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RESEARCH ARTICLE

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Reconstructing breastfeeding and weaning practices in the Bronze Age Near East using stable nitrogen isotopes

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Abstract

Objectives: Breastfeeding and childhood diet have significant impact on morbidity and mortality within a population, and in the ancient Near East, it is possible to compare bioarchaeological reconstruction of breastfeeding and weaning practices with the scant textual evidence.

Materials and Methods: Nitrogen stable isotopes ($\delta^{15}N$) are analyzed here for dietary reconstruction in skeletal collections from five Bronze Age (ca. 2,800–1,200- BCE) sites in modern Lebanon and Syria. We employed Bayesian computational modeling on cross-sectional stable isotope data of collagen samples (n = 176) mainly from previous studies to test whether the bioarchaeological evidence aligns with the textual evidence of breastfeeding and weaning practices in the region, as well as compare the estimated weaning times to the global findings using the WARN (weaning age reconstruction with nitrogen isotope analysis) Bayesian model.

Results: Though the Near East sites in this study had different ecological settings and economic strategies, we found that weaning was introduced to the five sites at 0.5 ± 0.2 years of age and complete weaning occurred around 2.6 ± 0.3 years of age on using the WARN computational model. These weaning processes are within the time suggested by historical texts, though average estimated weaning age on the Mediterranean coast is later than inland sites.

Discussion: Compared globally, these Near Eastern populations initiated the weaning process earlier but completed weaning within the global average. Early initial weaning may have created short spacing between pregnancies and a high impact on demographic growth within these agricultural populations, with some variation in subsistence practices accounting for the inland/coastal discrepancies.

KEYWORDS
Bayesian analysis, childhood, diet, infancy, Lebanon, stable isotope analysis, Syria

1 | INTRODUCTION

1.1 | Breastfeeding and weaning in bioarchaeological research

Within the last three decades, breastfeeding and infant feeding strategies have become a topic of growing importance in bioarchaeology and historical demography. The timing and nature of weaning (the introduction of complementary foods to a breastfeeding child's diet) and complete weaning (the cessation of breastfeeding) have long-lasting impacts on morbidity and mortality through infancy, a particularly vulnerable period to extrinsic stressors in a person's life, and into adulthood (Humphrey, 2010; Jiménez-Arenas, 2015; Lewis, 2007). Beyond individual health, breastfeeding and infant feeding strategies affect demography. Prolonged lactation has been considered a major factor controlling fertility in foraging groups, and earlier weaning is attributed to early farming communities with higher assumed population growth (Bocquet-Appel, 2011; E. A. Roth, 2004). The development of biochemical methods in bioarchaeology has enabled direct insight into differences in weaning practices in ancient human groups.

Understanding the timing and nature of weaning, its onset and completion, in the Bronze Age Near East offers an additional dimension to the picture of well-established urban centers reliant on farming hinterlands. In Western Asia, agriculture was introduced earlier than elsewhere in the world and coincided with the emergence of urban civilizations in different ecological settings and the establishment of wide-reaching exchange networks (Algaze, 2018; Atkins, Simmons, & Roberts, 1998; Bogaard, 2005; Lev-Yadun, Gopher, & Abbo, 2000; Zeder, 2011). Against this backdrop, we aim to investigate whether weaning practices were uniform across the sites analyzed or if they were influenced by local environmental background.

1.2 | Evidence of breastfeeding and weaning in the Near East

Breastfeeding and weaning practices were rarely the topic of interest for ancient authors, but fortunately, there exist a few textual sources from the Near East, which provide some background on the weaning process. There are some mentions of breastfeeding in religious texts: books in the Bible written around the fifth through second centuries BCE (2 Macc. 7:27, 2 Chr. 31:16) note breastfeeding lasting for 3 years, and later sources from the first millennium CE such as the Quran (II 233, 31, 14) and the Babylonian Talmud (Ketubboth 60a V, 5) estimate this period as 2 years (Gruber, 1989; Stol, 2000). Later, Avicenna (10th/11th c. CE) stated that the first solid food should be introduced when the first incisors are erupting, and complete weaning should occur at 2 years of age (Modanlou, 2008). Some details concerning the first solid food may be again found in the Bible (Isa. 7, 15) where we read that a child capable of rational thought should be feeding upon weaning foods, yogurt/cheese and honey (Gruber, 1989). Mesopotamian cuneiform tablets frequently refer to unweaned (*ša zizibi*, *ša irti* in Akkadian) and weaned (*pirsu*) children, although the period of breastfeeding was not explicitly defined. However, there are many Babylonian contracts with wet nurses (*mušēniqtu*) dated to the early second millennium BCE and in most of them the contracted period was as long as 3 years (Gruber, 1989; Stol, 2000). While this textual evidence is not conclusive, it suggests that complete weaning in the Near East could have been expected between 2 and 3 years.

There could be substantial differences in the length of the breastfeeding period between girls and boys. A few sociological studies in the wider region have been undertaken, but no ethnographic considerations as to the motivations behind sex-based differences are available. Among Palestinian Arabs in the early 20th century, boys were weaned around the age of 2.5 years, and girls around the age of 1.5 years (Granqvist, 1947). Boys in Jordan were significantly more likely to be breastfed beyond 9 months in 1970s Jordan (Akin, Bilsborrow, Guilkey, & Popkin, 1986) and boys in rural Egypt were more likely to be exclusively breastfed in the first 6 months of life (Ghwass & Ahmed, 2011). Similar differences in ancient Mesopotamian society are suggested by two ancient documents. The Assyrian Doomsday Book, a seventh c. BCE census of several households in the Harran district (Northern Mesopotamia, nowadays Turkey), specifies the number of adults and nonadults, of which the latter group are assigned to six age categories including weaned infants" and "unweaned infants" (M. T. Roth, 1987). In total, there are 48 sons listed including one weaned (*pirsu*) and three unweaned infants and 24 daughters including 3 weaned and no unweaned infants. It is possible that not all unweaned children were noted or that the difference in proportions between the sexes is a sampling bias, but this text may suggest an earlier weaning time for girls. The wet-nurse contract, dated to 551 BCE, concerns breastfeeding of a girl only for a year (Stol, 2000), although there is the possibility that she was not a newborn.

