

RESEARCH ARTICLE

Estimating fertility using adults: A method for under-enumerated pre-adult skeletal samples

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Abstract

Objectives: Infant underrepresentation poses a great risk to accurate palaeodemographic findings when analyzing skeletal samples. Empirically derived palaeodemographic methods all require unbiased or minimally biased pre-adult representation for estimating demographic characteristics, including fertility. Currently, there are no reliable methods for estimating palaeodemographic parameters when pre-adults are underrepresented in skeletal samples, consequently such samples are often excluded from palaeodemographic analyses. The aim of this article is to develop a method for estimating total fertility rate (TFR) using reproductive aged adults, specifically for samples with suspected pre-adult under-enumeration.

Methodology: United Nations mortality data and TFR from the World Population Prospects was utilized. The correlation between known fertility and the proportion of individuals in key reproductive years (15–49 years) to total adult sample (15+ years) was assessed as an indirect means to estimate fertility.

Results: It was determined that the proportion of reproductive aged adults is a reasonable proxy for fertility. A significant positive correlation was observed between the TFR and those who died aged 15–49 years of age as a proportion of those who died ≥ 15 years (D15-49/D15+). SE of the estimate revealed reasonable predictive accuracy. When applied to two modern non-agricultural populations, the method showed some variability in accuracy but good potential for an improved outcome over existing methods when pre-adults are underrepresented.

Conclusion: This research has provided a new method for estimating fertility in archeological skeletal samples with pre-adult under-enumeration. In combination with a contextually focused approach, this provides a significant step toward further use of biased samples in palaeodemography.

KEYWORDS

bias, fertility, infant under-enumeration, palaeodemography, uniformitarianism

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1 | INTRODUCTION

Palaeodemography is the study of past human population structures and dynamics, typically using one, or a combination of archeological sources, with the aim of providing further evidence for understanding human behaviors, interactions and adaptivity across time and space (Bocquet-Appel & Masset, 1982; Boldsen et al., 2021; Chamberlain, 2009; DeWitte, 2018; McFadden, 2021; Milner et al., 2018). Skeletal remains are one of the most commonly used sources of data in palaeodemographic research, with French et al. (2021) also arguing that they provide the most direct form of demographic evidence for past populations. An underlying premise for the employment of skeletally based palaeodemographic methods is the reliability or representativeness of archeological skeletal samples (Bocquet-Appel & Masset, 1982; Roksandic & Armstrong, 2011; Storey, 2007; Walker et al., 1988; Wood et al., 1992). Improvements continue to be made to palaeodemographic methods (e.g., McFadden & Oxenham, 2018a) building on a substantial history of skeletal palaeodemography, including foundational works by Masset and Bocquet-Appel (1977), Bocquet-Appel (2002), and Séguy and Buchet (2013). Recent methods have sought to improve accuracy as well as methodological suitability with regard to archeological data, there has been little development regarding palaeodemographic measures for use on skeletal samples with potential or suspected pre-adult under-enumeration. Notwithstanding, all skeletally based methods to date use various proportions of juveniles in an assemblage, where there is reason to assume relatively good archeological representation, as a means by which to estimate fertility and rate of natural population growth. These calculations further provide vital contextual information toward the ongoing goal of understanding past population adaptive responses to major changes in their environment, biology, or social interactions (Bocquet-Appel, 2002; Masset & Bocquet-Appel, 1977; McFadden & Oxenham, 2018a, 2018b; Séguy & Buchet, 2013). The key issue, as such, is the representativeness of these skeletal series and what can be done where a reasonable case for under-enumeration or bias is suspected.

Pre-adult under-enumeration refers to contexts where the representation of juveniles in a skeletal sample has been affected by a range of factors, including preservation and differential burial. There is an ongoing discussion of how pre-adult representation effects bioarchaeological, and, more specifically, palaeodemographic research (Bello et al., 2006; Halcrow & Tayles, 2008; Jackes, 2011). Walker et al. (1988) attempted to illustrate the extent of preservation biases, arguing that preservation can cause significant issues in pre-adult representation where the mortality frequencies are no longer accurate in representing the original age distribution. Causes for demographic bias in skeletal samples have been attributed to multiple factors. Paine and Harpending (1998) have previously categorized presentation biases as being caused by one or more of four factors: cultural practices, taphonomic processes, archeological recovery, and age-at-death estimation bias. Delving deeper into the specifics of these categories, taphonomic processes may be influenced by the physical properties

