Article:
Cocozza, Carlo, Fernandes, Ricardo, Ughi, Alice et al. (2 more authors) (2021) Investigating Infant Feeding Strategies at Roman Bainesse through Bayesian Modelling of Incremental Dentine Isotopic Data. International Journal of Osteoarchaeology. pp. 429-439. ISSN 1047-482X

https://doi.org/10.1002/oa.2962

Cocozza Carlo (Orcid ID: 0000-0002-8614-5459)

Investigating Infant Feeding Strategies at Roman Bainesse through Bayesian Modelling of Incremental Dentine Isotopic Data

Carlo Cocozza[1,2,3*] carlo.cocozza@campus.lmu.de

Ricardo Fernandes[2,4,5] fernandes@shh.mpg.de

Alice Ughi[3] au578@york.ac.uk

Marcus Groß[2] marcus.gross@inwt-statistics.de

Michelle M. Alexander[3] michelle.alexander@york.ac.uk

1. Ludwig-Maximilians-Universität München, Fakultät für Kulturwissenschaften, Geschwister-Scholl-Platz 1, 80539 München, Germany.
2. Max Planck Institute for the Science of Human History, Department of Archaeology, Kahlaische Str. 10, 07745 Jena, Germany
3. University of York, Department of Archaeology, BioArCh, Environment Building, Wentworth Way, York, YO10 5DD, UK
4. University of Oxford, School of Archaeology, 1 Parks Road, Oxford, OX1 3TG, UK
5. Masaryk University, Arne Faculty of Arts, Nováka 1, 602 00 Brno-střed, Czech Republic.

* corresponding author

Running Head: **Infant Feeding Strategies at Roman Bainesse.**

Keywords: Roman Britain; Bainesse; Stable Carbon and Nitrogen Isotope Analysis; Dentine Incremental Analysis; Breastfeeding and Weaning; Infant Feeding Practices; Physiological Stress; Bayesian modelling.

ABSTRACT

We present the first study employing Bayesian modelling of isotopic measurements on dentine increments (five human upper first molars) to address Romano-British infant feeding practices at Bainesse (UK). The stable carbon and nitrogen isotope results modelled to six-month intervals with novel OsteoBioR software, revealed some common patterns, with weaning not starting before the age of six months and higher animal protein consumption after the age of seven. The latter possibly indicated a 'survival' threshold, evidenced by historical sources and osteological data, hence marking a rise in social status of children. The important role of Bainesse as commercial hub in relation to the fort of Cataractonium does not exclude a priori the possibility that medical treatises and Roman culture were known at the site. However, our results also showed significant intra-individual differences with weaning cessation taking place between two and five years, suggesting that these were followed only partially and other aspects influenced family decisions on infant feeding practices in Bainesse.

INTRODUCTION

Infant feeding practices are the human cultural reflection of a natural physiological need. New-borns consume breast milk as an easily digestible food source of high nutritional quality essential for the support of their immunological system. WHO and UNICEF currently recommend that infants are exclusively breastfed during the first six months following birth, and indicate breast milk can provide up to a third of an infant's nutritional needs into their second year of life alongside solid foods (World Health Organization 2013). Exclusive breastfeeding is defined as "an infant's consumption of human milk with no supplementation of any type" (Gartner *et al.* 2005), whereas weaning is "the process by which a baby slowly gets used to eating family or adult foods and relies less and less on breast milk." (World Health

Organization & United Nations Children's Fund 1988). In practice, cultural and socio-economic factors have much control over the timing and speed at which weaning takes place, which can vary widely across past and present day human populations (Wells 2006).

Within the Roman Empire, infant feeding practices have been investigated using a variety of methods. The study of material culture, such as fictile baby-bottles, provides evidence of the techniques employed by Roman carers to feed their infants, albeit these may be biased by the funerary context in which they are found (Carroll 2018: 82–85). The critical study of written evidence such as medical works of ancient physicians and of other ancient sources (e.g. work contracts for wet-nurses) provides invaluable information on otherwise invisible socio-cultural habits (Centlivres-Challet 2017). However, we still have to consider that medical works must be contextualised to the audience they were written for, mostly higher strata of Roman society, and that socio-cultural practices suggested by both archaeological and historical evidence may have varied within the Empire (Centlivres-Challet 2017).

Stable isotope analysis of skeletal remains has been widely applied in Roman contexts to investigate adult and infant diets (Müldner 2013). Nitrogen and carbon stable isotope analyses of bones and teeth have been employed to estimate breastfeeding and weaning age onsets (Dupras *et al.* 2001; Fuller *et al.* 2006a; Dupras & Tocheri 2007; Prowse *et al.* 2008; Redfern *et al.* 2018). Group comparisons of isotopic measurements on collagen extracted from bone remains of adult females and non-adults apparently suggest fairly consistent weaning times across the Roman Empire, i.e. between two and four years of age (Prowse *et al.* 2008; 2010; Redfern *et al.* 2018). However, these group comparisons constitute an example of the 'osteological paradox' since these rely on the study of infants that died prematurely (Wood *et al.* 1992; Beaumont *et al.* 2015). The presence of a potential association between early mortality and weaning practices could thus bias the interpretation of the results (Beaumont *et al.* 2018). Group comparisons also lack temporal resolution as they are conducted on bones that typically integrate dietary isotopic signals from multiple years of an adult individual due to turnover (Hedges *et al.* 2007). These group comparisons also do not allow for a direct matching of the diets of individual mothers/carers and their infant(s) (Reynard & Tuross 2015).

Higher temporal precision in the study of past weaning practices can be achieved by isotopic measurements carried out on dentine extracted from multiple teeth in a single individual, with each tooth having specific formation periods (Dupras & Tocheri 2007). A subsequent methodological improvement was the ability to perform isotopic measurements on tooth dentine increments offering a chronological resolution equal or better than one year (Beaumont *et al.* 2013; 2014). Nitrogen stable isotopes provide information on protein sources according to their position in a food chain and their measurements on tooth sections usually provide a clear temporal signal for weaning, since the isotopic values of the carers' milk are higher than those of their own diet (Fogel *et al.* 1989; Schurr 1998). As infants consume less breastmilk in favour of solid foods during the weaning process, their stable isotope nitrogen ratios values decrease. Measurements of carbon stable isotopes on tooth sections are also employed to study weaning although they offer a less clear signal for the onset and completion of weaning (Fuller *et al.* 2006b; Beaumont *et al.* 2018). Stable isotope measurements of tooth sections have been widely employed to investigate weaning practices in past populations (e.g. King *et al.* 2018). However, until now, this method has not been employed to investigate Roman infant feeding practices.

In this paper, we present the first study to investigate Romano-British weaning practices through nitrogen and carbon stable isotope measurements in incrementally-sampled dentine. Permanent first molars were sampled from five individuals from Bainesse (UK), aged between 15 and 45 years (Holst *et al*. 2019). We employed Bayesian modelling to allow for the comparison of isotopic patterns in different individuals using a common temporal scale.

MATERIALS AND METHODS

The settlement at Bainesse (Fig. 1), founded during the Flavian period (69–96 CE), was likely a civilian settlement that had potential links with the nearby *Cataractonium* fort (Wilson 2002; Teasdale *et al.* 2019). The settlement was initially built in timber, but during the second century CE a new phase of stone buildings may represent a period of economic prosperity; both agricultural and crafting activities are inferred, although Wilson (2002) also proposes the important commercial role Bainesse may have fulfilled for travellers. The location itself of the settlement on both the Swale river and along Dere Street, the main Roman road in Northern Britain, may have promoted Bainesse as an important commercial hub in the area. The settlement was permanently inhabited, unlike the nearby *Cataractonium* fort, and continued to be occupied even after the departure of Roman troops from Britain in 409–410 CE, as implied by the presence of later Anglian burials. However, a period of decline during the third and fourth centuries is still suggested by Wilson (2002).

