

THE LIFE-HISTORY OF A LATE MESOLITHIC WOMAN IN IBERIA: A SEQUENTIAL MULTI-ISOTOPE APPROACH

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Abstract: Multi-isotope analyses on diverse body tissues can offer valuable information on individual life-histories at different temporal resolutions. Here, we reconstruct the diet and mobility of a Late Mesolithic (ca. 5500 cal. BC) young woman buried in Aizpea rockshelter (Navarre, north-central Iberia). To this end, we combine $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ isotope analyses of bone collagen, together with sequential $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ isotope analyses of tooth dentine and $^{87}\text{Sr}/^{86}\text{Sr}$ analysis of tooth enamel from the permanent maxillary right second molar. We also present results of bone collagen measurements for a wide range of coeval faunal remains, including terrestrial ungulates, freshwater fish and birds, and plant remains (i.e. carbonized pome fruits and hazelnut shells) to characterize baseline isotopic signatures. Results suggest a broad-spectrum diet with a relatively high and stable protein intake during early childhood and significant changes in diet during late childhood, including two marked dips in $\delta^{15}\text{N}$ at 8.5 and 11.5 years old, and a progressive decrease in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ from adolescence onwards. The dips may relate to metabolic processes related to growth or, more probably, to age-related subsistence practices, particularly supplementation by children of the parentally provisioned diet, while the sustained drop in isotope values may be associated with a progressively higher dietary contribution from plants that extends into adulthood. Strontium isotope data supports relatively restricted mobility from age 2.5 to 8 (i.e. the approximate time-span covered by enamel formation in the permanent maxillary second molar), consistent with the high degree of territoriality attributed to the last hunters-gatherers in northern Iberia.

Keywords: Isotope biography, micro-sequential analysis, Early-Middle Holocene transition, Iberia.

1. Introduction

Multi-isotope analyses at an individual level on diverse body tissues have revolutionized bioarcheological research, addressing questions regarding past individual lifestyle changes rarely explored before (e.g. [Lamb et al., 2014](#)). Human remains other than bone and tooth are rarely preserved in the archaeological record. However, even with only these materials quite detailed life-history approaches are possible. This is because, while adult bone collagen isotope analysis can only provide an average diet of approximately the last decade of an adult's life, primary dentine analysis records sub-annual variation in subsistence practices, because it does not remodel once deposited (e.g. [Lee-Thorp, 2008](#)). Similarly, enamel does not remodel, which

allows the reconstruction of aspects of an individual's mobility during the period represented by the formation of the crown of the tooth analyzed (e.g. [Frei et al., 2015](#)).

Here, we explore the subsistence and residential mobility of a Late Mesolithic (ca. 5500 cal. BC) young adult female found at the rockshelter of Aizpea (Navarre, central-northern Iberia) through stable isotope analysis of carbon and nitrogen in bone collagen from a fragment of the left scapula, sequential isotope analysis of carbon and nitrogen of increments of dentine collagen from the permanent maxillary right second molar, and sequential strontium isotope analysis of enamel from the same tooth by laser ablation. This approach allows the reconstruction of a significant part of the dietary and residential biography of this individual at a subannual scale from early childhood to adolescence, and presents a long-term average of diet during early adulthood. The human isotope results are compared to those obtained from contemporary faunal and plant remains recovered at the site to ascertain the variability of baseline isotopic signatures, and modelled in combination with the use of FRUITS, a Bayesian mixing model software that allows the simulation of human diet ([Fernandes et al., 2014a](#)).

This case study is particularly relevant because the skeleton analyzed dates to the end of the Mesolithic – a period for which human remains are scarce across much of the Iberian Peninsula (especially outside the shell middens of central Portugal), and permits the observation of the subsistence and mobility patterns immediately prior to the arrival of animal and plant domestication ([García-Martínez de Lagrán, 2008](#)). While dietary changes associated with the Mesolithic-Neolithic transition are relatively well-known in coastal areas of the Atlantic façade (e.g. [Richards et al., 2003](#); [Arias, 2005](#); [Cubas et al., 2018](#)), in interior areas of western Europe these aspects have been rarely explored, particularly at such a fine-grained resolution. In addition, important questions remain concerning the role of plant foods in the subsistence of pre-agrarian societies, such as their relatively dietary contributions and the preference or differential access to some plants over others. The present study aims at providing some new insights into these topics.

2. The site and the Mesolithic burial of Aizpea

The rockshelter of Aizpea is located at the end of a canyon eroded by the Irati river in the Pre-Pyrenees (720 m above sea level) in the north of Navarre (north-central Iberia) ([Figure 1](#)). The site was practically destroyed by nearby roadworks and only 5 m² of its original extent could be excavated during fieldwork carried out in 1989 and 1991 ([Barandiarán and Cava, 2001](#)).

The site showed a stratigraphic sequence with three layers: *c*, *b* and *a*, from bottom to top. Layer *c* was archaeologically sterile, whereas layer *a*, very partially preserved, provided little diagnostic material, mainly some undecorated potsherds, a few flint tools and scattered bones. By contrast, layer *b* showed evidence of an intense human occupation from the Late Mesolithic to the Early Neolithic (from ca. 6907-6461 to ca. 5476-5221 cal BC (95.4%), based on five radiocarbon dates obtained from bone collagen) and provided abundant and well preserved archaeological materials and animal and plant remains related to the exploitation of different resources ([Barandiarán and Cava, 2001](#)). Flint was mainly exploited from Artxilondo (99% of the assemblage), an area located 12 km to the north, with the remainder being mainly pebbles collected from the nearby terraces of the Irati river ([Tarriño, 2001](#)). Diverse ungulates (red deer, wild boar, roe deer, auroch, wild goat and chamois) were hunted in different ecological niches (i.e. forest, open and rocky areas), all available in a catchment area of less than 5 km from the site ([Castaños, 2001](#)). Barbel and trout, whose remains are very abundant, could have been caught in the Irati river ([Roselló et al., 2001](#)). There is also a varied representation of birds and small mammals, matching the spectrum expected for the surrounding landscape and climatic conditions ([Sarà, 2001](#)). Some of the larger bird specimens (e.g. anatids and ardeids) may have been hunted and consumed by Mesolithic groups ([Hernández-Carrasquilla, 2001](#)). The presence of hundreds of land snail shells has also been attributed to human collection ([Moreno and Aparicio, 2001](#)). Wild plants are represented by carbonized hazelnut shells and a number of

carbonized fruits (whitebeam, crabapples and/or serviceberry apples) are particularly well preserved. It is likely that many other species that have not preserved (e.g. herbs, fungi) would also have been gathered, favored by the expansion of mixed woodland documented from the beginning of the early Holocene (Zapata, 2001). Evidence for seasonality (the hunting of ungulates and the gathering of hazelnuts and apples) suggests that the site was used throughout most of the year with the possible exception of the coldest winter months, when conditions at this elevation would have been difficult given the region's high snowfall (Barandiarán and Cava, 2001).

In the central part of Late Mesolithic layer *b* (Figure 2) was also found a complete human skeleton that has been radiocarbon dated to 5621-5481 cal BC (95.4%) (GrA-779: 6600±50 BP; Cava, 1997), making it the 'the last authenticated Mesolithic date currently known' in NE Iberia (García-Puchol et al., 2018: 200). The skeleton was lying on the right side with the lower limbs in flexion in front of the upper body, under a pile of medium and large sized stones that may have marked the grave. No grave goods were clearly associated with the burial (Barandiarán, 2001). Osteological and mtDNA analyses by de-la-Rúa et al. (2001) and Hervella et al. (2018) indicate that the skeleton is that of a woman of ca. 30 years age belonging to haplogroup U5b1b, which is strongly associated with European hunter-gatherers and their descendants (Torroni et al., 1996; Brandt et al., 2015). De-la-Rúa et al. (2001) also suggest that she had borne children, based on specific osteolytic indicators on the pubic symphysis. She may have been right-handed and shows enthesal changes ('musculoskeletal stress markers') in the lower limbs compatible with a degree of mobility over rough terrain. There is evidence of linear enamel hypoplasias indicating potential stress episodes during early childhood (age 3 to 6), as well as traces of healed *cribra cranii* and *cribra orbitalia* traditionally attributed to nutritional deficiencies, especially anaemia. Unusually for Mesolithic hunter-gatherers (see Meiklejohn et al., 1988), multiple carious lesions were observed in premolars and molars, along with severe dental wear potentially related to a diet rich in carbohydrates. This is consistent with the high strontium and barium concentrations resulting from the trace elemental analysis of a bone apatite sample from the left femur (de-la-Rúa et al., 2001), which was one of the first studies including this approach in the field of Iberian paleoanthropology.