of the bone as well as factors such as geology and environment. Similarly, recovery may be influenced by skeletal preservation, archeological methods employed, and excavator experience. As such, a range of intrinsic and extrinsic factors influence the interacting causes of infant representation, contributing to the diversity of underrepresentation contexts observed in the archeological record (Djuric et al., 2011; Ērkšķe, 2020). In contrast, several authors have argued for reasonable infant representation in skeletal samples including those from Dakhleh Oasis, Egypt (Wheeler, 2012), Man Bac, Vietnam (Domett & Oxenham, 2011, p. 12), and other Southeast Asian sites (Halcrow et al., 2016).

Archeological contexts, Man Bac, Vietnam (Domett & Oxenham, 2011) and the Latvian Iron Age cemeteries discussed by Ērkšķe (2020) represent extreme examples of how infant representation can vary between skeletal samples. Man Bac demonstrated a high frequency of well-preserved pre-adults within the skeletal sample (46/78, 59%), with the 1–4 age group and infant (<1 year) category having the most individuals respectively (Domett & Oxenham, 2011). This differs remarkably to previous literature where it has been argued that pre-adults are generally underrepresented in archeological skeletal samples due to taphonomic processes (Bello et al., 2006; Bello & Andrews, 2006; Guy et al., 1997; Walker et al., 1988). Latvian Iron Age cemeteries, however, are a good example how cultural practices may influence the representation of pre-adults, with the age cohort of “0 and 5 years” typically being represented in <6% of Latvian Iron Age skeletal samples (Ērkšķe, 2020). Ērkšķe (2020) hypothesized that while preservation would have played a part, several complex issues, including the possibility of differing burial treatment for young children, is the likely cause for the significant underrepresentation of pre-adults in these cemeteries. Pre-adult representation is variable across archeological cemeteries, therefore each skeletal sample should be analyzed individually given the multiple, potentially confounding, factors to consider which may influence how pre-adults are preserved and are subsequently represented in an archeological sample.

Clearly, the consideration of infant representation is a necessary component of all palaeodemographic research as preservation and representation vary greatly between sites. Unfortunately, however, there is currently no reliable method for determining the extent of pre-adult bias in a sample without prior knowledge of the population's fertility levels (Paine & Harpending, 1998).

A lack of a solution to this issue saw early palaeodemographic methods simply excluding infants from consideration (Halcrow et al., 2018, p. 95), as observed in Masset and Bocquet-Appel (1977) and Bocquet-Appel (2002), where the 0–4 year-old cohort is not considered. McFadden and Oxenham (2018a), however, included all age categories, arguing that the 0–4-year-old age category was the most sensitive to changes in fertility and must be included for the most accurate results. However, the method decreases in accuracy as infant underrepresentation increases (McFadden & Oxenham, 2019), rendering the approach inappropriate for many samples. The mortuary context of any given assemblage of interest is critical to a more complete

understanding of its demographic history (Ērkšķe, 2020; McFadden et al., 2021). For instance, differential burial of adults and children may result in little or no pre-adults observed in demographic breakdowns (Finlay, 2000; Kamp, 2001).

Tangentially, Robbins (2011) proposed an equation for estimating gross reproduction rate for samples with adult under-enumeration, based on the proportion of infants within a pre-adult sample, yet no such solution has been proposed for samples with pre-adult underrepresentation. Wilmoth et al. (2012) have previously demonstrated strong correlations between adult mortality and the probability of dying under 5 years for indirect demographic estimation, with the correlation decreasing as age increases. Given this relationship and that between the 0 and 4 age group and fertility as shown by McFadden et al. (2021), it seems logical that the proportion of adults in the reproductive age range should also tell us something of the fertility of a population, though there are notable complexities. The reproductive age range for women is commonly reported as 15–49 years old (Chamberlain, 2006, p. 35; Low et al., 2008; Stevens et al., 2013), but of course the number of children (if any) that will be born to any individual woman within that age range varies significantly based on myriad sociocultural, biological, and environmental factors (Heazell et al., 2018; Lampinen et al., 2009; Rindfuss, & St. John, 1983). For bioarchaeological contexts, understanding how fertility influences reproductive aged adults in a population is arguably a critical aspect of palaeodemographic research. It can be hypothesized that the ratio between reproductive aged adults and total adults can provide a reasonable estimate for total fertility rate in bioarchaeological contexts.