A cemetery (54.370449 N; -1.635731 W) containing more than 200 burials has been intensively excavated and the archaeological evidence suggests that it was used from the late first to the late fifth centuries CE (Teasdale *et al.* 2019). Osteological and palaeopathological analyses, (Holst *et al.* 2019), radiocarbon dating (Moore *et al.* 2019) and stable carbon and nitrogen isotope analyses (Chenery *et al.* 2011; Moore *et al.* 2019) have previously been carried out on the burial assemblage at Bainesse. Isotopic results of faunal remains as reported by Chenery *et al.* (2011) suggested a primarily C_3 plant based human diet with some contribution from ^{15}N-enriched foods such as freshwater fish or pork.

We performed stable carbon and nitrogen isotope analysis on first upper molar sections from five individuals buried at the Bainesse cemetery, radiocarbon dated somewhere between the third and fifth centuries CE (Moore *et al.* 2019). The sampled individuals consist of one 36–45 year old female (BN213, Cal 230–400 yrs CE), one 26–35 year old likely female (BN144, Cal 265–410 yrs CE), one 18–25 year old male (BN15, Cal 255–395 yrs CE), one male older than 36 years (BN197a, Cal 260–420 yrs CE), and one 15–16 year old individual whose sex is undetermined (BN124, Cal 315–420 yrs CE) (Holst *et al.* 2019; Tab. 1). Within the cemetery there were differences in burial practices including burial location. However, it is unclear if these were related to socio-economic aspects or if they were influenced by kinship relationships (Teasdale *et al.* 2019). In our sampled population there is an absence of grave goods, little variation in burial practice but burials were chosen from across different cemetery locations (Teasdale *et al.* 2019: Grave Catalogue). This dataset is not representative of the whole Bainesse population, although sample selection followed criteria of equal representation in terms of age and sex.

Teeth, once fully formed, do not undergo further remodelling and in the case of first molars the sequential deposition of dentine allows for the reconstruction of dietary histories from birth until approximately the age of 10 (AlQahtani *et al.* 2010). Different methodologies have been proposed to investigate infant feeding practices by sampling tooth sections (e.g. Eerkens *et al.* 2011; Beaumont *et al.* 2013). The Beaumont *et al.* (2013) sampling methodology, with temporal estimates described in Beaumont & Montgomery (2015), has become a standard for investigating infant feeding practices given the high temporal resolution (ca. six months) that it offers. In our study we employed method 2 as described in Beaumont *et al.* (2013).

Collagen was extracted using a modified Longin (1971) method for carbon and stable isotope measurements. The lab work was carried out at the BioArCh laboratories (University of York). Further details on employed lab protocols can be found in Supporting Information Method S1.

We employed the novel Bayesian model OsteoBioR developed within the Pandora and IsoMemo initiatives (https://isomemoapp.com) to model stable isotope measurements on tooth increments. This allowed us to take into account the varying thickness of sampled tooth increments and to estimate the temporal progress of $\delta^{15}N$ and $\delta^{13}C$ at equal time intervals (six months) for all individuals. Further details on model description and its implementation can be found in Supporting Information Method S2.

RESULTS AND DISCUSSION

Measurement results of stable isotope analysis on dentine increments are reported in Supporting Information Table S1. To avoid bias related to different intra- and inter-individual temporal scales arising from combined increments (due to low collagen yield) and small variations in the thickness of sampled sections we employed the Bayesian model OsteoBioR to represent for each individual the variations in isotopic ranges at a common scale (Supporting Information Method S2). Traditional $\delta^{13}C$-$\delta^{15}N$-Age plots are available in Supporting Information Figure S1. The model uncertainty for isotopic ranges is larger than raw measurements since variations in sample thickness and measurement on combined segments are taken into account.

The first increment of the M1 tooth corresponds approximately to the first six months of the life of an individual, a period during which the infant is expected to rely only on breastmilk (Beaumont & Montgomery 2015). The highest $\delta^{15}N$ values are expected for the first increment assuming that only the mother breastfed the infant and that she did not change her diet prior to weaning completion. This maximum is typically followed by a temporal decrease which is indicative of a reduction in breastfeeding and an increase in the consumption of solid foods. Physiological stress may also impact isotopic values and thus can complicate dietary interpretation (Beaumont & Montgomery 2016). In our dataset, only BN144 lacks palaeopathological evidence for undetermined physiological stress during childhood, although this might also be a preservation bias (Holst *et al.* 2019; Tab. 1). There are some instances where a rise in $\delta^{15}N$ section values is accompanied by a decrease in $\delta^{13}C$ (BN124, BN144, BN213) for which one cannot exclude a possible malnutrition event. However, a clear distinction between nutritional stress and dietary change is problematic. Research on modern individuals has primarily relied on hair keratin allowing for a high temporal resolution. Neuberger *et al.* (2013) and D'Ortenzio *et al.* (2015) reported isotopic shifts of 1-2‰ for $\delta^{15}N$ and ~1‰, for $\delta^{13}C$ in extreme cases of starvation and cachexia over short time spans and were related with different physiological stress conditions (e.g. terminal cancer). However, these shifts might also reflect a contribution from a change in diet as exemplified in the case of a pregnant woman by D'Ortenzio *et al.* (2015). Assuming that isotopic shifts of similar magnitude are expected for tooth dentine we can probably assign larger isotopic shifts primarily to dietary changes. As for the interpretation of smaller isotopic changes we are constrained by instrumental uncertainty and uncertainties introduced during sampling although the latter are reflected in the Bayesian modelling results. Furthermore, it is possible that dietary shifts may result in isotopic patterns that could also be associated with malnutrition. An increase in the consumption of freshwater fish results in an increase in human collagen $\delta^{15}N$ values and a decrease in $\delta^{13}C$ values, an isotopic pattern that could otherwise be associated with metabolic stress (Fuller *et al.* 2006b).

At Bainesse exclusive breastfeeding appears to cease at six months or soon after. Bayesian estimates show that weaning for the Bainesse individuals was completed between [2–2.5] and [4.5–5] years (Fig. 2–6). Previous research relying on the comparison of bone and tooth isotopic measurements of infants and mothers from across the Roman Empire placed the completion of weaning between the ages of two and four (e.g. Dupras *et al.* 2001; Prowse *et al.* 2008), a range consistent with that proposed for Roman Britain (e.g. Fuller *et al.* 2006a;

Redfern *et al.* 2018). Nonetheless, this result might be biased by methodological issues related to group comparisons of bone measurements (Reynard & Tuross 2015). Our results would indicate that this range may be extended even further, perhaps up to the age of five. Given a lack of incremental studies from other Roman sites, we compared our data with published examples from early medieval individuals from Britain (fifth and tenth centuries) (Beaumont *et al.* 2014; 2018), Greece (fifth–sixth centuries) (Kwok *et al.* 2018) and continental Europe (fourth–seventh centuries) (Czermak *et al.* 2018; Crowder *et al.* 2019). To make our results directly comparable with previous literature results we also modelled these at six-months intervals using the Bayesian model OsteoBioR (see Methods section). For early Anglo-Saxon Britain, a single individual from fifth-century West Heslerton, Yorkshire, completed weaning at [1.5–2] years (after Beaumont *et al.* 2014). Another six British individuals from late Anglo-Saxon Raunds (tenth century) completed weaning between [2.5–3] and [4–4.5] years (after Beaumont *et al.* 2018). A study at early Byzantine Nemea (no.=25) showed that the majority of infants were fully weaned at approximately between [1.5–2] and [2.5–3] years apart from two outliers fully weaned at [1–1.5] and [4–4.5] years (after Kwok *et al.* 2018). As for populations that settled within the Roman Empire during the Migration Period, we compared our results with those from a Gepid cemetery in Archiud, Romania and an unspecified Germanic population settled in Niedernai, France. At Archiud, four individuals completed their weaning between [2.5–3] and [4–4.5] years (after Crowder *et al.* 2019). At Niedernai, four individuals completed weaning between [2–2.5] and [3.5–4] years (after Czermak *et al.* 2018). Thus, most sampled early medieval individuals completed weaning between the ages of two and four, although there were a few with earlier or later dates of weaning completion. In contrast, our Romano-British dataset, shows that three out of five individuals were fully weaned after the age of four, i.e. BN124 at [4.5–5], BN144 at [4–4.5] and BN213 at [4–4.5]. BN15 and BN197a were fully weaned at [2.5–3] and [2–2.5], respectively.