The re-examination of the collection during the course of this study identified additional human remains that were not described in previous publications, namely a right radius diaphysis fragment attributed to layer *b* (AI.B.8B.z?) and both a complete left radius (AI.A.9B.z30.n°2-8) and the distal half of a right humerus (AI.sup.n°109-110) attributed to layer *a*. The two radii provide much later radiocarbon dates of 2471-2234 cal BC (95.4%) (OxA-34520: 3887±34 BP) and 2858-2488 cal BC (95.4%) (OxA-34519: 4071±37 BP), respectively. The associated stable carbon and nitrogen isotope values suggest typical terrestrial C₃ diets (Table 1). The dates suggest that the right radius was either wrongly numbered or that it represents an intrusion from the upper layers into the top part of layer *b*, and also that layer *a* may have held a number of disturbed Middle Chalcolithic burials. Some disturbance of upper layers is also shown by the documented intrusion of three cereal grains in layer *b* (Zapata, 2001), one of which was dated to 2136-1782 cal BC (95.4%) (GrA-13263: 3610±50 BP) (Barandiarán and Cava, 2001), suggesting Bronze Age activity at the site as well.

3. Material and methods

3.1. Material

A fragment of the left scapula from the Mesolithic human skeleton of Aizpea was sampled for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ isotope analysis of bone collagen. The maxillary right second molar was also sampled for sequential $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ isotope analyses of tooth dentine and $^{87}\text{Sr}/^{86}\text{Sr}$ analysis of tooth enamel.

A wide range of faunal remains, including bone fragments from different terrestrial wild ungulates (3 aurochs/bison, 3 red deer, 2 roe deer, 3 goats, 2 chamois and 3 wild boars), freshwater fish (8 trout and 14 barbel) and birds (3 grey herons, 1 barn owl, 1 common buzzard, 1 tawny owl, 1 wild duck and 1 northern goshawk), and plant remains (6 charred *Sorbus* and *Malus* pomes, and 3 charred hazelnut shells), all recovered from Aizpea's central part of layer *b* (i.e. Late Mesolithic), were sampled to ascertain the variability of baseline isotopic signatures.

Samples were collected at the Museum of Navarre in the case of the human skeleton, and at the Archaeological Deposit of the Government of Navarre, where the rest of the archaeological materials are curated, both institutions being located in Pamplona, Spain. Materials can be accessed upon request to the Archaeology Section of the Government of Navarre.

3.2. Bone and tooth dentine collagen stable carbon and nitrogen isotope analysis

Human and animal bone collagen extraction was carried out following a modified Longin method (Richards and Hedges, 1999). Bulk collagen sample weights were between 0.5 and 0.8 g. Fifteen human dentine collagen samples from the maxillary right second molar were sequentially taken from crown to apical root (mesial side) using a 1 mm diameter KAI Medical biopsy punch with plunger on a 2 mm central tooth slice, longitudinally cut, following complete demineralization in 0.5M hydrochloric acid in glass vials at 4° C (Fernández-Crespo et al., 2020). Dentine microsamples, weighing between 0.5 and 0.9 mg, were labeled and their approximate age assigned by comparing their anatomical location to the stage of dental development, following AlQahtani et al. (2010). Demineralized dentine samples were freeze-dried without denaturation (cf. Sealy et al., 2014) before being weighed into tin capsules and loaded into a SerCon EA-GSL continuous flow 20/22 isotope ratio mass spectrometer coupled with an elemental analyzer at the Research Laboratory for Archaeology and the History of Art (RLAHA), University of Oxford. Bone collagen was analysed in duplicate, but this was not possible with dentine samples due to the small yields resulting from the sampling technique and the impossibility of precisely replicating a sample elsewhere on the same tooth due to the complexity of dentine growth (Dean and Scandrett, 1995). An alanine standard was used to correct for machine drift. Measurements were adjusted using a three-point calibration comprising two in-house collagen standards and one international standard with well-characterized isotopic compositions bracketing the measured samples: SEAL-1 (seal bone collagen), COW (cow bone collagen), and IAEA-600 (caffeine). Collagen preservation quality was assessed according to several widely used criteria: collagen yield greater than 1%, carbon content between ca. 30 and 44% weight (wt%), nitrogen content between ca. 11 and 16 wt%, and atomic weight C/N ratios between 2.9 and 3.6 for bone collagen (DeNiro, 1985; Ambrose, 1990; van Klinken, 1999) and between 2.9 to 3.4 for dentine collagen, in a conservative approach given the aforementioned lack of duplicate measurements (e.g. Fernández-Crespo et al., 2020). Analytical precision for bulk bone and dentine collagen analysis was determined to be $\pm 0.2\text{‰}$ for both $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ on the basis of repeated measurements of calibration standards and samples.

3.3. Charred plant carbon and nitrogen isotope analysis

Charred plant isotope preparation was carried out following an acid-only procedure (Vaiglova et al., 2014). Sample weights were between 0.20 and 0.15 g (Nitsch et al., 2015). The homogenized powders of each plant sample were weighed into tin capsules for IRMS analysis on a SerCon EA-GSL continuous flow 20/22 isotope ratio mass spectrometer coupled with an elemental analyzer at the RLAHA. The $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values were measured in separate runs due to low %N in the plant samples. Stable carbon and nitrogen isotopic compositions were corrected for machine drift relative to the VPDB and AIR scales using the abovementioned alanine standard. For $\delta^{13}\text{C}$, two-point normalization to the VPDB scale was obtained using IAEA-CH6 and IAEA-CH7, while for $\delta^{15}\text{N}$ the standards were IAEA-600 and IAEA-N2 (Coplen et al., 2006). The $\delta^{13}\text{C}$ and $\delta\text{N}^{15}\text{N}$ values of the carbonized plant remains were

corrected for the effect of charring by subtracting 0.11‰ and 0.31‰, respectively, taking an approach used for C₃ cereals (Nitsch et al., 2015), since hazelnuts and wild apples have not been studied experimentally and so it is unknown how they respond to charring. The $\Delta^{13}\text{C}$ values of archaeological plants were calculated from the measured $\delta^{13}\text{C}_{\text{plant}}$ and a $\delta^{13}\text{C}_{\text{air}}$ value approximated by the AIR-CO₂_LOESS system (Ferrio et al., 2005), using the equation in Farquhar et al. (1989). There are no set rules for accepting or rejecting plant isotope measurements based on their C/N ratios as there are with collagen. Generally, to assess the reliability of the plant isotope measurements obtained, parameters are compared to those of similar plants experimentally charred (e.g. Fraser et al., 2013). However, there are no available comparanda for the type of wild fruit macro-remains analyzed here. Analytical precision was determined to be $\pm 0.2\text{‰}$ for both $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ on the basis of repeated measurements of calibration standards and samples.

3.4. Agent-based simulation of human diet

In order to attempt a reconstruction of the diet of the Mesolithic human skeleton of Aizpea, the Bayesian mixing model open source (<https://sourceforge.net/projects/fruits/>) software FRUITS (Food Reconstruction Using Isotopic Transferred Signals; Fernandes et al., 2014a) was used. This helps handle dietary routing and allows the incorporation of prior information, including data from ecological, archaeological, biochemical or physiological sources to model different dietary scenarios.

Diet was modeled using diet-collagen offsets of $4.8 \pm 0.2\text{‰}$ for $\delta^{13}\text{C}$ and $5.5 \pm 0.5\text{‰}$ for $\delta^{15}\text{N}$, taking into account varying macronutrient concentrations as suggested by Fernandes and colleagues (Fernandes et al., 2012, 2015) and conservative routing values for carbon of $75 \pm 10\%$ from protein and $25 \pm 10\%$ from carbohydrates/lipids (Supplementary Table A.1). Following recent practice, a $+2\text{‰}$ tissue fractionation offset was added to faunal collagen $\delta^{15}\text{N}$ values to estimate flesh values (Fernandes et al., 2014b; Sjögren, 2017). The raw source/food values used in the model were mainly obtained from the mean isotope values (± 1 SD) measured for the fauna and plants. For the macronutrient composition of foods, modern data obtained from the United States Department of Agriculture Food Composition Database (<https://ndb.nal.usda.gov/ndb/>) were used. A prior delimiting the proportion of protein consumed for a healthy human diet, expected to be between 4 and 40% (see Sjögren, 2017, after Noli and Avery, 1988), was also entered into the model.