The primary aim of this article is to develop a new method for estimating the total fertility rate (TFR) for skeletal samples where pre-adult under-enumeration is suspected. The method developed and applied here is based on the working hypothesis that the proportion of reproductive aged adults can be used as a proxy for estimating fertility. This will allow for a fertility estimate to be made for archaeological skeletal samples where pre-adults are absent or under-represented.

2 | MATERIALS AND METHODS

2.1 | The dataset

The approach tests a series of mortality proportions, where pre-adults aged 0–14 are excluded, to investigate the relationship between reproductive aged adults and fertility. In line with a uniformitarian approach (French & Chamberlain, 2021; Howell, 1976; McFadden, 2021; McFadden & Oxenham, 2018b), the World Population Prospects project within the United Nations (2019), containing mortality and TFR data from 1950 to 2020, is used in this study. Data from this project are based on numerous sources including population, housing censuses and other surveys, births and deaths registrations, migration records, and statistics reported to the Demographic Yearbook of the United Nations (United Nations, 2021) and other United Nations reports (United Nations, 2019).

The uniformitarian approach to palaeodemographic analysis has allowed for modern samples, with known or reasonably-well estimated mortality rates, to be used as a proxy for past populations (Johansson & Horowitz, 1986; McFadden & Oxenham, 2018a; Paine, 1989; Robbins, 2011). Modern datasets are a good resource for palaeodemographic method development due to their reliable age-at-death distributions with minimal bias, an issue which archeological samples are typically susceptible to, and recorded population variables (such as TFR). They also provide large sample sizes for statistical analyses, with a significant magnitude of population heterogeneity captured by the dataset, making developed methods more justifiable when applied to archeological samples. Notwithstanding, it must be acknowledged that modern population datasets often over-represent socio-economically advantaged nations (due to their greater capacity to collect and report population data) and therefore such datasets tend to be skewed toward lower levels of fertility, decreased infant mortality, and increased representation of the elderly. A range of other issues are encountered when modern and historical non-agriculturalist population data are used to make predictions about past population dynamics (Page & French, 2020). As such, we consider the limitations of using the modern United Nations dataset to be outweighed by the aforementioned advantages of using accurate and comprehensive data.

Mortality and TFR data were presented in several formats for each 5-year period, including by country, region, and other identifiers such as developing countries. Mortality data is also reported for each 5-year age group (until 95+ years) in the thousands, combined sex, and reported for males and females separately. For the purposes of this study, data provided by country was utilized. The 5-year period of 1960–1965 was chosen as this period had a broad range of fertility rates among countries (1.81–8.20). A total of 201 countries were originally examined in the dataset, however, 59 countries were excluded in order to focus on those which had greater than 1000 deaths in each age category for more stable estimates. This left a total of 142 countries to be included in this analysis. All statistical analyses were completed using Microsoft Excel and SPSS. An outline of the 142 countries used and their raw fertility and mortality data can be found in the Data S1.

2.2 | Pearson's correlation and regression analysis

Given our purpose is to assess whether adults within the reproductive age range can be used as a proxy for estimating fertility in skeletal samples when pre-adult mortality data are not available, mortality data for the age groups of 0–4 years, 5–9 years, and 10–14 years were excluded. As the reproductive age range of females is typically 15–49 years (Chamberlain, 2006, p. 35; Low et al., 2008; Stevens et al., 2013), it was hypothesized that this proportion of the population may be predictive of fertility. Pearson's correlation and simple linear regression were used to evaluate the relationship of each 5-year age group between 15 and 49 years with reported TFR (e.g., D15-19/ D15+, etc.). We examined linear regression models only, as it was

TABLE 1 Descriptive statistics, Pearson's correlation and regression results of the D15-49/D15+ proportion with total fertility rate.