The isotopic results for post-weaning stages vary among the different individuals (Fig. 2). Individual BN197a, in particular, shows temporal oscillations in $\delta^{15}N$ values and for the last age interval [9–9.5] also a significant drop in both $\delta^{13}C$ and $\delta^{15}N$ values. Lower $\delta^{15}N$ values are likely to result from a lower intake of animal protein whereas lower $\delta^{13}C$ values could arise from a higher consumption of an unknown fat source with comparatively more negative $\delta^{13}C$ values than protein or carbohydrates (Fernandes 2016). However, it is also possible that this isotopic shift is associated with malnutrition or physiological stress (D'Ortenzio *et al.* 2015). The remainder of the individuals show an overall increase in $\delta^{15}N$ values with age, as expected during anabolic growth stage, although this occurs at different rates and at different time gaps following the completion of weaning. The increase of $\delta^{15}N$ values becomes steeper around the ages of seven or eight for individuals BN15, BN144, and BN213. BN124 also shows an increase in $\delta^{15}N$ following weaning but the sample was not preserved beyond the interval [6–6.5] years. The $\delta^{13}C$ values for the different individuals are approximately within the range -22 to -20‰, which likely indicates dietary intakes from predominantly terrestrial C_3-type protein sources, but some consumption of freshwater fish cannot be excluded, as also hypothesised by previous isotopic analysis undertaken on adults from the site (Chenery *et al.* 2011; Moore *et al.* 2019).

Contextualising Roman sources on childhood and non-adult data at Bainesse

The most notable ancient Roman authors on topics related to infant feeding practices were Soranus of Ephesus (second century CE), Galen (129–ca. 200 CE), and Oribasius (ca. 320–403 CE), who spent most of their professional lives in Rome and wrote primarily for Roman aristocracy and Roman provincial elites (see Prowse *et al.* 2008). The start of weaning practices observed in our study are generally consistent with the advice given by Soranus (*Gyn.*, 2.17–48; Temkin 1956) to Roman parents, who recommended the introduction of semi-solid foods six months after infants' birth. The Greek physician Damastes (second century CE) (reported in *Soranus, Gyn.,* 2.48; Temkin 1956) recommended prolonging exclusive breastfeeding up to the age of one but only for female infants. The $\delta^{15}N$ values for the female individual BN213 show an increase after six months which could have resulted from a change in the mother's diet, or malnutrition (Neuberger *et al.* 2013; Reitsema 2013) or continued breastfeeding by the employment of a wet-nurse (Centlivres-Challet 2017). For this individual the peak in $\delta^{15}N$ values was reached at the age of one year and few months approximately in accordance with the Damastes' recommendations. A similar pattern is observed in BN144, a probable female individual. As for the completion of the weaning process, Soranus suggested that this should be completed at the age of two. The same recommendation was given by Antyllus (second century CE) (lost work cited in *Orybasius*, *Incert.*; Grant 1997) and Oribasius (*Incert.*; Grant 1997). However, Galen (*Hygiene*; Johnston 2018), recommended that weaning should be completed at the later age of three. To what extent the population at Bainesse would have access to the recommendations made by Roman physicians is unclear. It is possible that they were knowledgeable of the medical treatises, perhaps through the medium of travellers and soldiers headed to *Cataractonium*, but if so, our results suggest that this was followed only partially.

It is possible that local and family traditions influenced the adoption of certain weaning practices, but the variability that we observed may also be indicative of socio-economic aspects. Written evidence (e.g. Diocletian's *Edictum de pretiis rerum venalium*; Graser 1940) points to the greater economic value that animal foods had in comparison to plant foods and thus it is expected that they were less accessible to individuals belonging to lower socio-economic classes, which possibly included infants. Concerning the latter, many ancient Graeco-Roman physicians and philosophers identified the age of seven as the end of early childhood (*infantia*) (Laes 2011: 77–100). Gaius' (*c.* 110–170 CE) *Institutes*, collected in Justinian's *Institutes* (sixth century CE), regulated that a child under the age of seven was "*non multum a furioso distant, quia huius aetatis pupilli nullum intellectum habent*" ('not very different from a mentally disabled person, since during this age, children do not possess any intellectual faculty') (*Inst.* 3.19.10; Moyle 1911), remarking how an *infans* (or *pupillus*) could not be considered an autonomous person. This age transition seems to have been part of a cultural concept commonly recognised by Graeco-Roman authors, likely to be grounded on changing biological features (such as the transitional replacement of deciduous teeth and physical growth) and philosophical beliefs (Eyben 1972; Laes 2011: 77–100).

The idea of a common cultural knowledge in the Roman world has been heavily criticised, especially when it comes to Britain (e.g. Barrett 1997; Freeman 1997). However, what is here inferred is not the vision of a deterministic homogeneous Roman culture, where one could imply the existence of common patterns in Rome as well as in Northern Britain for the only reason of being 'Roman' ('Romanisation', see Pinto 2017), but rather an observation on the mechanisms that may have led to this similarity suggested by our results. Beyond the possibility that culture was spread with goods in the commercial hub of Bainesse due to its relationship with *Cataractonium*, a concurring socio-demographic explanation may also be possible. Graeco-Roman authors imbued symbolism to an individual's every seventh year of life, which was considered an *annus climactericus* ('critical year') of transition on both biological and social levels (Eyben 1972). Although we are aware of the risks of the 'osteological paradox' and bias related to funerary commemoration, a high degree of mortality during early childhood is attested in the Roman world (Rawson 2003; Carroll 2011). In Bainesse, Holst *et al.* (2019) observed that 69% of non-adult buried individuals were aged between one and six years, with a peak between three and five years. Hence, it is possible that to the eyes of Roman society, even in Bainesse, the age of seven may have marked a perceived 'survival' threshold and thus a step on the social scale.

Isotopic studies have also shown that Roman male individuals reaching the status of *PaterFamilias* during adulthood increased their intake of animal protein (Martyn *et al.* 2018). Also Prowse *et al.* (2008; 2010) found that children in Roman Italy likely had a lower social status that was reflected by a lower quality of their diet. Thus, a hypothesis that emerges from our study is that an improvement in children's diet, perhaps with the addition of higher trophic level protein such as freshwater fish, was only made once these passed the socio-cultural step at seven years. This 'survival' threshold in Bainesse might also help to find an explanation for the prolonged weaning process we observed in surviving individuals from our dataset. Families possibly may have spent more time and care in the process of weaning as a logical solution attempting to protect the child from morbidity and malnutrition. In conclusion, our results would concur with the cultural idea that a certain age may have led to an elevation of Roman children's status and, perhaps, also the access to foods of a higher economic value.