3.5. Tooth enamel strontium isotope analysis

The enamel of the aforementioned human second molar was subject to both sequential and bulk strontium isotope analysis using routine methods in the MC-ICP-MS facility, Department of Geological Sciences, University of Cape Town (after Copeland et al., 2008; le Roux et al., 2014). The ASI RESolution laser ablation system used here for *in situ* sequential Sr isotope analyses replaced the system used in le Roux et al. (2014), and analyzed tracks 540 μm in length, with an initial surface cleaning run (100 μm spot; 75% overlap; 30 Hz) followed by the analysis run (80 μm spot; 30 Hz; $2.5\mu\text{m}\cdot\text{sec}^{-1}$; $8\text{ J}\cdot\text{cm}^{-2}$). All MC-ICP-MS settings and methods used were otherwise as in le Roux et al. (2014). The error associated with $^{87}\text{Sr}/^{86}\text{Sr}$ measurements by laser ablation on this system is ± 0.0003 (2σ). The average of analyses of a shark tooth from the North Atlantic acting as a control in the same session ($^{87}\text{Sr}/^{86}\text{Sr}$ 0.7090; $n=5$) lies within analytical error of the accepted modern ocean water value of 0.709175 (McArthur et al., 2001).

The bulk enamel sample was dissolved in HNO_3 , and routine facility procedures for strontium separation chemistry (Pin et al., 1994) and MC-ICP-MS isotope analysis followed (Copeland et al., 2008). The analysis is referenced to the international standard NIST SRM987 with $^{87}\text{Sr}/^{86}\text{Sr}$

value of 0.710255. Instrumental mass fractionation is corrected using the exponential law and a value of 0.1194 for $^{86}\text{Sr}/^{88}\text{Sr}$; while isobaric interference of ^{87}Rb at 87 amu is corrected using the measured ^{85}Rb signal and natural $^{85}\text{Rb}/^{87}\text{Rb}$ ratio. Routine analytical error associated with Sr isotope measurements by solution in this facility is ± 0.00002 (2σ). The in-house carbonate reference material NM95 (0.708911 ± 40 , $n = 414$), measured alongside the bulk sample, returned a $^{87}\text{Sr}/^{86}\text{Sr}$ value of 0.708898 ± 11 .

4. Results and discussion

4.1. Collagen and charred plant preservation

Both the sequential dentine and bulk bone collagen carbon and nitrogen isotope results obtained from Aizpea's Late Mesolithic female skeleton provided collagen yields, carbon and nitrogen percentages and C/N ratios indicating generally well-preserved collagen (Table 2). Two of the 15 dentine samples obtained (AI_M2_7 and AI_M2_13) showed carbon and nitrogen percentages slightly above the generally accepted limits, but they have been retained for analysis due to the small difference and the fact that archaeological dentine collagen generally shows higher values than bone collagen, as observed in other studies (e.g. [Fernández-Crespo et al., 2020](#)).

Thirty-five of the 46 faunal samples analyzed provided collagen yields, carbon and nitrogen percentages and C/N ratios indicating well-preserved collagen (Table 3). Four of the remainder exhibited clearly anomalous C/N ratios, yields and percentages (probably because of charring) and were excluded from subsequent analyses. The remaining eight samples exhibited %C and %N slightly below or above the generally accepted limits. However, they have been retained for analyses, given that the other two criteria show values within the accepted ranges and their $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values do not substantially differ from those samples of the same species showing acceptable collagen preservation.

Plant isotope measurements (Table 4) are consistent with expectations for charred plants, although due to the absence of previous experimentation on these kinds of wild plants, their preservation quality criteria (i.e. C/N ratios and carbon and nitrogen percentages) may not be comparable to those obtained from experimentally charred modern cereals (e.g. [Fraser et al., 2013](#)).

4.2. Faunal and plant isotope ecology

The $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ means for terrestrial ungulates ($\delta^{13}\text{C} \bar{x} = -20.6 \pm 0.8\text{‰}$; $\delta^{15}\text{N} \bar{x} = 4.2 \pm 0.6\text{‰}$) are consistent with expectations for a temperate C_3 ecosystem ([DeNiro and Epstein, 1978](#); [Schwarcz and Schoeninger, 1991](#)) (Table 3). Results suggest fully herbivorous diets for all taxa, including wild boar, with no significant differences in mean values between species, although this observation should be taken with caution due to small sample sizes. The relatively high variability in carbon isotope values (ranging from -19.3‰ to -21.9‰) may be explained by animals feeding in different environments (valley vs. mountains, forested vs. open areas) offered by the geographical setting of Aizpea. The higher $\delta^{15}\text{N}$ values seen in some specimens (e.g. AI15) may be attributed to residual nursing signals, as they correspond to juvenile individuals.

Freshwater fish values are consistent with those obtained for similar species in other western European Paleolithic and Mesolithic sites ([Drucker and Bocherens, 2004](#); [Drucker et al., 2016](#)). That both taxa analyzed show similar $\delta^{13}\text{C}$ values (trout: $\bar{x} = -21.6 \pm 0.1\text{‰}$; barbel: $\bar{x} = -21.9 \pm 1.0\text{‰}$) is consistent with both species living in the same aquatic ecosystem. This would have probably been the Irati river, as suggested not only by its proximity to the site, but also by measurements made on the flesh of modern trout from the same and nearby rivers ([Vedia et al.,](#)

2019) which, adjusted by ca. $+2.9 \pm 1.0\text{‰}$ for the expected flesh to bone collagen tissue fractionation (Robson et al., 2012), and by another $+1.5\text{‰}$ for the world-wide decrease in atmospheric ^{13}C caused by the burning of fossil fuels (the Suess effect) (Keeling, 1979), provide similar values ($\bar{x} = -22.2 \pm 2.3\text{‰}$). The fact that freshwater fish mean $\delta^{13}\text{C}$ values are ca. 1‰ more depleted than those of local terrestrial ungulates is also worth mentioning, since it is consistent with earlier observations that stable carbon isotopes in freshwater aquatic systems, though highly variable, are usually ^{13}C -depleted (Dufour et al., 1999). With regard to $\delta^{15}\text{N}$ values, the most relevant observation is the marked difference between species, with trout showing considerably higher values ($\bar{x} = 9.4 \pm 0.1\text{‰}$) than barbel ($\bar{x} = 7.0 \pm 0.6\text{‰}$), consistent with the consumption of higher trophic level foods by trout (e.g., including other fish). The trout values for both isotopes are very tightly clustered, while the barbel values are more variable. Barbel are known to have more varied diets than trout, which may partly explain this difference (Encina et al., 2004), but it is the clustering of the trout values that is remarkable, being greater than that seen in modern trout (Vidia et al., 2019).

Birds show very heterogeneous values, reflecting very different catchments. Thus, grey heron values ($\delta^{13}\text{C} \bar{x} = -21.3 \pm 0.1\text{‰}$; $\delta^{15}\text{N} \bar{x} = 11.3 \pm 0.3\text{‰}$) stand ca. one trophic level ($\delta^{13}\text{C} +0.5\text{‰}$; $\delta^{15}\text{N} +3.4\text{‰}$) above the mean combined values of barbel and trout, consistent with their expected fish-based diet. By contrast, both the duck ($\delta^{13}\text{C} = -19.1\text{‰}$; $\delta^{15}\text{N} = 7.8\text{‰}$) and the raptors ($\delta^{13}\text{C} \bar{x} = -19.4 \pm 0.8\text{‰}$; $\delta^{15}\text{N} \bar{x} = 8.8 \pm 0.5\text{‰}$) show diets reflecting a combination of aquatic and terrestrial C_3 plant-based food sources, based on their higher $\delta^{13}\text{C}$ and lower $\delta^{15}\text{N}$ values.

The charred wild plants demonstrate marked isotope variability (Figure 3). However, the absence of parallel studies based on the same or similar taxa either from prehistoric or modern times precludes an assessment whether or not this heterogeneity is representative of the species under study. In any case, it can be noted that wild apples are lower in both carbon and nitrogen ($\delta^{13}\text{C} \bar{x} = -26.0 \pm 0.7\text{‰}$; $\delta^{15}\text{N} \bar{x} = 0.1 \pm 3.3\text{‰}$) than hazelnuts ($\delta^{13}\text{C} \bar{x} = -24.1 \pm 0.8\text{‰}$; $\delta^{15}\text{N} \bar{x} = 5.5 \pm 2.5\text{‰}$). The more depleted carbon values of wild apples suggest a more forested environment (e.g. Bonafini et al., 2013), in keeping with the calculated $\Delta^{13}\text{C}$ values.