		D15-49/D15+	D0-14/D	D5-19/D5+
Descriptive results	N	142	142	142
	Mean	0.34	0.42	0.13
	SD	0.17	0.21	0.09
Pearson's correlation	r	0.81	0.94	0.83
	r ²	0.66	0.88	0.68
	95% CI	7.53–9.60	7.57–8.55	14.95–18.78
	p Value	<0.001	<0.001	<0.001
Fitted regression model		y = 8.564x + 2.508	y = 8.064x + 2.047	y = 16.864x + 3.22

Note: The D0-14/D ratio by McFadden and Oxenham (2018a) and D5-19/D5+ by Bocquet-Appel (2002) are also included for comparison. Raw data can be viewed in Data S1.

anticipated that the relationship between predictor and outcome variables would be linear.

2.3 | Testing and comparing TFR estimates

The new equation for estimating fertility using reproductive adults was applied to the same United Nations mortality dataset to assess accuracy. Results were compared to the actual TFR reported by the United Nations. This was achieved by calculating the Standard error of the estimate (SEE):

$$SEE = \sqrt{\frac{\sum(Y - Y')^2}{N}}$$

where Y is the actual fertility rate and Y' is the estimated fertility rate.

To assess the susceptibility of the selected proportion to age-estimation error, a rudimentary test including the 50–54 age group into the proportion was undertaken. SEE was then calculated again to observe the effect it would have on the fertility estimates.

The equation was then applied to two modern hunter-gatherer populations; Hadza, Tanzania (Blurton Jones et al., 2002) and Hiwi, Venezuela (pre-contact mortality data reported in Hill et al. (2007) used), which have known mortality and TFRs (see Data S2 for this data). These populations were chosen for application of this method as they can represent some of the diverse population age-structures and dynamics seen in non-agriculturalist populations which may parallel some past populations (Page & French, 2020).

Results were then compared to the fertility estimate calculated using the D0-14/D equation. To further examine how useful this new equation may be for archeological samples with suspected infant underrepresentation, the D0-14/D equation was further applied to the Hadza and Hiwi mortality data where pre-adult age groups 0–1 years, 0–4 years, and 0–9 years were excluded. By further comparing these manipulated fertility estimates with the D15-49/D15+ proportion, we were able to evaluate what degree of underenumeration rendered the D0-14/D equation inaccurate and infer potential suitability for the application of the D15-49/D15+ proportion.

3 | RESULTS

3.1 | Descriptive statistics, Pearson's correlation and regression analysis

The descriptive statistics for the D15-49/D15+ proportion are reported in Table 1. Table 1 also includes the Pearson's correlation results using the proportions D0-14/D and D5-19/D5+ for comparison against traditionally used fertility estimators. The correlation between the D0-14/D proportion and fertility is stronger than originally reported (McFadden & Oxenham, 2018a), and is likely due to the larger sample size included in this study. The D15-49/D15+ proportion achieved a similar predictive power to that of the D5-19/D5+ proportion.

When examining the contribution of each 5-year category to this relationship, it was found that each of the groups between 15 and 49 years correlated similarly with TFR (r² ranging from 0.58 to 0.65; see Data S3 for complete results), and indicated moderate predictive power. A substantial drop in the explanatory power of the predictor variable was noted for the 50–54 age group (r² = 0.31), further confirming the appropriateness of the D15-49/D15+ proportion for estimating fertility.

The fitted regression models are also provided in Table 1 with the corresponding linear regression plot in Figure 1 for the D15-49/D15+ proportion.

Based on these results, the proposed equation for estimating TFR using reproductive aged adults is:

$$TFR = \left(8.564 \times \frac{D15-49}{D15+} \right) + 2.508$$

3.2 | Testing and comparing TFR estimates

To achieve a more nuanced understanding of the accuracy of the estimator, the equation was then tested on the United Nations mortality dataset and compared to the actual TFRs. SEE was calculated with a result of 1.07. Based on these results, we can say that there is a modest degree of error when using the new equation to estimate the