CONCLUSIONS

This study presented the first use of isotopic measurements on tooth increments to reconstruct Roman infant feeding practices for five individuals from the Romano-British settlement at Bainesse. Bayesian modelling was employed to make diachronic results directly comparable among the different individuals and to generate temporal isotopic estimates with an uncertainty reflecting the tooth section sampling process. This revealed significant differences in weaning and post-weaning practices. Nonetheless, all individuals were fed exclusively on breastmilk at least until six months of age. Following the introduction of semi-solid food into infants' diet, each individual completed weaning at different ages, between two and five years. The variability in our data suggests that local socio-economic aspects may have had an impact on weaning practices at Bainesse, although some degree of observed consistency with ancient medical recommendations leads us not to *a priori* exclude that these were known. Post-weaning isotopic values show an increase in the consumption of animal protein following weaning completion. This becomes particularly accentuated around the age of seven for most individuals, when Roman children potentially rose from their '*infantia*' status.

Future tooth incremental studies on other Roman populations are necessary to characterize in more detail the variability in infant feeding practices across regions and time periods. It would be of particular interest to investigate how infant feeding practices at the heart of the Roman Empire contrasted with those in Roman provinces. At Bainesse, we suggest that future bioarchaeological analysis could focus on the relationship between the site and the nearby fort of *Cataractonium*.

ACKNOWLEDGEMENTS

We thank Malin Holst (York Osteoarchaeology) and Northern Archaeological Associates Ltd. for access to samples, in particular Hannah Russ and Frederick Foulds. We also thank Prof Matthew Collins and Dr Giulia Pedrucci for their precious advice and shared information. We thank Dr Helen Goodchild for helping us with figures. We thank Matthew von Tersch and the staff at BioArCh for technical assistance during the analysis. We thank the two anonymous reviewers for strengthening the argument with their comments. The authors declare no conflict of interests.

REFERENCES

AlQahtani SJ, Hector MP, Liversidge HM. 2010. Brief communication: The London atlas of human tooth development and eruption. *American Journal of Physical Anthropology* **142**: 481–490. DOI: 10.1002/ajpa.21258

Barrett JC. 1997. Romanization: a critical comment. In *Dialogues in Roman Imperialism. Power, discourse and discrepant experience in the Roman Empire*, Mattingly DJ (ed.). Cambridge University Press: Cambridge; 51–64.

Beaumont J, Craig-Atkins E, Buckberry J, Haydock H, Horne P, Howcroft R, Mackenzie K, Montgomery J. 2018. Comparing apples and oranges: Why infant bone collagen may not reflect dietary intake in the same way as dentine collagen. *American Journal of Physical Anthropology* **167**: 524–540. DOI: 10.1002/ajpa.23682

Beaumont J, Gledhill A, Lee-Thorp J, Montgomery J. 2013. Protocol for sectioning human dentine: expanded from Methods 1 and 2. Written as a response to questions arising from: Beaumont J, Gledhill A, Lee-Thorp J and Montgomery JA (2013) Childhood diet: a closer examination of the evidence from dental tissues using stable isotope analysis of incremental human dentine. *Archaeometry* **55**(2): 277–295. https://bradscholars.brad.ac.uk/handle/10454/5635

Beaumont J, Gledhill A, Montgomery J. 2014. Isotope analysis of incremental human dentine: towards higher temporal resolution. *Bulletin of the International association for paleodontology* **8**: 212–223.

Beaumont J, Montgomery J. 2015. Oral histories: a simple method of assigning chronological age to isotopic values from human dentine collagen. *Annals of Human Biology* **42**: 407–414. DOI: 10.3109/03014460.2015.1045027

Beaumont J, Montgomery J. 2016. The Great Irish Famine: Identifying starvation in the tissues of victims using stable isotope analysis of bone and incremental dentine collagen. *PLoS ONE* **11**: e0160065. DOI: 10.1371/journal.pone.0160065

Beaumont J, Montgomery J, Buckberry J, Jay M. 2015. Infant mortality and isotopic complexity: New approaches to stress, maternal health, and weaning. *American Journal of Physical Anthropology* **157**: 441–457. DOI: 10.1002/ajpa.22736

Carroll M. 2011. Infant death and burial in Roman Italy. *Journal of Roman Archaeology* **24**: 99–120.

Carroll M. 2018. *Infancy and Earliest Childhood in the Roman World. 'A Fragment of Time'.* Oxford University Press: Oxford.

Centlivres-Challet CE. 2017. Feeding the Roman Nursling: maternal milk, its substitutes, and their limitations. *Latomus* **17**: 895–909.

Chenery C, Eckardt H, Müldner G. 2011. Cosmopolitan Catterick? Isotopic evidence for population mobility on Rome's Northern frontier. *Journal of Archaeological Science* **38**: 1525–1536. DOI: 10.1016/j.jas.2011.02.018

Crowder KD, Montgomery J, Gröcke DR, Filipek KL. 2019. Childhood "stress" and stable isotope life histories in Transylvania. *International Journal of Osteoarchaeology* **29**: 644–653. DOI: 10.1002/oa.2760

Czermak A, Schermelleh L, Lee-Thorp J. 2018. Imaging-assisted time-resolved dentine sampling to track weaning histories. *International Journal of Osteoarchaeology* **28**: 535–541. DOI: 10.1002/oa.2697

D'Ortenzio L, Brickley M, Schwarcz H, Prowse T. 2015. You are not what you eat during physiological stress: Isotopic evaluation of human hair. *American Journal of Physical Anthropology* **157**: 374–388. DOI: 10.1002/ajpa.22722

Dupras TL, Schwarcz HP, Fairgrieve SI. 2001. Infant feeding and weaning practices in Roman Egypt. *American Journal of Physical Anthropology* **115**: 204–212. DOI: 10.1002/ajpa.1075

Dupras TL, Tocheri MW. 2007. Reconstructing infant weaning histories at Roman period Kellis, Egypt using stable isotope analysis of dentition. *American Journal of Physical Anthropology* **134**: 63–74. DOI: 10.1002/ajpa.20639

Eerkens JW, Berget AG, Bartelink EJ. 2011. Estimating weaning and early childhood diet from serial micro-samples of dentin collagen. *Journal of Archaeological Science* **38**: 3101–3111. DOI: 10.1016/j.jas.2011.07.010

Eyben E. 1972. Antiquity's view of puberty. *Latomus* **31**: 677–697.

Fernandes R. 2016. A simple(R) model to predict the source of dietary carbon in individual consumers. *Archaeometry* **58**: 500–512. DOI: 10.1111/arcm.12193

Freeman PWM. 1997. Mommsen to Haverfield: the origins of studies of Romanization in late 19th-c. Britain. In *Dialogues in Roman Imperialism. Power, discourse and discrepant experience in the Roman Empire*, Mattingly DJ (ed.). Cambridge University Press: Cambridge; 27–50.

Fogel ML, Tuross N, Owsley D. 1989. Nitrogen isotope tracers of human lactation in modern and archaeological populations. *Carnegie Institution of Washington Yearbook* **88**: 111–117.

Fuller BT, Molleson TI, Harris DA, Gilmour LT, Hedges REM. 2006a. Isotopic evidence for breastfeeding and possible adult dietary differences from Late/Sub-Roman Britain. *American Journal of Physical Anthropology* **129**: 45–54. DOI: 10.1002/ajpa.20244

Fuller BT, Fuller JL, Harris DA, Hedges RE. 2006b. Detection of breastfeeding and weaning in modern human infants with carbon and nitrogen stable isotope ratios. *American Journal of Physical Anthropology* **129**: 279–293. DOI: 10.1002/ajpa.20249

Gartner LM, Morton J, Lawrence RA, Naylor AJ, O'Hare D, Schanler RJ, Eidelman AI. 2005. Breastfeeding and the use of human milk. *Pediatrics* **115**: 496–506. DOI: 10.1542/peds.2004-2491

Grant M. 1997. *Dieting for an Emperor: A Translation of Books 1 and 4 of Oribasius' Medical Compilations*. Brill Academic Publishers: Leiden.