1.3 | Stable isotopes in the reconstruction of infant feeding practices

The most common bioarchaeological method used for reconstructing the feeding practices of infants and young children is the analysis of nitrogen stable isotope ratios in collagen (Tsutaya & Yoneda, 2015). The principle of investigating weaning using nitrogen stable isotope values (reported as δ^{15}N in parts per thousand, ‰) is that an infant consuming its mother's breast milk is one trophic level higher than her own tissues. As animals within a food web display δ^{15}N values ~3–5‰ higher than their prey (Bocherens & Drucker, 2003; Minagawa & Wada, 1984; Perkins et al., 2014), it follows that breastfeeding practices and age-at-weaning can be extrapolated using this stepwise nitrogen enrichment (Dupras & Tocheri, 2007), although studies of modern mothers and children found maternal milk δ^{15}N composition to vary and generally be 2‰ lower than infant tissues rather than the expected 3–5‰ (Herrscher, Goude, & Metz, 2017). Stepwise nitrogen enrichment from being breastfed has been observed in living populations, with fetal and neonatal δ^{15}N values showing a strong relationship with maternal δ^{15}N values (de Luca et al., 2012; Fogel, Tuross, Johnson, & Miller, 1997; Fuller, Fuller, Harris, & Hedges, 2006). Katzenberg et al. (1993)

conducted the first study of prehistoric humans to observe elevated $\delta^{15}N$ values in infants relative to the adult population, and many others have utilized nitrogen isotope analysis to understand infant and young child feeding practices and mortality (J. Beaumont et al., 2013; J. Beaumont & Montgomery, 2015; Bourbou, Fuller, Garvie-Lok, & Richards, 2011; Howcroft, Eriksson, & Lidén, 2012; Waters-Rist, Bazaliiskii, Weber, & Katzenberg, 2011).

1.4 | Bayesian modeling of infant and childhood feeding practices

Bayesian computational models are increasingly relied upon in stable isotopes studies to address and remediate the multiple sources of uncertainty in dietary interpretation (Fernandes, 2016; Fernandes, Millard, Brabec, Nadeau, & Grootes, 2014; Layman et al., 2012). This study uses a Bayesian model known as WARN (weaning age reconstruction with nitrogen isotope analysis) created by Tsutaya and Yoneda (2013). WARN version 1.2 is open-license and freely available as an R package (R Core Team, 2000). WARN uses approximate Bayesian computation, a flexible and powerful computational method that is known in life sciences to be strong when dealing with multiple uncertainties (M. A. Beaumont, 2010; Jabot, Faure, & Dumoulin, 2013). By inputting cross-sectional data of $\delta^{15}N$ data of nonadults along with the $\delta^{15}N$ values of adult females to provide the following mean density estimates (MDE) and posterior probabilities of:

1. t_1, or age when weaning begins;
2. t_2, or age of complete weaning;
3. E, the ^{15}N-enrichment between mothers and infants;
4. $\delta^{15}N_{wnfood}$, the average $\delta^{15}N$ value of complementary foods.

The WARN model simulation produces these outputs using the age (in years) and $\delta^{15}N_{bone}$ values of nonadults under 10 years of age and the mean (±1 *SD*) of $\delta^{15}N_{bone}$ values of females within the given population. Using approximate Bayesian computation is stronger than subjectively estimating from visual inspection of graphed data; in addition to creating confidence intervals, the model accounts for variables that estimation from visual inspection cannot address:

1. Collagen turnover rates, which are relatively fast in infants and decrease with time (Hedges, Clement, Thomas, & O'Connell, 2007; Szulc, Seeman, & Delmas, 2000).
2. Inter- and intra-populational variability in $\delta^{15}N_{wnfood}$.
3. Variability in E between populations.

1.5 | Some universal limitations of investigating weaning in the past

Though approximate Bayesian computation is a powerful computational method that attempts to account for many of the uncertainties using cross-sectional data, there are still many limitations to this method. These limitations have been discussed in-depth by others (Kendall, 2016; Reynard & Tuross, 2015) and the main issues will be summarized here.

First, there are complications relating to the "Osteological Paradox" (Wood et al., 1992; Wright & Yoder, 2003). The nonadults studied are those who died during childhood and may not have experienced the same weaning and feeding practices as those who survived (J. Beaumont et al., 2013; J. Beaumont, Montgomery, Buckberry, & Jay, 2015; Dupras & Tocheri, 2007; Lewis, 2007). Indeed, a different weaning trajectory may have been the cause of death for some (Kramer & Kakuma, 2004).

A fundamental assumption when reconstructing weaning patterns in prehistoric populations is that the methods used to estimate age from the skeleton and dentition are accurate and reliable (Scheuer & Black, 2000). This assumption is important when considering any age-based differences, but accurate and reliable age estimation methods are even more important due to the finer scale of examination required when reconstructing weaning patterns. Compared to what is necessary for investigating adult age group differences, this is a scale of months and years rather than decades. The paucity of aging standards specific for nonadults of non-European descent is acknowledged (Cruz-Landeira et al., 2010; Danforth, Wrobel, Armstrong, & Swanson, 2017; Halcrow, Tayles, & Buckley, 2007; Lukacs, 2016), although there is some evidence that the differences between populations are insignificant (Liversidge et al., 2006), especially if age-at-death estimation is based on dental development.

Further uncertainties arise in relation to the isotopic enrichment factors: notable offsets that are still poorly understood are the differences in nitrogen values between a mother and her diet, a mother and her breast milk, and the breast milk and the infant (Reynard & Tuross, 2015). Contrary to the findings of Fuller et al. (2006) that $\delta^{15}N$ values should be dramatically higher in postneonatal infants compared to neonates, several archaeological studies of nonadults have found postneonate infant $\delta^{15}N$ values indistinguishable to the population or adult female mean (J. Beaumont et al., 2015; Jay, Fuller, Richards, Knüsel, & King, 2008). In utero stress and/or restricted diets were hypothesized as the underlying causes, although little is known about how isotopic values are affected by fetal and perinatal stress (J. Beaumont et al., 2015).