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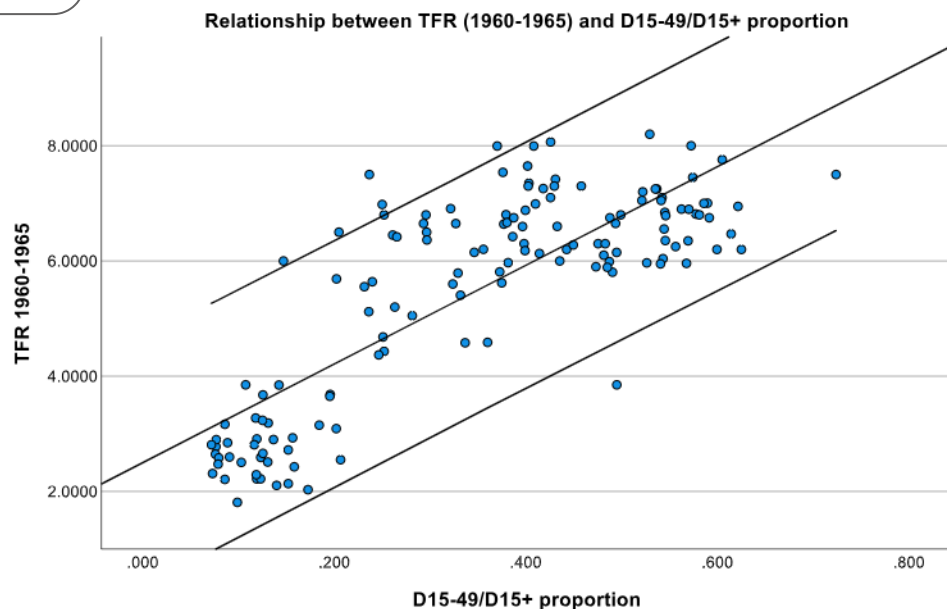


FIGURE 1 Linear regression model illustrating the relationship between total fertility rate (TFR) between 1960 and 1965 and the D15-49/D15+ proportion.

TABLE 2 Fertility estimates using the D15-49/D15+, D0-14/D equation, and D0-14/D again under infant-biased proportions on Hadza, Tanzania and Hiwi, Venezuela non-agricultural populations.

	D	TFR	D15-49/D15+	D0-14/D ^b	D2-14/D2+ ^b	D5-14/D5+ ^b	D10-14/D10+ ^b
Hadza, Tanzania	125	6.2	5.914	4.513	4.469	3.883	3.153
Hiwi, Venezuela ^a	146	5.1	8.818	5.932	4.518	3.837	3.280

^aMortality rates from the pre-contact (1960) dataset (Hill et al., 2007).

^bFertility estimates calculation using equation from McFadden and Oxenham (2018a, 2018b).

fertility level of a population using the proportion of reproductive age adults in a mortality sample.

The inclusion of some older adults (those aged 50–54 years), which may be expected to occur due to the limitations of age-estimation methods, did not affect the correlation ($r = 0.81$) and only slightly increased the SEE to 1.20. This demonstrates that our model can accommodate some error in age-estimation.

Lastly, the new equation was applied to the Hadza, Tanzania (Blurton Jones et al., 2002) and Hiwi, Venezuela (Hill et al., 2007; Page & French, 2020) non-agricultural populations to compare with known TFR and fertility estimates using the D0-14/D method (Table 2). The results illustrate population-based variability in the accuracy of the D15-49/D15+ equation, both in comparison to the known TFR and the D0-14/D estimated TFR. As expected, application of the D0-14/D equation and manipulated proportions to test different levels of infant biases illustrated a consistent decreasing accuracy as infant bias increased.

4 | DISCUSSION

The results illustrate that fertility may be estimated using the proportion of reproductive age adults relative to the total adult sample. This differs from previously proposed methods which invariably use a proportion of pre-adults relative to the entire sample (e.g., Bocquet-Appel

(2002) and McFadden and Oxenham (2018a)). The method proposed here provides a solution for those skeletal samples suspected of being biased with respect to pre-adults. This is a significant step forward for palaeodemographic research, as it has previously been suggested that biased skeletal samples should not undergo further palaeodemographic analysis (Paine & Harpending, 1998; Roksandic & Armstrong, 2011).

Analyses indicated that all 5-year age categories between 15 and 49 years were contributing to the overall predictive power of the D15-49/D15+ proportion for TFR. This supports the hypothesis that the frequency of reproductive age adults within an adult sample can be used as a proxy for estimating demographic measures such as fertility. It should be acknowledged that this analysis used data from modern, rather than archeological, populations and that reproductive ages may vary. We can assume, however, that reproduction outside of this range did not substantially contribute to the TFR of a population. Therefore, the 15–49 age group is still a representative age range for the core reproductive years for populations from the deep past. From an archeological perspective, D15-49 is a useful numerator as it includes a significant number of what are generally the best preserved individuals within a sample (Bello et al., 2006), and is therefore less likely to be biased than other ratios. Furthermore, the 15–49 age group corresponds to the upper adolescent ages, and the “Young Adult” (20–34 years) and “Middle Adult” (35–49 years) categories as described by Buikstra and Ubelaker (1994), and therefore may be retrospectively

applied to existing datasets that use this commonly employed age-at-death categorization.