Graser ER. 1940. A text and translation of the Edict of Diocletian. in *An Economic Survey of Ancient Rome Volume V: Rome and Italy of the Empire*, Frank T (ed.). Johns Hopkins Press: Baltimore; 305–421.

Holst M, Keefe K, Newman S, Löffelmann T. 2019. Human remains. in *A1 Leeming to Barton. Death, Burial and Identity. 3000 Years of Death in the Vale of Mowbray*, Speed G, Holst M (ed.). Northern Archaeological Associates Ltd: Marwood House; 372–466.

Johnston I. 2018. *Hygiene*. Harvard University Press: Cambridge, Massachusetts.

King CL, Halcrow SE, Millard AR, Gröcke DR, Standen VG, Portilla M, Arriaza BT. 2018. Let's talk about stress, baby! Infant-feeding practices and stress in the ancient Atacama Desert, Northern Chile. *American Journal of Physical Anthropology* **166**: 139–155. DOI: 10.1002/ajpa.23411

Kwok CS, Garvie-Lok S, Katzenberg MA. 2018. Exploring variation in infant feeding practices in Byzantine Greece using stable isotope analysis of dentin serial sections. *International Journal of Osteoarchaeology* **28**: 563–578. DOI: 10.1002/oa.2690

Laes C. 2011. *Children in the Roman Empire. Outsiders Within*. Cambridge University Press: Cambridge.

Longin R. 1971. New method of collagen extraction for radiocarbon dating. *Nature* **230**: 241–242. DOI: 10.1038/230241a0

Martyn REV, Garnsey P, Fattore L, Petrone P, Sperduti A, Bondioli L, Craig OE. 2018. Capturing Roman dietary variability in the catastrophic death assemblage at Herculaneum. *Journal of Archaeological Science: Reports* **19**: 1023–1029. DOI: 10.1016/j.jasrep.2017.08.008

Moore J, Hamilton D, Speed G. 2019. Scientific analyses. In *A1 Leeming to Barton. Death, Burial and Identity. 3000 Years of Death in the Vale of Mowbray*, Speed G, Holst M (ed.). Northern Archaeological Associates Ltd: Marwood House. 579–599.

Moyle JB. 1911. *Institutes*. Oxford University Press: Oxford.

Müldner G. 2013. Stable isotopes and diet: their contribution to Romano-British research. *Antiquity* **87**: 137–149. DOI: 10.1017/S0003598X00048675

Neuberger FM, Jopp E, Graw M, Püschel K, Grupe G. 2013. Signs of malnutrition and starvation—Reconstruction of nutritional life histories by serial isotopic analyses of hair. *Forensic Science International* **226**: 22–32. DOI: 10.1016/j.forsciint.2012.10.037

Pinto R. 2017. A death greatly exaggerated: Robin G. Collingwood and the 'Romanisation' of Roman Britain. *Hérodoto* **2**: 544–563. DOI: 10.31669/herodoto.v2i2.297

Prowse TL, Saunders SR, Fitzgerald C, Bondioli L, Macchiarelli R. 2010. Growth, morbidity, and mortality in antiquity: a case study from Imperial Rome. In *Human Diet and*

Nutrition in Biocultural Perspective, Moffat T., Prowse T. (ed.). Berghan Press: New York; 173–196.

Prowse TL, Saunders SR, Schwarcz HP, Garnsey P, Macchiarelli R, Bondioli L. 2008. Isotopic and dental evidence for infant and young child feeding practices in an Imperial Roman skeletal sample. *American Journal of Physical Anthropology* **137**: 294–308. DOI: 10.1002/ajpa.20870

Rawson B. 2003. *Children and Childhood in Roman Italy*. Oxford University Press: Oxford.

Redfern R, Gowland R, Millard A, Powell L, Gröcke D. 2018. 'From the mouths of babes': A subadult dietary stable isotope perspective on Roman London (*Londinium*). *Journal of Archaeological Science: Reports* **19**: 1030–1040. DOI: 10.1016/j.jasrep.2017.08.015

Reitsema LJ. 2013. Beyond diet reconstruction: Stable isotope applications to human physiology, health, and nutrition. *American Journal of Human Biology* **25**: 445–456. DOI: 10.1002/ajhb.22398

Reynard LM, Tuross N. 2015. The known, the unknown and the unknowable: weaning times from archaeological bones using nitrogen isotope ratios. *Journal of Archaeological Science* **53**: 618–625. DOI: 10.1016/j.jas.2014.11.018

Schurr MR. 1998. Using stable nitrogen isotopes to study weaning behaviour in past populations. *World Archaeology* **30**: 327–342. DOI: 10.1080/00438243.1998.9980413

Teasdale A, Speed G, Griffith DG. 2019. Burial at Bainesse Cemetery and its surrounding area, in *A1 Leeming to Barton. Death, Burial and Identity. 3000 Years of Death in the Vale of Mowbray*, Speed G, Holst M (ed.). Northern Archaeological Associates Ltd: Marwood House; 41–268.

Temkin O. 1956. *Soranus' Gynecology*. John Hopkins University Press; Baltimora.

Wells J. 2006. The role of cultural factors in human breastfeeding: Adaptive behaviour or biopower?. *Human Ecology* **14**: 39–47.

Wilson PR. 2002. *Cataractonium: Roman Catterick and Its Hinterland. Excavations and Research, 1958-1997*. Council for British Archaeology: York.

Wood JW, Milner GR, Harpending HC, Weiss KM. 1992. The osteological paradox: problems of inferring prehistoric health from skeletal samples. *Current Anthropology* **33**: 343–370. DOI: 10.1086/204084

World Health Organization. 2013. *WHO recommendations on postnatal care of the mother and newborn*. WHO press: Geneva.

World Health Organization, United Nations Children's Fund (UNICEF). (1988). *Weaning: from breast milk to family food, a guide for health and community workers.* WHO press: Geneva. https://apps.who.int/iris/handle/10665/39335

DATA AVAILABILITY STATEMENT

The data that supports the findings of this study are available in the supplementary material of this article.