Estimating ages of initial weaning and complete weaning within a population using a cross-sectional approach, whether using Bayesian modeling or other techniques, implicitly assumes homogeneity of feeding strategies within the nonsurvivors and the population as a whole. Creating an interpretive framework that is based on this assumption limits exploring variable practices, such as different weaning strategies between social groups, differing access to breast milk and types of complementary foods based on the infant's sex or gender, or variable feeding strategies dependent on the infant's health. The diet of adult females is also assumed to be homogenous, to create the mean and 1 *SD* $\delta^{15}N$ values necessary to establish the population-specific maternal baseline.

Newer methods in stable isotope analysis using incremental sections of dentine for longitudinal studies of dietary changes within individuals reduces or negates some of the limitations a cross-sectional study such as this will encounter. Incremental studies do not negate the influence of nondietary factors on $\delta^{13}C$ and $\delta^{15}N$ values in human tissues, but do allow a finer-grained approach to identifying these factors as tooth formation is much more immune to environmental factors and more tightly controlled by genetics than bone development (J. Beaumont et al., 2018; Cardoso, 2007; King et al., 2018; Scharlotta, Goude, Herrscher, Bazaliiskii, & Weber, 2018). In addition, while collagen turnover rates are relatively fast in infants and young children (Szulc et al., 2000), the bone collagen turnover of adults is slower, leading to bone stable isotope values reflecting an averaged value over roughly the last 10 years of life with individual variation from factors such as malnutrition and disease (Geyh, 2001; Hedges et al., 2007; Szulc et al., 2000). Even though nonadult bone tissue remodels at a much faster rate than adult bone, it is still capturing a longer time period than thin (~1 mm) sections of incremental dentine would.

1.6 | Aims and hypotheses

Despite these potential issues, the examination of cross-sectional isotopic data is the best means of understanding population-averaged weaning times in past populations in the absence of longitudinal isotopic data from dentine sections (J. Beaumont et al., 2015; J. Beaumont, Gledhill, & Montgomery, 2014), and Bayesian modeling strengthens this methodological approach as outlined above. This study uses samples collected as part of larger population dietary studies (Mosapour Negari, 2003; Schutkowski & Ogden, 2011; Sołtysiak & Schutkowski, 2015; Styring et al., 2017), where early childhood diet was not the main research aims. While acknowledging that analyses of bone collagen can have their limitations as outlined in the section above, bone data may still have valuable insights to offer in questions about early childhood diet. As such, this article aims to determine the ages of weaning onset and completion using Bayesian modeling of nitrogen stable isotope values from archaeologically derived Near Eastern human remains. With little to no textual evidence about age of weaning onset, but acknowledging that in agricultural populations access to food suitable for infants was secured, we hypothesize that weaning started around or earlier than the estimated global average and World Health Organization recommended minimum of 6 months (WHO, 2009). We also hypothesize that expected age of complete weaning is within the age range given by textual evidence, that is, 2–3 years. Despite the environmental differences between the sites studied (outlined below), given that all five sites had ready access to cereals due to well-established farming practices we expect no difference in weaning times between the sites.

2 | MATERIALS AND METHODS

2.1 | Site contexts

Data for the present research have been acquired at five archaeological sites spanning the Bronze Age (ca. 2,800–1,200 BCE): Tell Brak (ancient Nagar/Nawar), Tell Barri (ancient Kahat) and Tell Arbid (ancient name unknown) in the Khabur drainage, Tell Bi'a (ancient Tuttul) on the Euphrates in the contemporary city of Ar-Raqqa, as well as Saida (ancient Sidon) in southern Lebanon on the coast of the Mediterranean Sea (Figure 1).

Tell Brak was a primary urban center as early as the Late Chalcolithic 2/3 (late fifth and early fourth millennium BCE) and is one of the largest sites in northern Mesopotamia, at least partially due to its prime position connecting the major trade routes of the region (Oates, 2005). During the Early Bronze Age (EBA), it was a capital city of the kingdom of Nagar and an important regional cultic center. While nonadults from the EBA stratum were unearthed from regular burials within the settlement, adults were found mainly in secondary contexts (Sołtysiak, 2009).

Tell Barri was an important city located ca. 8 km from Tell Brak upstream of Wadi Jaghjagh. The site was inhabited almost without any hiatus from the EBA to the Islamic period (Sołtysiak, 2008). Several human skeletons were retrieved from various strata, and previous isotopic research suggests a shift in subsistence between the Middle Bronze Age (MBA) and Late Bronze Age (LBA) as evidenced by $\delta^{13}C$ values, but no significant differences in $\delta^{15}N$ values across the Bronze Age (Sołtysiak & Schutkowski, 2015). Thus, EBA through LBA individuals from Tell Barri are combined into one dataset.

Tell Arbid was a second-rank town during the EBA and then a small settlement with a large MBA cemetery, located ca. 20 km northwest of Tell Brak. A few nonadult skeletons have been found in late EBA/MBA strata (Sołtysiak, 2010). These three sites in the Khabur River Basin (Tell Arbid, Tell Brak, and Tell Barri) were in environments conducive to dry farming and agricultural extensification, compared to the oft-studied irrigation farming of southern Mesopotamia (Styring et al., 2017).

The fourth Syrian site, Tell Bi'a, is more distant from the other three and is located within the modern city of Ar-Raqqa near the confluence of the rivers Balikh and Euphrates. An important city during the EBA and MBA, Tell Bi'a flourished as one of the major trade centers along the Euphrates. This region experienced precipitation too low for dry farming, but floodplains may have been used for limited farming/horticultural pursuits with pastoralism practiced in the surrounding dry steppes (Wilkinson, 1998; Wossink, 2010). Human remains have been found in domestic contexts, small cemeteries and in mass graves (Strommenger, Kohlmeyer, Miftāḥ, & Stępniowski, 1998).

Sidon, located on the southern coast of Lebanon, has been occupied since the Late Chalcolithic. Evidence of substantial public, religious and domestic architecture dates to the third and second millennium BCE, when Sidon became established as a major Phoenician city state (Doumet-Serhal, 2009; Doumet-Serhal, Rabate, & Resek, 2004), alongside Tyre and Byblos. Numerous burials dating to the MBA were discovered in a layer of sand that covered the domestic installations of the third millennium, revealing sophisticated and socially diverse funerary rituals.