4.3. Human diet

Human dentine isotope results suggest the consistent consumption of foods at a similar, relatively high, trophic level ($\delta^{15}\text{N} > 9\text{‰}$) from age 2.5 to 8 followed by changes in diet in late childhood, including two marked dips at 8.5 and 11.5 years old, and a progressive decrease in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ from adolescence onwards (Figure 4). These two dips may relate to supplementation by children of the parentally provisioned diet, as proposed for other hunter-gatherers (Greenwald et al., 2016; Lew-Levy et al., 2017), or to changes in the amount and/or type of dietary protein consumed (Turner et al., 2007). Although some studies have indicated that metabolic processes associated with growth may affect nitrogen isotope fractionation (e.g. D'Ortenzio et al., 2015), the fact that other investigations have not consistently found such a correlation (e.g. Waters-Rist and Katzenberg, 2009) suggests that age-related subsistence practices are a more likely explanation for these findings. The progressive decrease in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values from adolescence onwards suggests an increasing reliance on plant foods. This may be explained by changes in access to certain resources during adulthood due to social status (whether or not related to biological sex), individual preference for some foods or even dietary taboos, which are well described in the literature (Meiklejohn and Zvelebil, 1991; Schulting and Richards, 2001; Hervella et al., 2018).

Another possibility might be local depletion of game (whether through overhunting and/or a series of bad winters), which, combined with the degree of territoriality that appears to be practiced by Late Mesolithic communities, could result in greater use of plant foods. It is worth recalling here the very late date of the Aizpea woman, potentially overlapping with the onset of the process of Neolithization in NE Iberia (García-Puchol et al., 2018). While there appears to

have been greater continuity of both practice (Alday, 2012) and population across the Mesolithic-Neolithic transition in Iberia (Villalba-Mouco et al., 2019) compared to some other regions of Europe (e.g., Britain; Brace et al., 2019), it is nevertheless possible that long-standing traditional support and alliance networks came under pressure and were disrupted, or re-organized, at this time. This could conceivably have created added stresses for some communities. To properly investigate these alternatives would require considerable further research, ideally including a larger sample size of human remains (e.g., to what extent is the Aizpea woman an outlier in her own community?), which at present does not exist for this region.

Bone collagen carbon and nitrogen isotope values are consistent with a reduction in the trophic level of protein consumed during the last decade or so of life. In fact, her nitrogen isotope value is not only the lowest documented among northern Iberian Mesolithic individuals analyzed to date (Figure 5), but is among the lowest values (if not *the* lowest) so far known for all of Mesolithic Europe (Schulting, 2018) (Supplementary Figure A.1). It may reflect a mainly vegetarian diet, as suggested by previously published strontium (345 ppm) and barium (110 ppm) concentrations measured on a bone apatite sample, and the high caries prevalence (34.5%) observed on the cervical and occlusal surfaces of the premolars and molars (Figure 6). The latter points to a diet rich in carbohydrates (de-la-Rúa et al., 2001), with sucrose being particularly suspect as proposed for Mesolithic populations of present-day Portugal (Meiklejohn et al., 1988). This suggests that a large part of her adult diet could have come from plant foods such as berries, nuts, roots and tubers. The finding of carbonized fragments of the meat of some pomes and of hazelnut shells may reveal the particular relevance of forest fruits (Zapata et al., 2002; McComb, 2009), which is also documented in Mesolithic communities of the Iberian Atlantic façade (López-Doriga, 2015). However, the observed $\Delta^{13}\text{C}_{\text{human-ungulate}}$ (+0.4‰) and $\Delta^{15}\text{N}_{\text{human-ungulate}}$ (+3.0‰) isotope enrichments fit well with the lower limit expected for a trophic level shift (Figure 7), which supports a limited but regular animal protein intake.

The results do not indicate a significant consumption of freshwater resources, despite hundreds of trout and barbel bone remains being recovered from level *b*, or of migratory birds, even with the presence of a number of potentially gastronomically appreciated species as wild duck, partridge, ringdove or even grey heron (Hernández-Carrasquilla, 2001; Bournery, 2009). However, it is possible that such resources were only seasonally exploited, as suggested for other European Mesolithic inland communities (Drucker et al., 2016), and, as consequence, their relative importance within a broad-spectrum diet was insufficient to be isotopically detected (e.g. >10-20%, depending on the food's isotopic distinctiveness). The potential dietary contributions of insects, molluscs and small mammals is also difficult to assess given the absence of baseline data. While such foods would probably make only a relatively minor contribution to the overall diet, some studies suggest that they could have been an important resource among some hunter-gatherer communities (e.g. Rizner et al. 2009; Raubenheimer et al., 2014). In this regard, the presence of hundreds of shells from land snails in layer *b* is noteworthy; considerable evidence for their use has been documented in other Mesolithic circum-Mediterranean and Atlantic sites (e.g. Lubell, 2004; Gutiérrez-Zugasti, 2009; Thomas, 2017; Álvarez-Fernández et al., 2020).

The dietary simulation created using the FRUITS software (Supplementary Table A.1) is consistent with the scenario presented above, though, of course, estimations are not exact and very much depend on the various different parameters and offsets used to build the models (Makarewicz and Sealy, 2015). The Aizpea woman's adult diet is modeled with a strong reliance on plants, reflected in the model by 'forest apples' (34-84% – 68% confidence interval) and hazelnuts (4-56%), whereas meat from herbivores would have had a lesser importance (1-13%), as would birds and freshwater fish in the diet (<5%) (Figure 8). Note that we are not concluding that 'forest apples' were the main dietary source, but that they serve as a proxy for a range of plants with similar isotopic values. Using more conservative parameters, with greater uncertainties in both food/source values and concentrations and/or a smaller $\delta^{15}\text{N}$ diet-collagen

offset (e.g. $4 \pm 0.5\text{‰}$ to better reflect the 3-5‰ range more commonly cited in the literature (e.g. [Hedges and Reynard, 2007](#))), does not significantly affect the model.

4.4. Human mobility

Sequential and bulk $^{87}\text{Sr}/^{86}\text{Sr}$ analysis of tooth enamel provided very homogeneous results (Table 5; Figure 9), supporting a lifestyle with a relatively limited geographical range for this Aizpea individual at least from age 2.5 to 8 (i.e., the approximate time-span of enamel formation in the permanent maxillary second molar). Although a more systematic study of the biologically available strontium in Aizpea's immediate region remains to be done, the bulk enamel $^{87}\text{Sr}/^{86}\text{Sr}$ value obtained (0.7087) seems to be in accordance with the isotope composition expected for the main local geological formations, consisting of late Upper Cretaceous and Paleocene limestone and loam (Figure 10), based on studies recently undertaken in nearby regions (e.g. [Fernández-Crespo et al., 2020](#)). If this is confirmed, the individual would have not only spent early childhood but also been buried some 20-25 years later within the same general territory. This, combined with the fact that the environment would have been capable of providing a full range of food resources and raw materials, including local flint from Artxilondo, supports some degree of residential stability or, at least, restricted mobility within a well-defined and relatively small territory over time. In this regard, archeozoological and paleobotanical data suggest that the site was used throughout most of the year with the possible exception of the coldest winter months, when groups perhaps shifted to the warmer northern slopes of the Pyrenees based on techno-typological similarities with Aquitanian assemblages and the occasional exploitation of transpyrenean flint sources ([Barandiarán and Cava, 2001](#)). Large-scale spatial modelling (i.e., 'isoscapes') suggests considerable variability in $^{87}\text{Sr}/^{86}\text{Sr}$ values for these northern valleys, though they are predominantly higher, ca. ≥ 0.7100 ([Bataille et al. 2018: fig. 9](#); [Willmes et al., 2018: fig. 8](#)) compared to values expected for the geologies associated with the environs of Aizpea in Navarre (e.g. [Fernández-Crespo et al. 2020](#)). No such movements are evident in the relatively homogeneous results of ca. 0.7084 ± 0.0002 provided by the sequential laser ablation sampling, nor are they clear in the averaged signal represented by the solution measurement of 0.7087. However, movement further down the northern valleys could encounter comparable $^{87}\text{Sr}/^{86}\text{Sr}$ values to those characterizing the landscape around Aizpea ([Willmes et al., 2018](#)). An intriguing alternative explanation is that, since Sr is incorporated into the body mainly through plant foods ([Bentley, 2006](#)), winter subsistence either depended largely on stored foods obtained from the southern slopes around Aizpea in the previous months, or that it emphasized other resources with lower strontium concentrations (e.g. meat), thus contributing far less to the signal in the teeth. This remains for future research.

This scenario is consistent with the marked degree of territoriality generally attributed to the last hunters-gatherers of northern Iberia (e.g. [Arias, 2005](#); [García-Martínez de Lagrán, 2008](#)). Despite emerging evidence for movements to procure or exchange allochthonous raw materials being increasingly described ([Álvarez-Fernández et al., 2020](#)), most sites show recurrent or stable occupation (both for inhabitation and burial) and a preference for the exploitation of diverse, but mainly local faunal, plant and lithic resources, with well-established settlement networks within a context of demographic increase ([Fano, 2019](#)). These networks may have seen a degree of continuity during the Early Neolithic, most notably in the upper Ebro valley and the southern slopes of the Pyrenees ([Alday, 2012](#)).