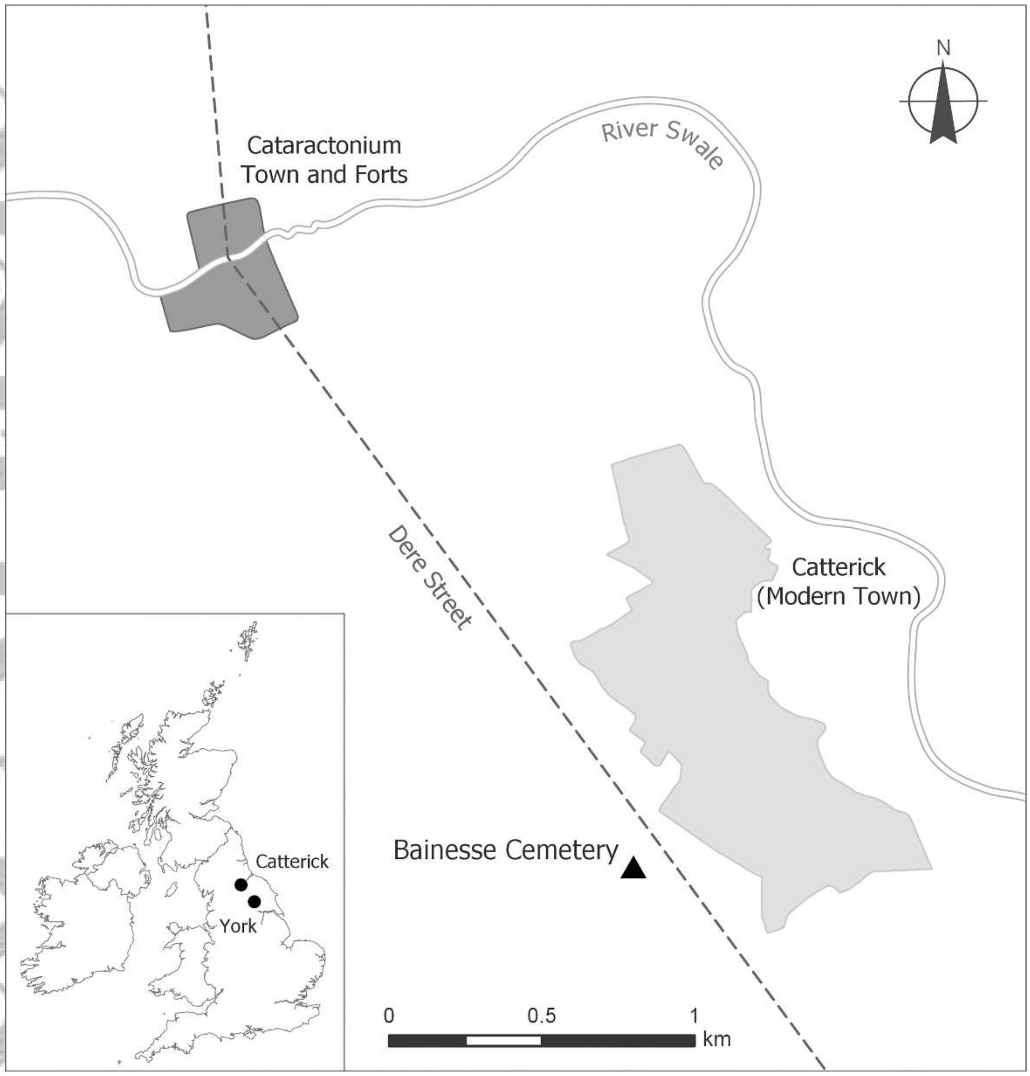

Fig. 1. Location of Bainesse cemetery. Map by Helen Goodchild, after Chenery *et al.* (2011); Contains OS data © Crown Copyright [and database right] (2020).

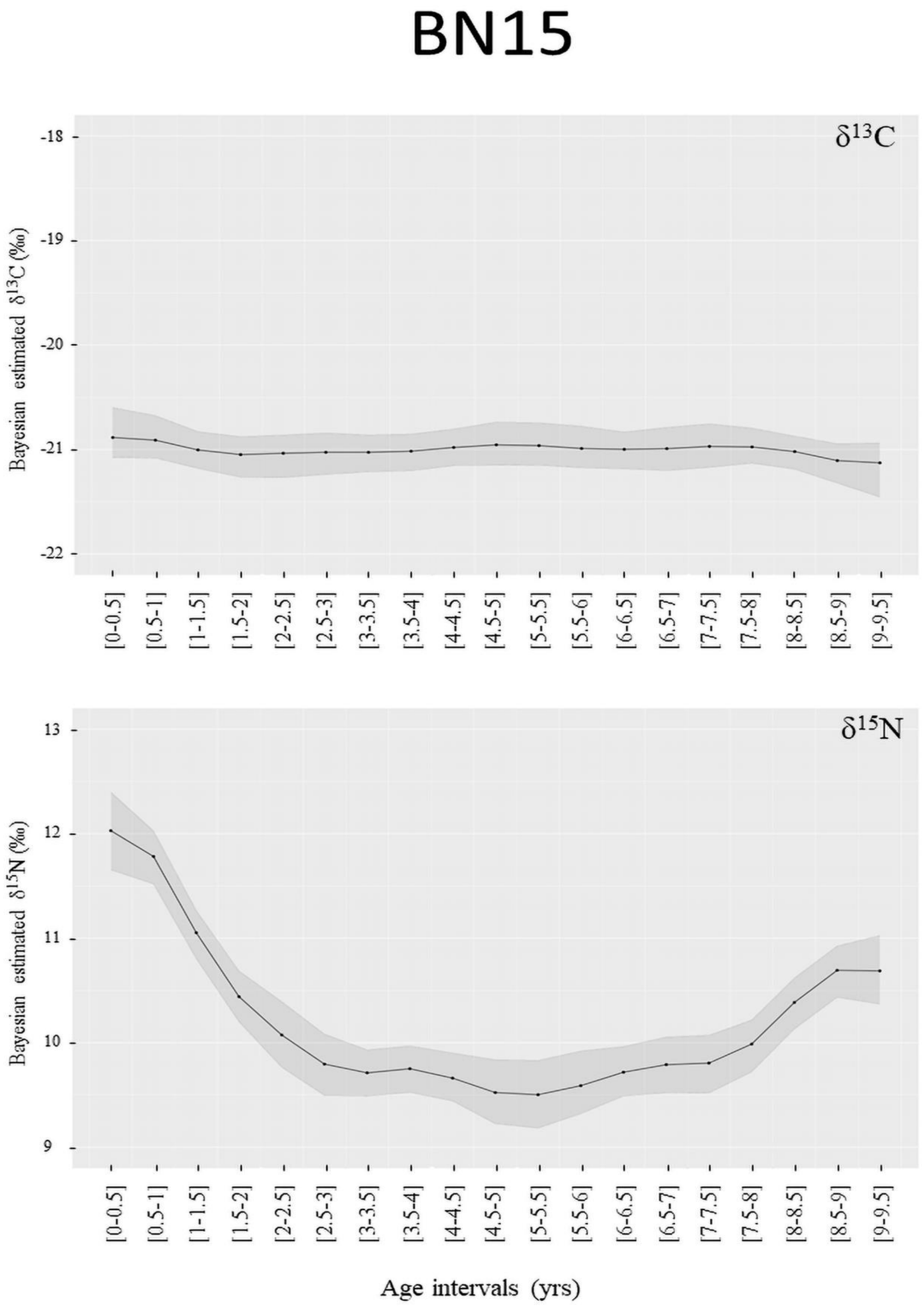

Fig. 2. Bayesian temporal modelling of M1 incremental dentine $\delta^{13}C$ and $\delta^{15}N$ for BN15.