Although occupation for many of these sites begins in the Chalcolithic, human remains from the Bronze Age chronostragraphic phases are generally more numerous and therefore were selected to

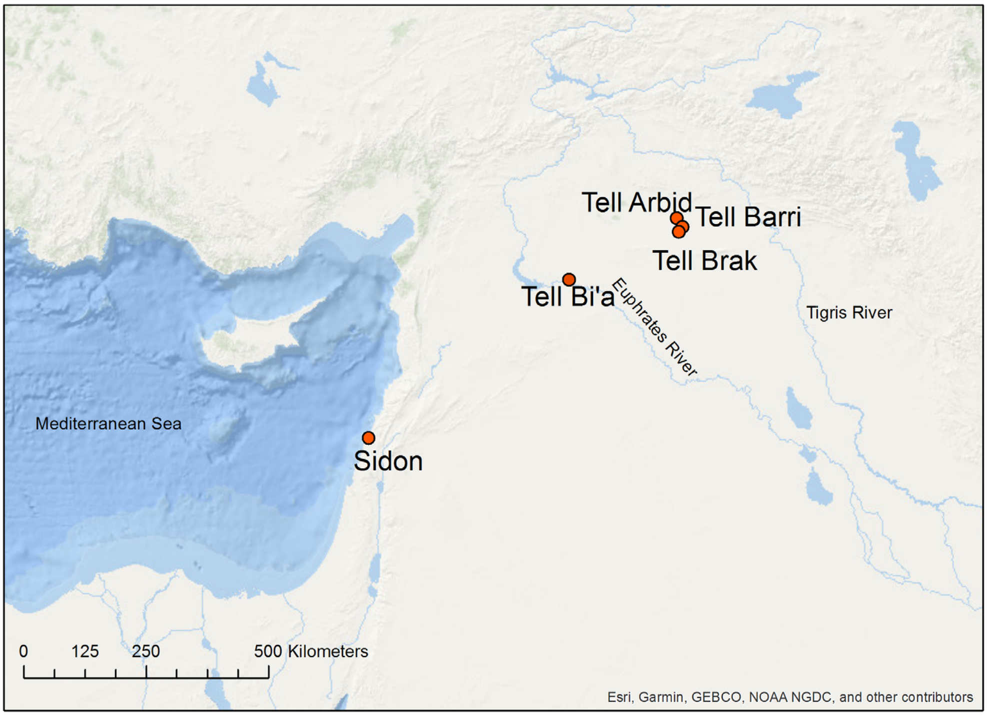

FIGURE 1 Site locations in the Near East

reduce the timescale of occupation, but to keep cohort sizes large enough to meet joint probability minima as well (see details below, in Section 3). To increase the statistical power, the Bronze Age individuals from the three sites within the Khabur river basin—Tell Barri, Tell Brak, and Tell Arbid—were combined. The maximum distance between these sites is 20 km and climatic conditions, ancient economies, political affiliations, and environments were very similar. Although it is understood that differences in subsistence strategies, annual precipitation, and periods of occupation may impact the average population δ^{15}N values, there were no significant differences in δ^{15}N values between adults in general (Kruskal–Wallis chi-squared = 0.1120, df = 2, p = .946) or females of the three Khabur basin sites (Kruskal–Wallis chi-squared = 0.7347, df = 2, p = .692) and so these sites were combined for WARN modeling. This created the following subsets for this study: (a) Khabur Basin, (b) Sidon, and (c) Tell Bi'a.

2.2 | Methods

Bone samples for analysis were taken from cortical bone. Some reference data for adults for the Khabur Basin were obtained using dentine of late developing permanent teeth, that is, third molars (Sołtysiak & Schutkowski, 2015). Bone samples were taken in duplicate. After cleaning the surfaces with aluminum oxide powder air abrasion to remove adhering soil particles, the samples were subjected to a modified Longin method (Brown, Nelson, Vogel, & Southon, 1988) for collagen extraction. Details of the applied protocol and quality control measures are described elsewhere (Schutkowski & Ogden, 2011; Sołtysiak & Schutkowski, 2015; Sołtysiak & Schutkowski, 2018). Collagen samples for Sidon, Tell Bi'a and the Khabur Basin were analyzed by Isotope Ratio Mass Spectrometry (Finnigan Delta Plus XL) in the School of Archaeological Sciences, University of Bradford, United Kingdom, except for individuals from Tell Brak which were analyzed at Oxford University (Styring et al., 2017). We acknowledge that there may be interlaboratory variation in isotope values (Pestle, Crowley, & Weirauch, 2014), but collagen isotope results tend to be relatively comparable between different laboratories, especially if the preparation methods are identical between labs. The analytical precision of the instruments at Bradford and Oxford was estimated as ±0.2‰ for nitrogen. C/N ratios between 2.9 and 3.6, %C values between 15–47%, and %N values between 5–17% have been considered sufficient to indicate preservation of authentic collagen (Ambrose, 1993; van Klinken, 1999). Except for Tell Brak samples, %C and %N values were not presented in the original publications or supplementary information as indicators of well-preserved collagen. Most of the original data files were still available from the University of Bradford lab, with the exception of some of the earlier Sidonian samples. Sidonian samples with missing %C and %N data were still included if the C/N ratios were within acceptable ranges.

2.3 | Modeling the data

The WARN model was employed using many of the author-recommended settings (Tsutaya & Yoneda, 2013), although two of the priors were changed from default. WARN utilizes an assumption of prior distributions for the weaning norms (i.e., the timing of t_1 and t_2: the ^{15}N-enrichment between mothers and infants, and the δ^{15}N value of complementary foods, respectively). These assumptions are:

1. t_1 will occur at 0.5 years of age, ± 3 years;
2. t_2 will occur at 3 years of age, ± 3 years;
3. E will be 1.9‰ ±0.9;

TABLE 1 Summary of dietary stable isotope results, by site

	Sidon	Tell Bi'a	Khabur Basin
n nonadults	33	14	27
n females	12	3	9
n all adults	44	6	52
Nonadult δ^{15}N mean (‰)	9.1	13.3	10.1
Female δ^{15}N mean (‰)	8.7	8.9	8.5
Adult δ^{15}N mean (‰)	8.5	10.9	8.9

4. $\delta^{15}N_{wnfood}$ will be the average δ^{15}N value of female bone collagen ±3.0‰.