5. Conclusions

The isotopic reconstruction of the dietary and mobility life-history of a Late Mesolithic woman buried in Aizpea rockshelter (northern Iberia) has provided evidence of a broad-spectrum diet with a relatively high-trophic-level protein consumption during the early childhood and a sustained drop in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values that may be associated with a progressively higher reliance on plants. With the available evidence a change of residence and/or landscape use after

late childhood cannot be ruled out as a reason for this shift. However, a gradual change in the access to certain foods due to the individual's social status, food preferences and/or taboos, seems a more plausible explanation. Firstly, because the shift is sustained in time and this requires some degree of stability in subsistence. And secondly, because strontium isotope data support movements from age 2.5 to 8 within a relatively limited geographical range that is very likely coincident with the catchment of the site where the individual was buried at adulthood, suggesting, if not stability, at least restricted mobility over her lifetime. This fits with the isotopic evidence for a degree of territoriality among the last hunters-gatherers in northern Iberia. The study demonstrates the potential of multi-isotope analyses on both bone collagen and tooth dentine to provide valuable information on individual life-histories at different temporal resolutions: neither tissue would have presented the complete, nor indeed the same, story. Yet, there is still much work to be done in this direction, particularly with regard to increasing the number of the case studies and the inclusion of additional approaches, such as bulk and sequential sulphur, hydrogen and oxygen isotope analysis or dental calculus analysis.

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References

- Alday, A., 2012. The Neolithic of the Iberian Peninsula: an explanation from the perspective of the participation of Mesolithic communities. *Zephyrus* LXIX, 75-94.
- AlQahtani, S.J., Hector, M.P., Liversidge, H.M., 2010. Brief communication: The London atlas of human tooth development and eruption. *Am. J Phys. Anthropol.* 142, 481–90.
- Álvarez-Fernández, E., Becares, J., Jordá Pardo, J. F., Agirre-Uribesalgo, A., Álvarez-Alonso, D., Aparicio, M. T., Barrera-Mellado, I., Carral, P., Carriol, R.-P., Cubas, M., Cueto, M., Douka, K., Elorza, M., Fernández-Gómez, M.J., Gabriel, S., García-Ibaibarriaga, N., Iriarte-Chiapusso, M.J., Llave, C., Maestro, A., Martín-Jarque, S., Portero, R., Suárez-Bilbao, A., Tarriño, A., Teira, L.C., Uzquiano, O., Arias, P., 2020. Palaeoenvironmental and chronological context of human occupations at El Cierro cave (northern Spain) during the transition from the late Upper Pleistocene to the early Holocene. *J. Archaeol. Sci. Rep.* 29, 102138.
- Ambrose, S.H., 1990. Preparation and characterization of bone and tooth collagen for isotopic analysis. *J. Archaeol. Sci.* 17, 431–451.
- Arias, P., 2005. Determinaciones de isótopos estables en restos humanos de la región Cantábrica. Aportación al estudio de la dieta de las poblaciones del Mesolítico y el Neolítico. *Munibe* 57, 359–374.
- Arias, P., Schulting, R.J., 2010. Análisis de isótopos estables sobre los restos humanos de la Braña-Arintero. Aproximación a la dieta de los grupos Mesolíticos de la Cordillera Cantábrica, in: Vidal Encinas, J., Encina Prada, M. (Eds.), *Los Hombres Mesolíticos de la Cueva de La Braña-Arintero* (Valdelugeros, León). Museo de León, Junta de Castilla y León, León, pp. 130–137.

Barandiarán, I., 2001. El dispositivo funerario, in: Barandiarán, I., Cava, A. (Eds.), *Cazadores-recolectores en el pirineo navarro. El sitio de Aizpea entre 8000 y 6000 años antes de ahora. Anejos de Veleia, Series maior 10*. Universidad del País Vasco, Vitoria-Gasteiz, pp. 431–443.

Barandiarán, I., Cava, A., 2001. La ocupación de Aizpea: medio, aprovisionamiento y usos, in: Barandiarán, I., Cava, A. (Eds.), *Cazadores-recolectores en el pirineo navarro. El sitio de Aizpea entre 8000 y 6000 años antes de ahora. Anejos de Veleia, Series maior 10*. Universidad del País Vasco, Vitoria-Gasteiz, pp. 459–528.

Bataille, C.P., von Holstein, I.C.C., Laffoon, J.E., Willmes, M., Liu, X.-M. and Davies, G.R., 2018. A bioavailable strontium isoscape for Western Europe: A machine learning approach. *PLoS ONE* 13(5), e0197386.

Bentley, R.A., 2006. Strontium isotopes from the earth to the archaeological skeleton: a review. *J. Archaeol. Method Theory* 13(3), 135–187.

Bonafini, M., Pellegrini, M., Ditchfield, P., Pollard, A. M., 2013. Investigation of the ‘canopy effect’ in the isotope ecology of temperate woodlands. *J. Archaeol. Sci.* 40(11), 3926–3935.

Bournery, A., 2009. Small game exploitation through the Mediterranean Pleistocene-Holocene transition in southern France: 152 a key resource augmenting the dietary range, in: McCartan, S., Schulting, R.J., Warren, G., Woodman, P. (Eds.), *Mesolithic Horizons*. Oxbow, Oxford, pp. 152–160.

Brace, S., Diekmann, Y., Booth, T.J., Faltyskova, Z., Rohland, N., Mallick, S., Olalde, I., Ferry, M., Michel, M., Oppenheimer, J., Broomandkoshbacht, N., Stewardson, K., Martiniano, R., Walsh, S., Kayser, M., Armit, I., Schulting, R.J., Craig, O.E., Sheridan, A., Parker Pearson, M., Stringer, C., Reich, D., Thomas, M.G., Barnes, I., 2019. Ancient genomes indicate population replacement in Early Neolithic Britain. *Nature Ecol. Evol.* 3, 765–771.

Brandt, G., Szécsényi-Nagy, A., Christina Roth, C., Alt, K.W., Haak, W., 2015. Human paleogenetics of Europe - the known knowns and the known unknowns. *J. Human Evol.* 79, 73–92.

Castaños, P., 2001. Estudio de los macromamíferos de Aizpea (Navarra), in: Barandiarán, I., Cava, A. (Eds.), *Cazadores-recolectores en el pirineo navarro. El sitio de Aizpea entre 8000 y 6000 años antes de ahora. Anejos de Veleia, Series maior 10*. Universidad del País Vasco, Vitoria-Gasteiz, pp. 225–240.

Cava, A., 1997. L’abri d’Aizpea. Un facies à trapezes et son évolution a la fin du Mésolithique sur le versant sud des Pyrénées. *Prehistoire Européenne* 10, 151–171.

Copeland, S.R., Sponheimer, M., le Roux, P.J., Grimes, V., Lee-Thorp, J.A., de Ruiter, D.J., Richards, M.P., 2008. Strontium isotope ratios ($^{87}\text{Sr}/^{86}\text{Sr}$) of tooth enamel: a comparison of solution and laser ablation multicollector inductively coupled plasma mass spectrometry methods. *Rapid Commun. Mass Spectrom.* 22, 3187–3194.

Coplen, T.B., Brand, W.A., Gehre, M., Gröning, M., Meijer, H.J., Toman, B., Verkouteren, R.M., 2006. New guidelines for $\delta^{13}\text{C}$ measurements. *Anal. Chem.* 78, 2439–2441.

Cubas, M., Peyroteo-Stjerna, R., Fontanals-Coll, M., Llorente-Rodríguez, L., Lucquin, A., Craig, O.E., Colonese, A.C., 2018. Long-term dietary change in Atlantic and Mediterranean Iberia with the introduction of agriculture: a stable isotope perspective. *Archaeol. Anthropol. Sci.* 11, 3825–3836.

D'Ortenzio, L., Brickley, M., Schwarcz, H., Prowse, T., 2015. You are not what you eat during physiological stress: Isotopic evaluation of human hair. *Am. J. Phys. Anthropol.* 157(3), 374–388.

de-la-Rúa, C., Baraybar, J.P., Iriondo, M., Izagirre, N., 2001. Estudio antropológico del esqueleto mesolítico del yacimiento de Aizpea, in: Barandiarán, I., Cava, A. (Eds.), *Cazadores-recolectores en el pirineo navarro. El sitio de Aizpea entre 8000 y 6000 años antes de ahora. Anejos de Veleia, Series maior 10*. Universidad del País Vasco, Vitoria-Gasteiz, pp. 363–414.