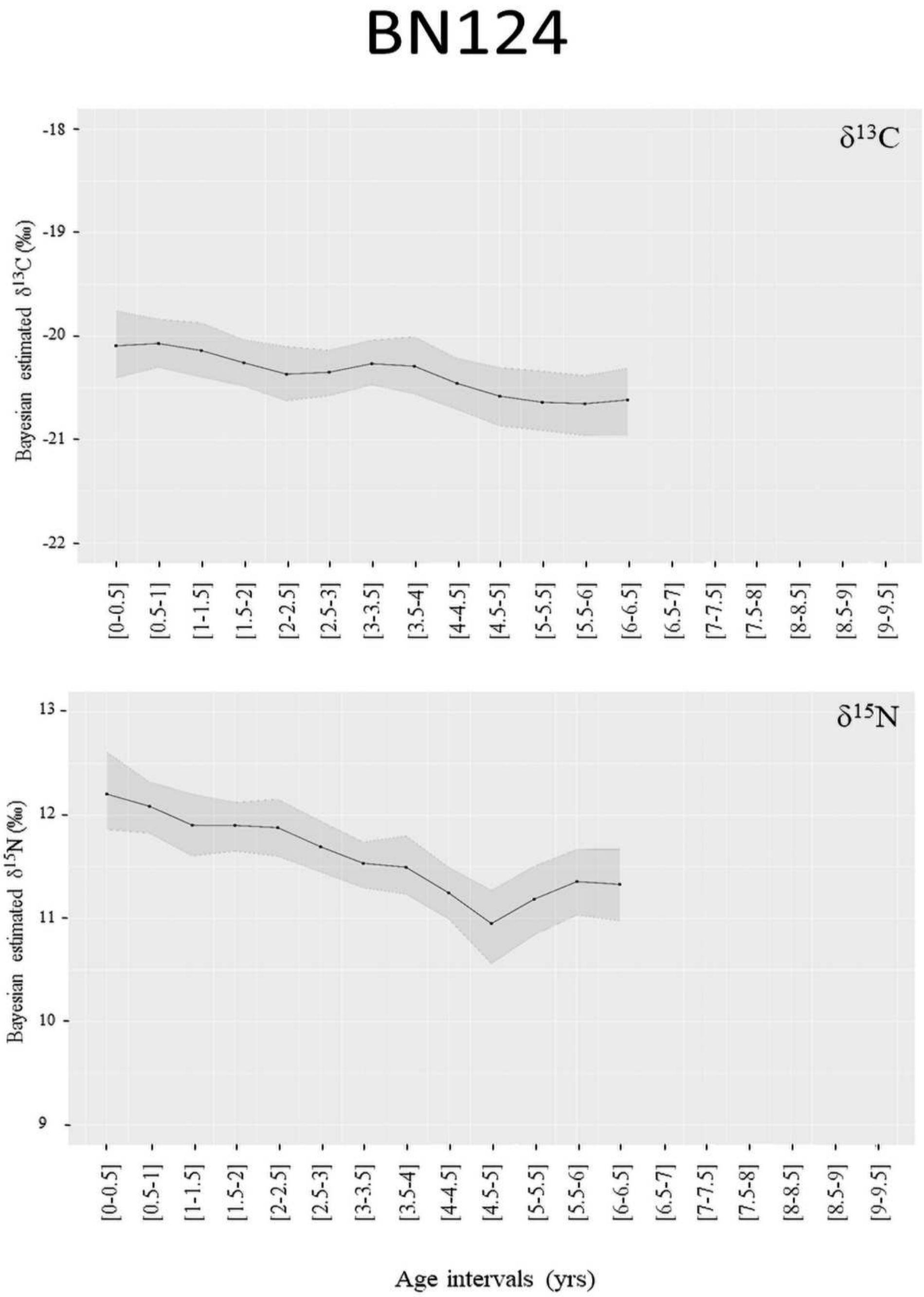

Fig. 3. Bayesian temporal modelling of M1 incremental dentine $\delta^{13}C$ and $\delta^{15}N$ for BN124.

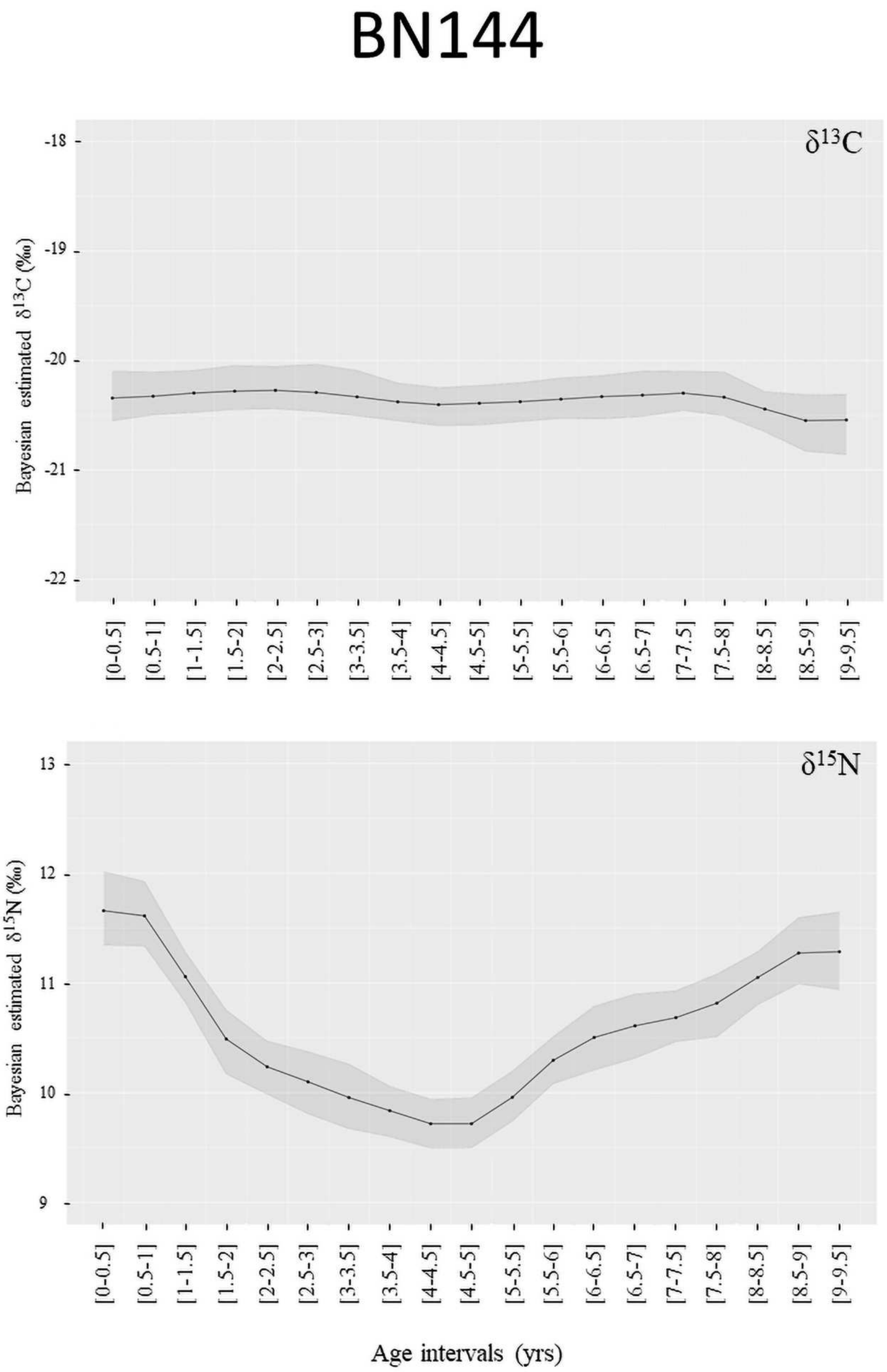

Fig. 4. Bayesian temporal modelling of M1 incremental dentine $\delta^{13}C$ and $\delta^{15}N$ for BN144.