Though the mean age of t_1 follows expectations of current health guidelines (WHO, 2009), the *SD* of 3 years does not follow biological sense: t_1 cannot be less than 0, and infants older than 6 months of age cannot derive sufficient nutrients from breast milk alone: a upper-range of this prior assumes a 3.5-year-old could have survived solely from breast milk. Instead, the prior distribution is altered to 0.5 years ±0.5. t_2 could conceivably happen immediately at birth but is unlikely. A more conservative estimate of 3 years ±1 is used for this prior. The other two priors are unchanged. Changes to prior distributions for parameter optimization leave the results comparable to other datasets (Tsutaya, 2017). “Adults” for the purposes of this study are individuals aged 17 years or older, and “nonadults” are younger than 17.

3 | RESULTS

The δ^{15}N results of those individuals of acceptable collagen quality standards are presented in the Supporting Information Table S1. The third molar and cortical bone values were compared at sites where both types of samples were used; there are no significant differences in values at Tell Arbid ($t[24]$ = 0.85, p = .413) or at Tell Brak ($t[13]$ = 0.15, p = .882).

Table 1 displays the summarized δ^{15}N results. The Sidon and Khabur Basin assemblages produced more samples with quality collagen than Tell Bi'a. This is not necessarily a cause for concern regarding sample size; Tell Bi'a is a larger cohort than many of the groups tested by Tsutaya and Yoneda (2013) in their metadata analysis using WARN, and their smaller cohorts often produced acceptable joint probability results.

For the WARN modeling, previous research used a minimum of 0.05 posterior probability and 0.0025 joint probability as minimum estimators for valid results (Tsutaya & Yoneda, 2013). MDEs with lower probabilities are highlighted and discussed. MDEs and credible intervals are tabulated by site (Tables 2–4). The WARN model package also produces graphical representations of the dietary δ^{15}N values and modeled δ^{15}N values for each cohort, shown in Figures 2–4.

Tell Bi'a is the only site whose Bayesian model produced probabilities below the minimum threshold; 0.04 probability for the t_2 MDE. The joint probability of t_1 and t_2 (0.0042, reported on Table 5) was above the minimum threshold of 0.0025 because of the relatively high

TABLE 2 Sidon results

Parameter	MDE	Probability	Range	Probability
t_1	0.7	.08	0–1.7	.95
t_2	2.9	.08	2.2–3.6	.95
E	1.9	.11	1.2–2.6	.95
$\delta^{15}N_{wnfood}$ (‰)	8.2	.14	7.6–8.6	.96
$\Delta^{15}N_{adult-wnfood}$	−0.2			

Note: WARN-generated maximum density estimators (MDEs) and range for t_1, t_2, E, and $\delta^{15}N_{wnfood}$, along with $\Delta^{15}N_{adult-wnfood}$.

TABLE 3 Tell Bi'a results

Parameter	MDE	Probability	Range	Probability
t_1	0.5	.10	0.0–1.6	.95
t_2	3.1	*.04*	1.2–50	.96
E	4.8	.08	3.9–5.9	.95
$\delta^{15}N_{wnfood}$ (‰)	10.5	*.03*	8.0–13.0	.95
$\Delta^{15}N_{adult-wnfood}$	0.4			

Note: WARN-generated MDEs and range for t_1, t_2, E, and $\delta^{15}N_{wnfood}$, along with $\Delta^{15}N_{adult-wnfood}$. Probabilities below the predetermined threshold are italicized.

TABLE 4 Khabur Basin results

Parameter	MDE	Probability	Range	Probability
t_1	0.4	.11	0.0–1.3	.96
t_2	2.3	.09	1.6–3.8	.96
E	3	.10	2.4–3.7	.96
$\delta^{15}N_{wnfood}$ (‰)	8.8	.08	7.8–9.7	.95
$\Delta^{15}N_{adult-wnfood}$	0.3			

Note: WARN-generated MDEs and range for t_1, t_2, E, and $\delta^{15}N_{wnfood}$, along with $\Delta^{15}N_{adult-wnfood}$.

probability value of t_1 (0.10). The high probability t_1 MDE/low probability t_2 MDE is likely a result of the age distribution of the nonadult assemblage: 12 of 13 nonadults are 0–2 years of age, with only one individual past weaning age at 10 years. This unequal distribution of ages is the likely cause of low probability of the $\delta^{15}N_{wnfood}$ MDE. The small sample size may also be a contributor of these low probabilities. Tsutaya and Yoneda (2013) do not have a minimum sample size recommendation for the model, as age distribution and δ^{15}N variability will also affect joint probability outcomes. Though altered priors were used for these Bayesian models, models were also run using the original, built-in priors for comparison (Table 6).

4 | DISCUSSION

The WARN models for all sites yielded acceptable joint probability distributions, suggesting that these results can be confidently