Dean, M.C., Scandrett, A.E., 1995. Rates of dentine mineralization in permanent human teeth. *Int. J. Osteoarchaeol.* 5, 349–358.

DeNiro, M.J., 1985. Postmortem preservation and alteration of in vivo bone collagen isotope ratios in relation to palaeodietary reconstruction. *Nature* 317, 806–809.

DeNiro, M.J., Epstein, S., 1978. Influence of diet on the distribution of carbon isotopes in animals. *Geochim Cosmochim Acta* 42, 495–506.

Drucker, D., Bocherens, H., 2004. Carbon and Nitrogen Stable Isotopes as Tracers of Change in Diet Breadth during Middle and Upper Palaeolithic in Europe. *Int. J. Osteoarchaeol.* 14: 162–177.

Drucker, D., Valentin, F., Thevenet, C., Mordant, D., Cottiaux, R., Delsate, D., Van Neer, W., 2016. Aquatic resources in human diet in the Late Mesolithic in Northern France and Luxembourg: insights from carbon, nitrogen and sulphur isotope ratios. *Archaeol. Anthropol. Sci.* 10 (2), 351–368.

Dufour, E., Bocherens, H., Mariotti, A., 1999. Palaeodietary implications of isotopic variability in Eurasian lacustrine fish. *J. Archaeol. Sci.* 26, 617–627.

Encina, L., Rodríguez-Ruiz, A., Granado-Lorencio, C., 2004. Trophic habits of the fish assemblage in an artificial freshwater ecosystem: the Joaquín Costa reservoir, Spain. *Folia. Zool.* 53(4), 437–494.

Fano, M.A., 2019. The Mesolithic "Asturian" culture (North Iberia), one century on. *Quat. Int.* 515, 159–175.

Farquhar, G.D., Ehleringer, J.R., Hubick, K.T., 1989. Carbon isotope discrimination and photosynthesis. *Annu. Rev. Plant Physiol. Plant Mol. Biol.* 40, 503–537.

Fernandes, R., Grootes, P., Nadeau, M.J., Nehlich, O., 2015. Quantitative reconstruction of a Neolithic population using a Bayesian mixing model (FRUITS): the case study of Ostorf (Germany). *Am. J. Phys. Anthropol.* 158, 325–340.

Fernandes, R., Meadows, J., Dreves, A., Nadeau, M.J., Grootes, P.M., 2014b. A preliminary study on the influence of cooking on the C and N isotopic composition of multiple organic fractions of fish (mackerel and haddock). *J. Archaeol. Sci.* 50, 153–159.

Fernandes, R., Millard, A.M., Brabec, M., Nadeau, M.J., Grootes, P., 2014a. Food reconstruction using isotopic transferred signals (FRUITS): a Bayesian model for diet reconstruction. *PLoS ONE* 9/2:e87436.

Fernandes, R., Nadeau, M.J., Grootes, P.M., 2012. Macronutrient-based model for dietary carbon routing in bone collagen and apatite. *Archaeol. Anthropol. Sci.* 4, 291–301.

Fernández-Crespo, T., Snoeck, C., Ordoño, J., de Winter, N.J., Czermak, A., Mattielli, N., Lee-Thorp, J.A., Schulting, R.J., 2020. Multi-isotope evidence for the emergence of cultural alterity in Late Neolithic Europe. *Sci. Adv.* 6, eaay2169.

Ferrio, J.P., Araus, J.L., Buxó, R., Voltas, J., Bort, J., 2005. Water management practices and climate in ancient agriculture: inferences from the stable isotope composition of archaeobotanical remains. *Veg. Hist. Archaeobot.* 14, 510–517.

Fraser, R.A., Bogaard, A., Schäferb, M., Arbogast, R., Heaton, T.H.E., 2013. Integrating botanical, faunal and human stable carbon and nitrogen isotope values to reconstruct land use and palaeodiet at LBK Vaihingen an der Enz, Baden-Württemberg. *World Archaeol.* 45, 492–517.

Frei, K.M., Mannering, U., Kristiansen, K., Allentoft, M.E., Wilson, A.S., Skals, I., Tridico, S., Nosch, M.L., Willerslev, E., Clarke, L., Frei, R., 2015. Tracing the dynamic life story of a Bronze Age Female. *Sci. Rep.* 5, 10431.

García-Martínez de Lagrán, I., 2008. La cuestión de la complejidad socioeconómica en las comunidades de cazadores-recolectores mesolíticas de la cuenca Alta y Media del Ebro. *Trabajos de Prehistoria* 65 (2), 49–71.

García-Puchol, O., Bernabeu-Aubán, J., Barton, C.M., Pardo-Gordó, S., McClure, S.B., Díez-Castillo, A., 2018. A Bayesian approach for timing the Neolithization in Mediterranean Iberia. *Radiocarbon* 60(1), 181-205.

Grandal, A., Amalia, A., 2017. Caracterización isotópica de Elba, la mujer mesolítica de Chan do Lindeiro (Pedrafita, Lugo, Península Ibérica). *Cadernos do Laboratorio Xeolóxico de Laxe* 39, 89–110.

Greenwald, A.M., Eerkens, J.W., Bartelink, E.J., 2016. Stable isotope evidence of juvenile foraging in prehistoric central California. *J. Archaeol. Sci.: Reports* 7, 146–154.

Gutiérrez-Zugasti, I., 2009. La explotación de moluscos y otros recursos litorales en la región cantábrica durante el Pleistoceno final y el Holoceno inicial. Universidad de Cantabria, Santander.

Hedges, R.E.M., Reynard, L.M., 2007. Nitrogen isotopes and the trophic level of humans in archaeology. *J. Archaeol. Sci.* 34, 1240–1251.

Hernández-Carrasquilla, F., 2001. Las aves de Aizpea, in: Barandiarán, I., Cava, A. (Eds.), *Cazadores-recolectores en el pirineo navarro. El sitio de Aizpea entre 8000 y 6000 años antes de ahora. Anejos de Veleia, Series maior 10*. Universidad del País Vasco, Vitoria-Gasteiz, pp. 269–277.

Hervella, M., Fernández-Crespo, T., Ventades, N.G., Laza, I.M., Schulting, R.J., de-la-Rúa, C., 2018. Sex-related Inequality in Mesolithic societies from northern Iberia: a diet and mitogenome study in hunter-gatherers, in: Gligor, M., Soficaru, A. (Eds.), *Archaeology of Women Mortuary practices and bioarchaeological reconstruction. Annales Universitatis Apulensis, Series Historica 22/I*. University of Alba Iulia, Alba Iulia, pp. 9–26.

Keeling, C.D., 1979. The Suess effect: ¹³Carbon-¹⁴Carbon interrelations. *Environ. Int.* 2(4-6), 229–300.