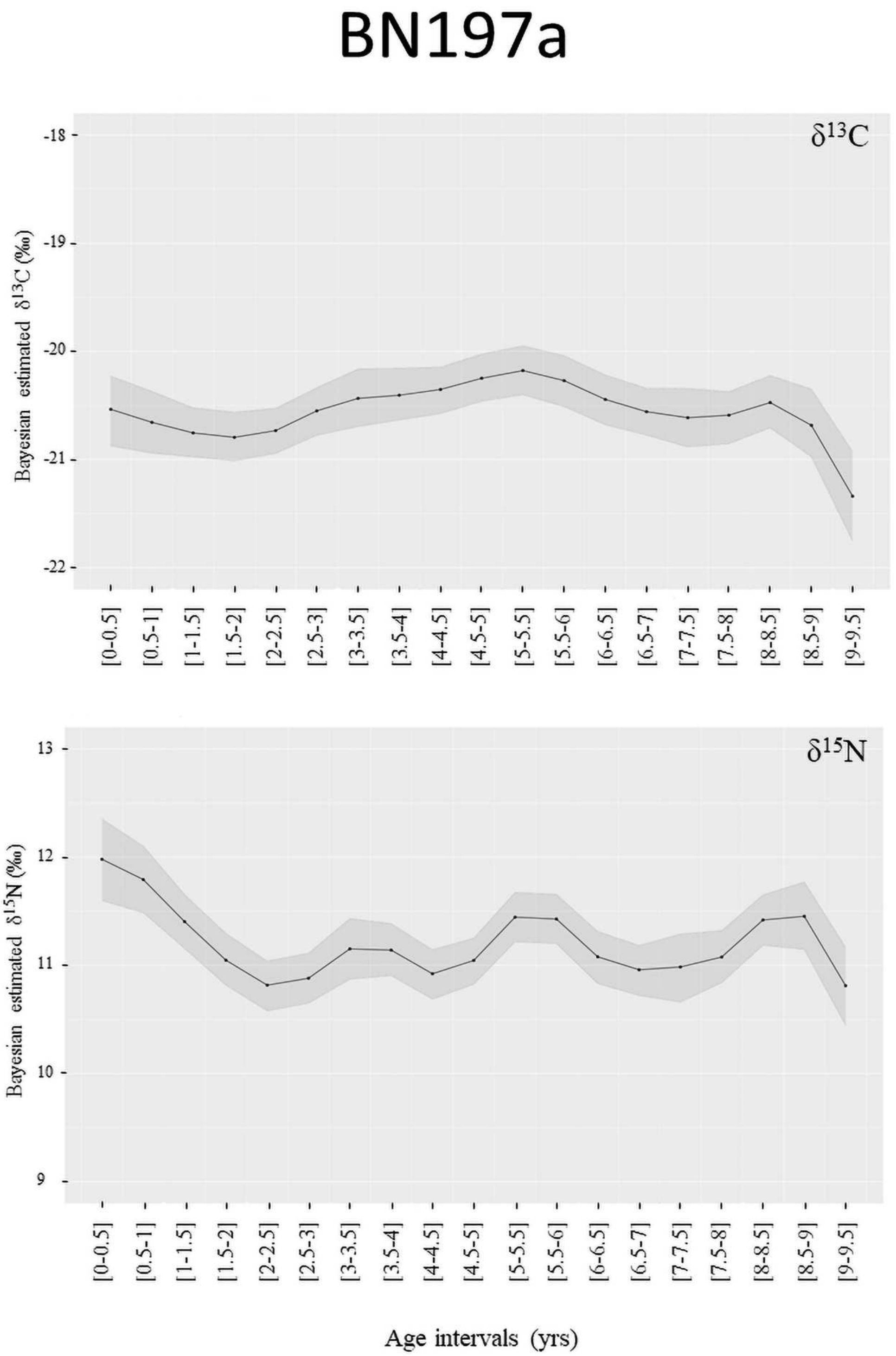

Fig. 5. Bayesian temporal modelling of M1 incremental dentine $\delta^{13}C$ and $\delta^{15}N$ for BN197a.

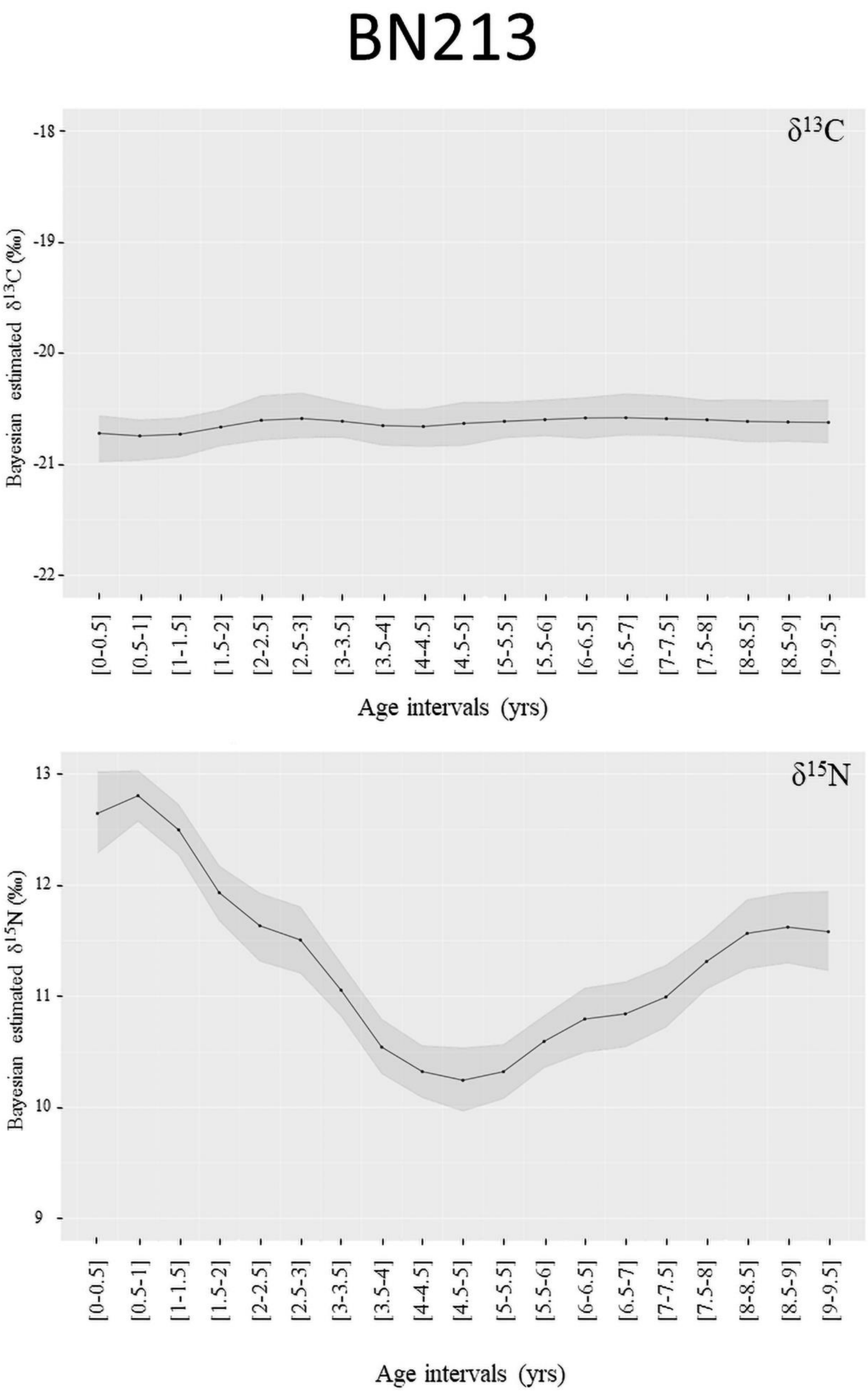

Fig. 6. Bayesian temporal modelling of M1 incremental dentine $\delta^{13}C$ and $\delta^{15}N$ for BN213.

Tab. 1. Description of individuals analysed in this study. Radiocarbon measurements were reported previously in Moore *et al.* 2019. Palaeopathological markers of potential stress were reported in Holst *et al.* 2019.

Individual	Radiocarbon Lab Code	Sex	Age at Death	Uncal 14C (yrs BP)	Cal 14C (yrs BP, 2σ)	Palaeopathological Stress Markers
BN15	SUERC-67722	M	18-25	1734 ±32	Cal 255-395 CE	Dental Enamel Hypoplasia; Cribra Orbitalia
BN124	SUERC-67693	UN	15-16	1705 ±32	Cal 315-420 CE	Dental Enamel Hypoplasia
BN144	SUERC-67704	?F	26-35	1724 ±32	Cal 265-410 CE	Absent
BN197a	SUERC-67716	M	36+	1678 ±32	Cal 260–420 CE	Dental Enamel Hypoplasia; Cribra Orbitalia
BN213	SUERC-67732	F	36-45	1758 ±32	Cal 230-400 CE	Dental Enamel Hypoplasia