Notwithstanding, it should be acknowledged that adult age-at-death estimation remains a significant issue in bioarchaeology and palaeodemography with a long history of debate regarding the reliability and replicability of methods (Bocquet-Appel & Masset, 1982, 1996; Boldsen et al., 2021; Konigsberg & Frankenberg, 1994; Milner et al., 2008; Van Gerven & Armelagos, 1983). The increase in SEE when individuals aged 50–54 years were included in the numerator of the D15-49/D15+ proportion was not large enough to cause concern. Consequently, although this method requires a reasonably accurate age-at-death estimation, it can tolerate some error.

Evaluations into adult age-at-death estimation error have demonstrated that estimation tends to be less accurate for the middle to older adult age categories (Miranker, 2016; Rissech et al., 2011; Wittwer-Backofen et al., 2008). While some error can be tolerated, we suggest that the use of the method presented here is paired with a discussion and acknowledgement of the age-at-death methods specifically used in accordance with this issue. Furthermore, given that some age-at-death estimation methods do produce reasonable results despite some error (Boldsen et al., 2002; Clark et al., 2020; Kim & Algee-Hewitt, 2022; Milner & Boldsen, 2012), it is likely that certain methods may be better suited to this particular method upon further investigation.

The new equation proposed here was tested on two modern non-agricultural populations, the Hadza, Tanzania and the Hiwi, Venezuela, with known TFRs and age-specific mortality rates for a more robust illustration of the applicability of the proposed method. The D15-49/D15+ equation estimated fertility for the Hadza reasonably well but overestimated fertility for the Hiwi population, demonstrating that population-specific factors are producing variability in the accuracy of the estimators. This inter-population variability was also observed when the D0-14/D equation was applied to the fully represented samples. In contrast, a consistent decrease in accuracy of the D0-14/D equation was observed across both samples with increasing infant underrepresentation (as discussed by McFadden & Oxenham, 2019), suggesting the method may not be suitable where individuals in the 0-9-year-old cohort are absent or poorly represented. Taken collectively, these results suggest that in some contexts the D15-49/D15+ provides a more accurate estimate where pre-adults under 10 years are suspected missing from the sample, and may provide an improved estimate where those under 5 years or even solely infants are absent.

To ensure the greatest possible accuracy of estimated fertility is achieved, we suggest that both methods should be applied to samples where some degree of underrepresentation of pre-adults under 10 years is suspected. This permits comparison of the two estimates and contextualization within the archaeology of the site and expected fertility based on the evidence for biological, environmental and social conditions. Indeed, past demographic reconstructions are limited in both accuracy and meaningfulness without such comprehensive contextual information. As set out by Page and French (2020), behavioral ecology may offer a useful framework to bioarchaeologists and

archeologists in identifying relevant intrinsic and extrinsic variables that influenced population dynamics in the past.

Palaeodemographic methods have traditionally assumed population stability (i.e., a consistent age structure and fixed rate of natural increase) and stationarity (a stable population with a natural increase rate of zero), failing to reflect the potential for population instability and the non-stationary nature of real populations (Sattenspiel & Harpending, 1983). The data used in the development of this method represent a range of natural increase rates and are derived from populations with varying stability. Due to the large size of most nations represented within the dataset and the tendency for large populations to assume a relatively stable structure, there is a degree of stability within the model presented here. However, while small populations are more prone to demographic fluctuations on a per annum basis, small archeological populations are less volatile as short term demographic variability typically stabilizes over the deep time usage period of cemeteries or burial sites (Sattenspiel & Harpending, 1983).