- Lamb, A.L., Evans, J.E., Buckley, R., Appleby, J., 2014. Multi-isotope analysis demonstrates significant lifestyle changes in King Richard III. *J. Archaeol. Sci.* 5, 559–565.
- Lee-Thorp, J.A., 2008. On isotopes and old bones. *Archaeometry* 50, 925–950.
- le Roux, P.J., Lee-Thorp, J.A., Copeland, S.R., Sponheimer, M.J., de Ruiter, D.J., 2014. Strontium isotope analysis of curved tooth enamel surfaces by laser-ablation multi-collector ICP-MS. *Palaeogeog. Palaeoclim. Palaeoecol.* 416, 142–149.
- Lew-Levy, S., Reckin, R., Lavi, N., Cristóbal-Azkarate, J., Ellis-Davies, K., 2017. How do hunter-gatherer children learn subsistence skills? A meta-ethnographic review. *Hum. Nature* 28(4), 367–394.
- López-Doriga, I., 2015. The Use of Plants during the Mesolithic and the Neolithic in the Atlantic coast of the Iberian Peninsula. Unpublished PhD dissertation. Universidad de Cantabria, Santander.
- Lubell, D., 2004. Prehistoric edible land snails in the circum-Mediterranean: the archaeological evidence, in: Brugal, J.P., Desse, J. (Eds.), *Petits Animaux et Sociétés Humaines. Du Complément Alimentaire aux Ressources Utilitaires*. Éditions APDCA, Antibes, pp. 77–98.
- Makarewicz, C.A., Sealy, J., 2015. Dietary reconstruction, mobility, and the analysis of ancient skeletal tissues: Expanding the prospects of stable isotope research in archaeology. *J. Archaeol. Sci.* 56, 146–158.
- McArthur, J.M., Howarth, R.J., Bailey, T.R., 2001. Strontium Isotope Stratigraphy: LOWESS Version 3: Best Fit to the Marine Sr Isotope Curve for 0–509 Ma and Accompanying Look-up Table for Deriving Numerical Age. *J. Geol.* 109, 155–170.
- McComb, A.M.G., 2009. The ecology of hazel (*Corylus avellana*) nuts in Mesolithic Ireland, in: McCartan, S., Schulting, R.J., Warren, G., Woodman, P. (Eds.), *Mesolithic Horizons*. Oxbow, Oxford, pp. 225–231.
- Meiklejohn, C., Baldwin, J.H., Schentag, C.T., 1988. Caries as a probable dietary marker in the western European Mesolithic, in: Kennedy, B.V., LeMoine, G.M. (Eds.), *Diet and Subsistence: Current Archaeological Perspectives*. Calgary University Press, Calgary, pp. 273–279.
- Meiklejohn, C., Zvelebil, M., 1991. Health status of European populations at the agricultural transition and the implications for the adoption of farming, in: Bush, H., Zvelebil, M. (Eds.), *Health in Past Societies: Biocultural interpretations of human skeletal remains in archaeological contexts*. British Archaeological Reports (International Series 567), Oxford, pp. 128–145.
- Moreno, R., Aparicio, M.T., 2001. Malacofauna terrestre del yacimiento de Aizpea (Navarra), in: Barandiarán, I., Cava, A. (Eds.), *Cazadores-recolectores en el pirineo navarro. El sitio de Aizpea entre 8000 y 6000 años antes de ahora*. Anejos de Veleia, Series maior 10. Universidad del País Vasco, Vitoria-Gasteiz, pp. 301–314.
- Nitsch, E.K., Charles, M., Bogaard, A., 2015. Calculating a statistically robust $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ offset for charred cereal and pulse seeds. *Sci. Technol. Archaeol. Res.* 1, 1–8.
- Noli, D., Avery, G., 1988. Protein poisoning and coastal subsistence. *J. Archaeol. Sci.* 15(4), 395–401.

- Pin, C., Briot, D., Bassin, C., Poitrasson, F., 1994. Concomitant separation of strontium and samarium-neodymium for isotopic analysis in silicate samples, based on specific extraction chromatography. *Anal. Chim. Acta* 298 (2), 209–217.
- Raubenheimer, D., Rothman, J.M., Pontzer, H., Simpson, S.J., 2014. Macronutrient contributions of insects to diets of hunter-gatherers: a geometric analysis. *J. Hum. Evol.* 71, 70–76.
- Redfern, R.C., Hamlin, C., Beavan Athfield, N., 2010. Temporal changes in diet: a stable isotope analysis of late Iron Age and Roman Dorset, Britain. *J. Archaeol. Sci.* 37, 1149–1160.
- Richards, M.P., Hedges, R.E.M., 1999. Stable isotope evidence for similarities in the types of marine foods used by Late Mesolithic humans at sites along the Atlantic coast of Europe. *J. Archaeol. Sci.* 26, 717–722.
- Richards, M.P., Schulting, R.J., Hedges, R.E.M., 2003. Sharp shift in diet at onset of Neolithic. *Nature* 425, 366.
- Rizner, M., Vukosavljevic, N., Miracle, P., 2009. The paleoecological and paleodietary significance of edible land snails (*Helix* sp.) across the Pleistocene-Holocene transition on the eastern Adriatic coast, in: McCartan, S., Schulting, R.J., Warren, G., Woodman, P. (Eds.), *Mesolithic Horizons*. Oxbow, Oxford, pp. 527–532.
- Robson, H., Andersen, S., Craig, O.E., Fischer, A., Glykou, A., Hartz, S., Lübke, H., Schmölcke, U., Heron, C., 2012. Carbon and nitrogen isotope signals in eel bone collagen from Mesolithic and Neolithic sites in northern Europe. *J. Archaeol. Sci.* 39, 2003–2011.
- Roselló, E., Morales, A., Cañas, J.M., 2001. Análisis de la ictiofauna de Aizpea (Navarra), in: Barandiarán, I., Cava, A. (Eds.), *Cazadores-recolectores en el pirineo navarro. El sitio de Aizpea entre 8000 y 6000 años antes de ahora. Anejos de Veleia, Series maior 10*. Universidad del País Vasco, Vitoria-Gasteiz, pp. 279–299.
- Sará, M., 2001. I piccolo mammiferi di Aizpea, in: Barandiarán, I., Cava, A. (Eds.), *Cazadores-recolectores en el pirineo navarro. El sitio de Aizpea entre 8000 y 6000 años antes de ahora. Anejos de Veleia, Series maior 10*. Universidad del País Vasco, Vitoria-Gasteiz, pp. 243–255.
- Sarasketa-Gartzia, I., Villalba-Mouco V., le Roux P, Arrizabalaga A, Salazar-García D.C., 2018. Late Neolithic-Chalcolithic socio-economical dynamics in Northern Iberia. A multi-isotope study on diet and provenance from Santimamiñe and Pico Ramos archaeological sites (Basque Country, Spain), *Quat. Int.* 481, 14–27.
- Sealy, J., Johnson, M., Richards, M.P., Nehlich, O., 2014. Comparison of two methods of extracting bone collagen for stable carbon and nitrogen isotope analysis: Comparing whole bone demineralization with gelatinization and ultrafiltration. *J. Archaeol. Sci.* 47, 64–69.
- Schulting, R.J., 2018. Dietary shifts at the Mesolithic-Neolithic transition in Europe: an overview of the stable isotope data, in: Lee-Thorp J.A., Katzenberg, M.A. (Eds.), *The Oxford Handbook of the Archaeology of Diet*. Oxford University Press, Oxford.
- Schulting, R.J., Richards, M.P., 2001. Dating women and becoming farmers: New paleodietary and AMS dating evidence from Breton Mesolithic cemeteries of Téviec and Hoëdic. *J. Anthropol. Archaeol.* 20, 314–44.
- Schwarcz, H.P., Schoeninger, M.J., 1991. Stable isotope analysis in human nutritional ecology. *Yearb. Phys. Anthropol.* 34, 283–321.

Sjögren, K.G., 2017. Modeling middle Neolithic funnel beaker diet on Falbygden, Sweden. *J. Archaeol. Sci.: Reports* 12, 295–306.

Tarriño, A., 2001. Procedencia de los sílex de la industria lítica del yacimiento de Aizpea (Arive, Navarra), in: Barandiarán, I., Cava, A. (Eds.), *Cazadores-recolectores en el pirineo navarro. El sitio de Aizpea entre 8000 y 6000 años antes de ahora. Anejos de Veleia, Series maior* 10. Universidad del País Vasco, Vitoria-Gasteiz, pp. 51–61.

Thomas, K., 2017. The land and other non-marine molluscs from the shell midden of Pico Ramos: taphonomic, environmental and anthropic interpretations, in: Zapata, L. (Ed.), *The Shell Midden of Pico Ramos (Muskiz, Bizkaia). Humans on the Basque Coast during the 6th and 5th Millennium B.C.* TRRRES, Bilbao, pp. 59–70.

Torroni, A., Huoponen, K., Francalacci, P., Petrozzi, M., Morelli, L., Scozzari, R., Obinu, D., Savontaus, M.L., Wallace, D.C., 1996. Classification of European mtDNAs from an analysis of three European populations. *Genetics* 144, 1835–1850.

Turner, B.L., Edwards, J.L., Quinn, E.A., Kingston, D.J., van Gerven, D.P., 2007. Age-related variation in isotopic indicators of diet in medieval Qulubnarti, Sudanese Nubia. *Int. J. Osteoarchaeol.* 17(1), 1–25.

Vaiglova, P., Snoeck, C., Nitsch, E.K., Bogaard, A., Lee-Thorp, J.A., 2014. Impact of contamination and pre-treatment on stable carbon and nitrogen isotopic composition of charred plant remains. *Rapid Comm. Mass Spectrom.* 28, 2497–2450.

van Klinken, G.J., 1999. Bone collagen quality indicators for palaeodietary and radiocarbon measurements. *J. Archaeol. Sci.* 26 (6), 687–695.

Vedia, I., Almeida, D., Rodeles, A.A., Leunda, P.M., Baquero, E., Galicia, D., Oscoz, J., Elustondo, D., Santamaría, J.M., Miranda, R., 2019. Behavioral interactions and trophic overlap between invasive signal crayfish *Pacifastacus leniusculus* (Decapoda, Astacidae) and native fishes in Iberian rivers. *Water* 11, e459.