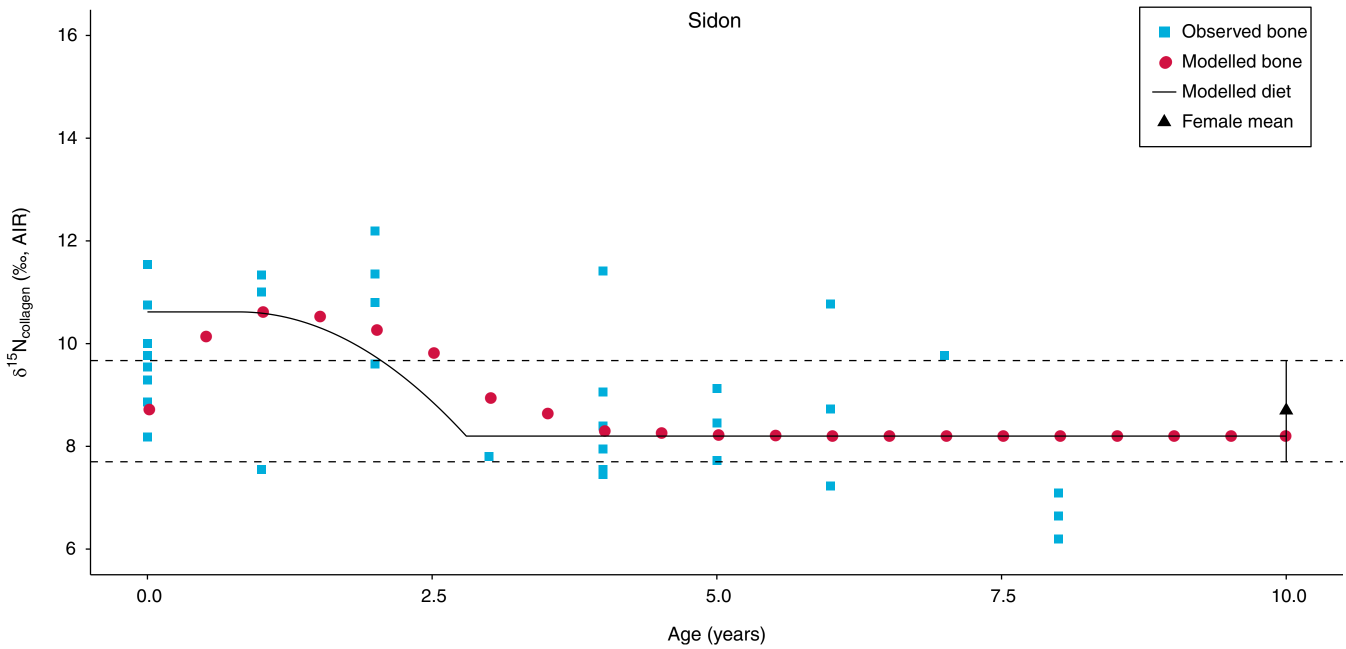

FIGURE 2 Sidon $\delta^{15}N_{bone}$ values with modeled bone and dietary $\delta^{15}N$ values and adult female mean ± 1 *SD*

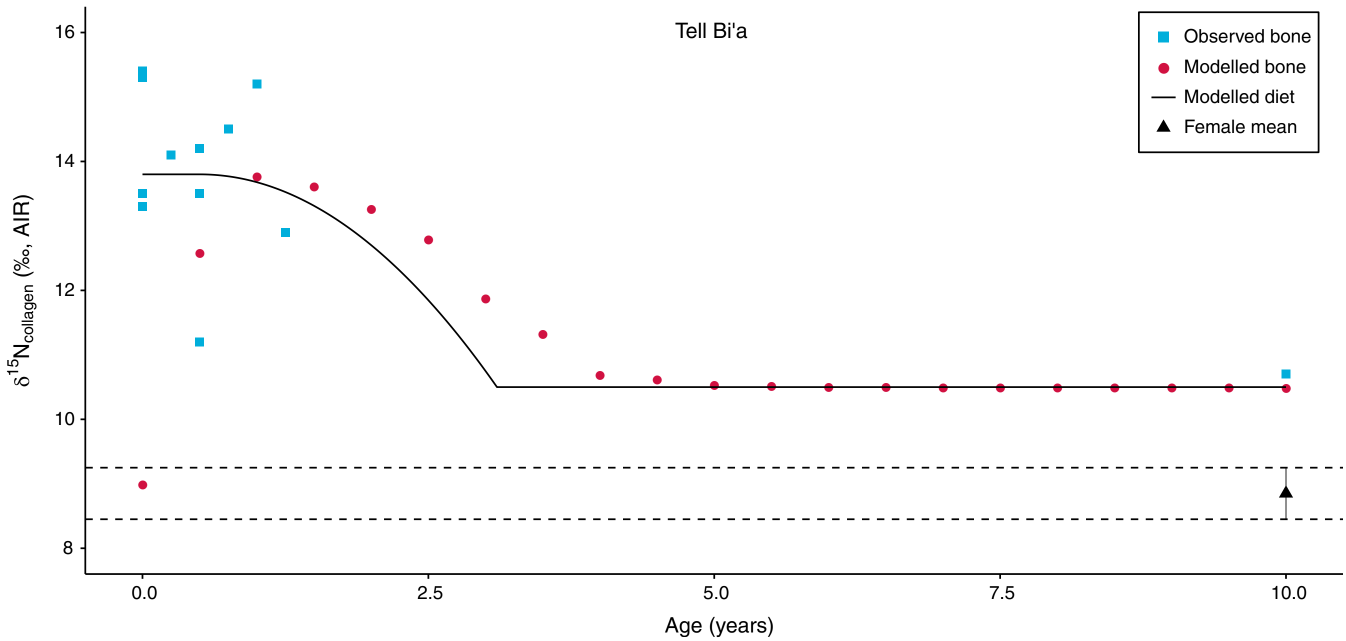

FIGURE 3 Tell Bi'a $\delta^{15}N_{bone}$ values with modeled bone and dietary $\delta^{15}N$ values and adult female mean ± 1 *SD*

interpreted and compared. For the Bronze Age sites analyzed in this study, t_1 MDEs ranged between 0.4 and 0.8 years of age and t_2 MDEs between 2.3 and 2.8 years of age, as hypothesized. These ages are similar to ethnographic and ethnohistoric data for modern preindustrial societies, which were found to have an average t_1 age at 0.5 years ±0.33 and t_2 at 2.45 years ±0.8 (Sellen, 2001). Combining third molar and cortical bone data is not ideal as they may be recording very different points of adult and adolescent life in which different food resources are available, but was necessary with the low sample sizes for the sites of Tell Arbid and Tell Brak; there were no significant differences between tissue types (p = .882) and so in these instances combination for the purpose of increased statistical power was acceptable.

Compiling those studies that have used WARN to calculate weaning and complete weaning times (Chinique de Armas & Pestle, 2018; King et al., 2018; Smith, Pestle, Clarot, & Gallardo, 2017; Tsutaya, 2017), t_1 MDE averages 1.1 ± 0.8 and t_2 MDE averages 3.0 ± 1.3.