Ongoing debates surrounding the representation of pre-adults in skeletal samples has led to their removal altogether from palaeodemographic analyses, or even excluding entire samples from further consideration (Bocquet-Appel, 2002; Mays et al., 2017; Roksandic & Armstrong, 2011). This has seen a push back in the last decade with revised approaches arguing that consideration of pre-adults is required for the most accurate results (McFadden & Oxenham, 2018a; Robbins, 2011). However, there is a notable absence of reliable methods for determining whether pre-adult underrepresentation is present and, if present, the severity of it. Paine and Harpending (1998) argued that there is no reliable way to test for infant bias without first knowing fertility levels. Historically, it has been assumed that a sample must be made up of at least 30% of infants and pre-adults to be perceived as representative (Grauer, 1991; Waldron, 1994, p. 23; Weiss & Wobst, 1973), though this assumption has recently been contested (McFadden et al., 2021). Brothwell (1971) proposed an alternative method for testing whether infant representation is reasonable within a population by using the proportion of infants under 1 year and the total number of individuals under 20 years. Whether or not we can test for pre-adult bias without prior knowledge of fertility rates is an area which clearly needs more research.

We have examined the relationship between the D15-49/D15+ proportion and TFR. It should be recognized, however, that it is birth rates that influence the proportion of reproductive aged adults within a population. The impact of population growth, including fertility, on the age-at-death distribution is already well known with variation to this when tested on archeological samples likely due to confounding factors relating to population non-representativeness and varying cultural contexts (Johansson & Horowitz, 1986; Milner et al., 1989; Paine, 1989; Sattenspiel & Harpending, 1983). The equation presented here can be applied easily to bioarchaeological samples and does not require the construction of life tables, which require age-at-death estimation precision (Boldsen et al., 2021), or complex demographic calculations to gain an estimate for fertility. Context should always be a consideration, with variation in this relationship identified from multiple components including cultural factors, preservation, and

archeological recovery biases (Paine, 1989). As demonstrated by the application of this method, however, it should be used with caution and users are encouraged to interpret results as broad estimates of fertility levels in archeological samples rather than an accurate measurement. This adds to the necessary caution which must be taken when applying this method.

Despite issues surrounding pre-adult representation, the method presented here allows for demographic approximations when pre-adults are underrepresented or absent in the sample. We have not addressed the issue of how to identify pre-adult bias in a skeletal sample, but rather provided a way to estimate fertility where pre-adult bias is suspected. Causes for biases in skeletal samples vary and so does the representation of demographic groups in burial contexts. This is something that we unfortunately cannot control for in archaeology and it is for this reason that adapting palaeodemographic methods to suit various burial types is so important. The method developed here allows for more samples, from bioarchaeological contexts which are usually excluded from palaeodemographic analysis due to inadequate pre-adult representation, to be included in demographic analyses and therefore incorporated into comparative research.

5 | CONCLUSION

This article aimed to provide an alternative method for estimating fertility for skeletal samples without reference to the proportion of pre-adults in the sample under consideration. Based on the results, we found that fertility can be estimated in an adult-only sample using the proportion of reproductive aged adults (D15-49/D15+) as a proxy. Fertility can now be estimated for unrepresentative skeletal assemblages, which were previously excluded from demographic analyses. There are limitations that still need to be considered when applying this method to a non-representative skeletal sample, including a degree of estimation error which should be considered and sample variation which may lead to over-estimation. Application to the Hadza and Hiwi have also highlighted the need for further research into how population variability influences the accuracy of the D15-49/D15+ and D0-14/D methods in diverse contexts. Though the inclusion of pre-adults may offer a more accurate and precise means of estimating fertility rates, the method proposed here opens up the possibility of undertaking rudimentary demographic analysis for the myriad samples that exhibit pre-adult underrepresentation. It may prove particularly valuable for many archeological assemblages globally, where conditions are not favorable for the preservation of infants and young children, and those cultures where infants and children are given different burial rites to adults.

AUTHOR CONTRIBUTIONS

Bonnie R. Taylor: Conceptualization (lead); data curation (lead); formal analysis (lead); investigation (lead); methodology (lead); writing – original draft (lead); writing – review and editing (equal). **Marc Oxenham:** Conceptualization (supporting); supervision (supporting); writing – review and editing (supporting). **Clare McFadden:** Conceptualization

(supporting); formal analysis (supporting); methodology (supporting); supervision (lead); writing – review and editing (equal).

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CONFLICT OF INTEREST STATEMENT

The authors declare that there are no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data which was used in this article are available in the Supporting Information. Original data source is referenced in this article and is publicly available for download from the United Nations World Population Prospects (<https://population.un.org/wpp/Download/Standard/Population/>).

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