D ratio. The correlation between the rate of natural increase and migration was not significant ($r = -0.158$, $p > 0.05$ two-tailed), with migration accounting for a minute amount of the variance ($r^2 = 0.025$). Similarly, migration was not a significant predictor of the D0-14/D ratio ($r = -0.232$, $p > 0.05$ two-tailed).

Simple linear regression produced the following equation to calculate the rate of natural increase:

$$\text{Rate of Natural Increase (\%)} = (10.06 \times D0 - 14/D) - 1.61$$

3. Discussion

A strong relationship ($r = 0.863$, 95% CI 0.777–0.917) between the D0–14/D ratio and the rate of natural increase was identified. In the absence of the mortality rate, the rate of natural population increase and the total fertility rate are inextricably linked, as they are both based on a linear relationship with juvenile mortality. This limits the interpretations that can be made based on the available data, as a high fertility rate will always be associated with high growth, and vice versa, when using this method. This should be noted when evaluating both measures. Additionally, given that a number of commentators (e.g., Konigsberg and Frankenberg, 1994; Milner et al., 1989; Sattenspiel and Harpending, 1983) have reported that fertility has a greater impact on the age-at-death distribution than mortality, this may limit the sensitivity of the method proposed in this study to mortality. Another potential limitation of the method is that it is based on a single year of data, whilst burial samples will very rarely represent a single year. It seems logical that applying the method to a burial sample would have the effect of averaging the rate of natural increase for the period of the burial depositions. Nonetheless, archaeological context is key, and consideration should be given as to whether the sample is substantial and cohesive enough to be taken as representative of a single population.

For this method, the D0-14/D ratio was used based on age-at-death data from real populations to estimate the rate of natural increase. A