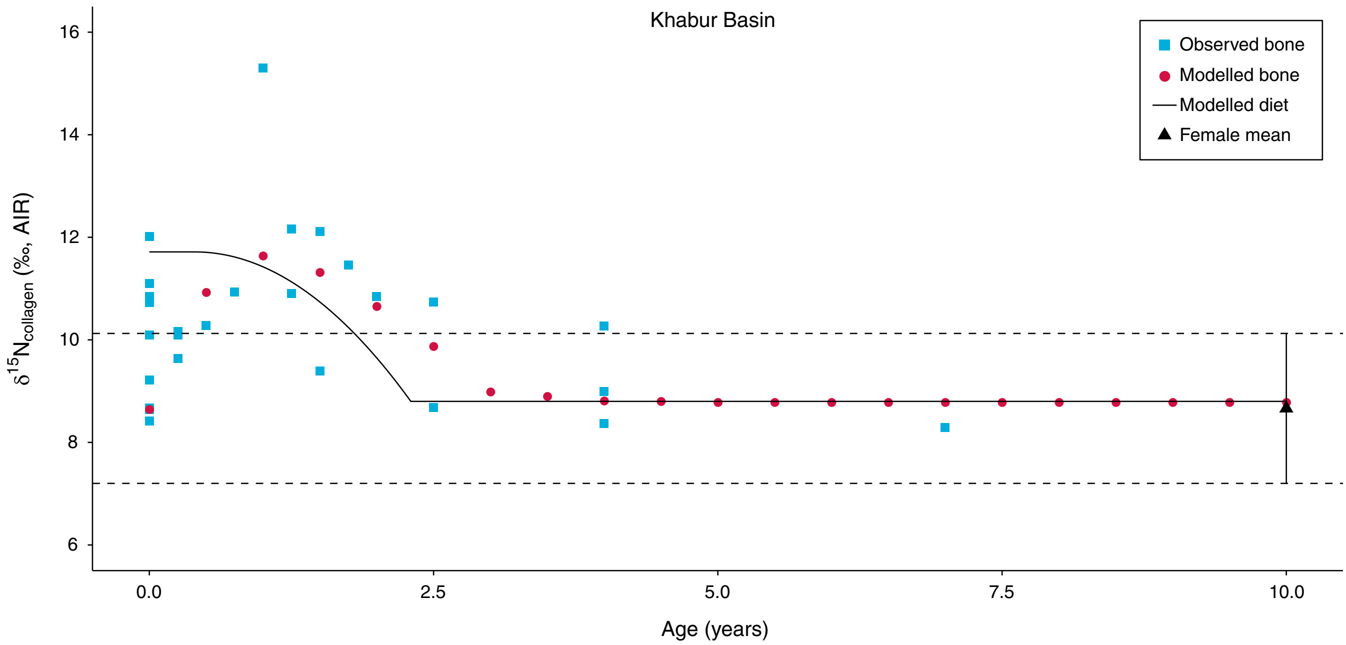

FIGURE 4 Khabur Basin δ^{15}N bone values with modeled bone and dietary δ^{15}N values and adult female mean ± 1 *SD*

TABLE 5 Summary of WARN-generated MDEs along with joint probability of t_1 and t_2

Site	t_1	t_2	Joint probability
Sidon	0.7	2.9	.0091
Tell Bi'a	0.5	3.1	.0042
Khabur Basin	0.4	2.3	.0117

This places this study's t_1 results earlier than most other sites and the t_2 values around the global average (Figure 5). The relatively earlier introduction of complementary foods may be a result of the relative abundance of cereals and dairy products (e.g., yogurt) in these agricultural societies. With a tight range in t_1 values, there seems to be an expected weaning pattern in the Near East during the Bronze Age across the Levant and northern Mesopotamia (with the knowledge that including more sites, especially in the southern Levant, might change this pattern). Early initial weaning would potentially generate low spacing between pregnancies, which would be expected during this period in farming populations with high demographic growth potential and increased fertility. The t_2 MDEs generated fall within the 2–3 years of age as found in the textual sources. The later t_1 timing observed in Sidon compared to the inland Mesopotamian sites could be reflective of different practices regarding the introduction of complementary foods. These differences could be a result of the differences in ecological zones (i.e., the greater reliance on crops in the inland areas) or cultural perceptions of the ideal weaning time. The prosperity of an outward-facing Mediterranean trade port may have very well facilitated a slightly delayed weaning regime and extended parental investment.

There is, as observed on Figure 5, a wide range of weaning times calculated by WARN which is possibly a result of small sample sizes creating biased, unrepresentative values for a population but potentially a reflection of the variety of weaning and childhood feeding practices within our species (Dettwyler, 1995). The creators of the WARN model admit that the validity of this method cannot be tested by modern samples as bone collagen turnover is included in the equations; hair, nail, or fluid studies cannot be compared (Tsutaya & Yoneda, 2015). When compared to ethnographic/ethnohistoric breastfeeding studies that contain both average t_1 and t_2 times (Sellen, 2001), the WARN results of previous studies yield much higher ages. This could be a difference in breastfeeding practices in the past compared to relatively modern nonindustrial populations, but more tantalizingly, this could be a result of the prior assumptions the base WARN models uses; the tighter probability ranges used in this study may yield lower age ranges in the other studies if applied. Analyzing this study's data with both altered and original parameters, the original WARN parameters yield later t_1 times and earlier t_2 times as seen on Figure 5. A new metadata analysis in the style of Tsutaya and Yoneda (2015) with different priors applied to the same datasets would address this question.

Utilizing incremental sections of dentine to create a finer timescale and longitudinal approach to investigating infant and childhood feeding would be a useful avenue of future research. It would also allow us to address the questions of sex-based differences in infant care, which cannot be addressed using a cross-sectional approach without genetic sex determination. The sample yield necessary for incremental sections of ~1 mm dentine may be difficult to acquire in these regions where collagen preservation is typically poor, but a future pilot study could address if incremental analysis is feasible.

Although the focus of this study was assessing weaning timing, the model also provides information about the estimated average δ^{15}N value of complementary foods introduced to infants

TABLE 6 Comparison of WARN-generated results using altered priors and the original priors

	Sidon		Tell Bi'a		Khabur Basin	
	Altered priors	Original priors	Altered priors	Original priors	Altered priors	Original priors
t_1	0.7	1.9	0.4	0.7	0.4	0.6
Probability	.08	.08	.10	.04	.11	.08
t_2	2.9	2.4	2.8	2.5	2.3	2.2
Probability	.08	.11	.04	.01	.09	.10
E	1.9	1.9	4.3	4.1	3.0	3.2
$\delta^{15}N_{wnfood}$ (‰)	8.2	8.2	10.4	10.7	8.8	8.8
$\Delta^{15}N_{adult-wnfood}$	−0.2	−0.2	0.2	−0.1	0.3	0.3
Joint probability	.0091	.0095	.0042	.0008	.0117	.0082

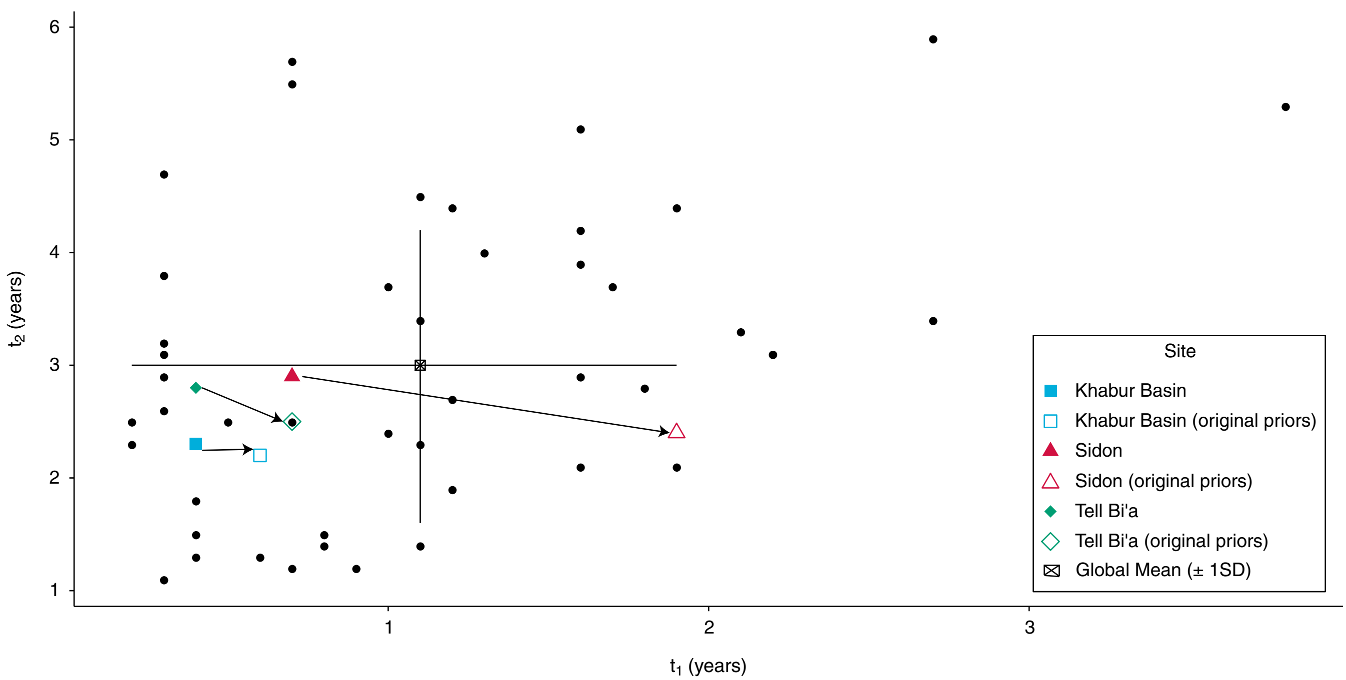

FIGURE 5 t_1 and t_2 ages in a global comparison of previous WARN studies (Chinique de Armas & Pestle, 2018; King, Millard, et al., 2018; Smith et al., 2017; Tsutaya & Yoneda, 2013) Global average with ±1 *SD* shown

during weaning, and how those values differ from the $\delta^{15}N$ values of the adult diet. The $\Delta^{15}N_{adult-wnfood}$ values are low, between −0.2 ± 0.3‰, suggesting that the weaning foods were relatively close in trophic level to the foodstuffs eaten by the general population. If weaning food traditions in the Bronze Age carried through to Modern time, weaning foods were most likely cereal/legume pulp mixed with dairy and perhaps honey; the isotopic composition of weaning foods in these populations would be roughly similar to adult diet, even if the food texture was different (Gruber, 1989). Textual and archaeological evidence of food in Mesopotamia find that the diet was based mainly on cereals (wheat and barley) consumed in the form of bread and beer, supplemented by some legumes as well as dairy products such as yogurt with meat and fish infrequently consumed (E. R. Ellison, 1978; R. Ellison, 1984; Gaspa, 2011; Guerra-Doce, 2015).

Isotopic differences between the three regions might be due to species consumed, animal management practices, and environmental effects, and it is important to remember the $\delta^{15}N$ values are not solely reflective of diet. In Sidon, substantial amounts of charred barley (*Hordeum vulgare*) and emmer (*Triticum dicoccum*) were found and evidence of animal remains comprises the common domesticates and a wide variety of wild fauna, including marine fish (Chahoud & Vila, 2011; De Moulins & Marsh, 2011; van Neer, 2006). Thus, a higher consumption of aquatic foods would be expected but was not observed in a dietary isotopes study of adults when compared to a zooarchaeological stable isotope baseline (Schutkowski & Ogden, 2011). The Tell Bi'a population displayed higher average $\delta^{15}N$ values than Sidon and the Khabur Basin sites, possibly a result of the arid environment, although primary dietary differences cannot be discredited. The focus of this study is on timing of introduction of new foods as calculated using the WARN model, and intersite differences in $\delta^{15}N$ values should not affect the Bayesian computations regarding the timing of weaning and complete weaning.

The use of Bayesian modeling on nitrogen stable isotope data found generally earlier initial weaning than previous studies using this model, supporting the hypothesis that infant feeding strategies in the Bronze Age Near East reflect high potential demographic growth that resulted from increased agricultural reliance, evidenced by intensified agricultural production (Algaze, 2018; Sołtysiak & Schutkowski, 2018). On a global scale, the differences in onset and completion of weaning between environmental areas in this study were minimal, even though the delayed weaning at Sidon is notable. It suggests that environmental pressure on subsistence strategies did not affect cultural approaches to weaning and reproductive strategy greatly, but further research into the coast/inland variation may follow the patterns observed here.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available in the Supporting Information Table S1, and are also available from the corresponding author upon reasonable request.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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