Villalba-Mouco, V., van de Loosdrecht, M., Posth, C., Mora, R., Martínez-Moreno, J., Rojo-Guerra, M.A., Salazar-García, D.C., Royo-Guillén, J.I., Kunst, M., Rougier, H., Crevecoeur, I., Arcusa-Magallón, H., Tejedor-Rodríguez, C., García-Martínez de Lagrán, I., Garrido-Pena, R., Alt, K.W., Jeong, C., Schiffels, S., Utrilla, P., Krause, J., Haak, W., 2019. Survival of Late Pleistocene hunter-gatherer ancestry in the Iberian Peninsula. *Curr. Biol.* 29(7), 1169–1177.

Waters-Rist, A.L., Bazaliiskii, V.I., Weber, A.W., Katzenberg, M.A., 2011. Infant and child diet in Neolithic hunter-fisher-gatherers from Cis-Baikal, Siberia: Intra-long bone stable nitrogen and carbon isotope ratios. *Am. J. Phys. Anthropol.* 146(2), 225–241.

Willmes, M., Bataille, C.P., James, H.F., Moffat, I., McMorrow, L., Kinsley, L., Armstrong, R.A., Eggins, S., Grün, R., 2018. Mapping of bioavailable strontium isotope ratios in France for archaeological provenance studies. *Applied Geochem.* 90, 75–86.

Zapata, L., 2001. El uso de los recursos vegetales en Aizpea (Navarra, Pirineo Occidental): la alimentación, el combustible y el bosque, in: Barandiarán, I., Cava, A. (Eds.), *Cazadores-recolectores en el pirineo navarro. El sitio de Aizpea entre 8000 y 6000 años antes de ahora. Anejos de Veleia, Series maior* 10. Universidad del País Vasco, Vitoria-Gasteiz, pp. 325–357.

Zapata, L., Cava, A., Iriarte, M.J., Baraybar, J.P., de-la-Rúa, C., 2002. Mesolithic plant use in the western Pyrenees: implications for vegetation change, use of wood and human diet, in:

Mason, S.L.R., Hather, J.G. (Eds.), Hunter-gatherer archaeobotany. UCL Institute of Archaeology, London, pp. 96–107.

Web references

<https://sourceforge.net/projects/fruits/>. Last accessed on 12 December 2019.

<https://ndb.nal.usda.gov/ndb/>. Last accessed on 14 December 2019.

Table 1. Radiocarbon dates and bone collagen $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values on Chalcolithic human remains from Aizpea.															
Sample ID	Layer	Element	Age	Sex	Lab. Ref.	^{14}C yr BP	\pm	cal BC (95%)		%Col	%C	%N	C/N	$\delta^{13}\text{C}$ (‰) VPDB	$\delta^{15}\text{N}$ (‰) AIR
AI.B.8B.z?	<i>b</i>	Right radius	Adult	Indet	OxA-34520	3887	34	2471	2234	5.4	45.2	15.8	3.3	-19.9	8.7
AI.A.9B.z30.n°2-8	<i>a</i>	Left radius	Adult	Indet	OxA-34519	4071	37	2858	2488	20.9	42.5	15.4	3.2	-19.7	9.9
AI.sup.n°109-110	<i>a</i>	Right humerus	Adult	Indet	-	-	-	-	-	23.0	46.2	16.7	3.2	-19.9	8.6

Table 2. Human sequential dentine and bulk bone collagen $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values from Aizpea's Mesolithic individual.									
Sample ID ¹	Element	Material	Age represented (years) ²	%Col	%C ³	%N ³	C/N	$\delta^{13}\text{C}$ (‰) VPDB	$\delta^{15}\text{N}$ (‰) AIR
AI2_M2_1	Permanent maxillary right second molar	Dentine	3.33	-	43.9	15.9	3.2	-20.0	9.2
AI2_M2_2			5.25	-	43.8	15.5	3.3	-19.3	9.5
AI2_M2_3			6.35	-	42.7	15.1	3.3	-19.4	9.1
AI2_M2_4			7.45	-	42.7	15.2	3.3	-19.4	9.3
AI2_M2_5			8.20	-	42.5	15.6	3.2	-19.0	9.1
AI2_M2_6			8.60	-	42.7	15.2	3.3	-19.7	8.1
AI2_M2_7			9.00	-	46.1	16.1	3.3	-19.5	7.8
AI2_M2_8			9.40	-	43.5	15.6	3.3	-19.4	8.3
AI2_M2_9			9.80	-	43.7	15.7	3.2	-19.5	8.1
AI2_M2_10			10.25	-	43.9	15.7	3.3	-19.5	8.0
AI2_M2_11			10.75	-	41.3	14.6	3.3	-19.7	8.2
AI2_M2_12			11.25	-	42.4	15.1	3.3	-20.0	7.6
AI2_M2_13			11.75	-	45.7	16.4	3.3	-19.5	8.5
AI2_M2_14			13.00	-	43.7	15.4	3.3	-20.3	8.5
AI2_M2_15			15.33	-	43.5	14.8	3.4	-20.8	7.8
AI2	Left scapula	Bone	ca. 20-30	1.8	37.0	12.2	3.5	-20.3	7.2

¹ The inventory number (AI.8A/8B.z70-60) is the same for both the left scapula and the maxillary right second molar analyzed.

² In the case of dentine samples, age was estimated by comparing the dentine sections' anatomical location to the stage of dental development, following AlQahtani et al. 2010. In the case of bone, the range selected is the last decade of the individual's life, as traditionally suggested in most literature.

³ Anomalous values are shown in italics.

Table 3. Faunal $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values from Aizpea, central part of layer <i>b</i> .									
ID	Inventory no.	Species	Element	%Col ¹	%C ¹	%N ¹	C/N ¹	$\delta^{13}\text{C}$ (‰) VPDB ¹	$\delta^{15}\text{N}$ (‰) AIR ¹
AI3	Layer <i>b</i> , unnumbered	Red deer (<i>Cervus elaphus</i>)	Calcaneus	4.2	40.5	14.3	3.3	-20.7	3.9
AI5	Layer <i>b</i> , unnumbered	Red deer (<i>Cervus elaphus</i>)	Ulna	1.9	34.4	12.1	3.3	-19.9	3.6
AI6	Layer <i>b</i> , unnumbered	Roe deer (<i>Capreolus capreolus</i>)	Mandible	4.9	37.5	13.0	3.4	-21.9	3.8
AI8	Layer <i>b</i> , unnumbered	Wild goat (<i>Capra pyrenaica</i>)	Calcaneus	4.9	47.5	16.6	3.3	-21.4	3.9
AI9	Layer <i>b</i> , unnumbered	Wild goat (<i>Capra pyrenaica</i>)	Calcaneus	8.0	38.6	13.7	3.3	-19.9	3.4
AI11	Layer <i>b</i> , unnumbered	Chamois (<i>Rupicapra rupicapra</i>)	Phalanx	1.1	29.7	10.1	3.4	-20.7	3.7
AI12	Layer <i>b</i> , unnumbered	Chamois (<i>Rupicapra rupicapra</i>)	Mandible	5.7	42.5	15.1	3.3	-19.3	4.5
AI13	Layer <i>b</i> , unnumbered	Auroch/ Bison (<i>Bos primigenius/ Bison bonasus</i>)	Carpal bone	8.2	41.3	14.7	3.3	-20.2	4.5
AI14	Layer <i>b</i> , unnumbered	Auroch/ Bison (<i>Bos primigenius/ Bison bonasus</i>)	Carpal bone	8.0	37.8	13.3	3.3	-21.4	4.5
AI28	AI.B.1338	Auroch/ Bison (<i>Bos primigenius/ Bison bonasus</i>)	Rib	3.3	40.5	14.2	3.3	-20.8	5.3
AI15	Layer <i>b</i> , unnumbered	Wild boar (<i>Sus ferus</i>)	Calcaneus	11.0	42.7	15.2	3.3	-20.2	5.0
AI17	Layer <i>b</i> , unnumbered	Wild boar (<i>Sus ferus</i>)	Calcaneus	2.9	31.0	11.0	3.3	-21.1	3.9
AI18a	Layer <i>b</i> , unnumbered	Trout (<i>Salmo trutta</i>)	Trunk vertebra	9.8	45.8	16.2	3.3	-21.8	9.3
AI18b	Layer <i>b</i> , unnumbered	Trout (<i>Salmo trutta</i>)	Trunk vertebra	2.9	40.2	13.7	3.4	-21.6	9.5
AI18c	Layer <i>b</i> , unnumbered	Trout (<i>Salmo trutta</i>)	Trunk vertebra	5.9	40.0	13.9	3.4	-21.6	9.2
AI18d	Layer <i>b</i> , unnumbered	Trout (<i>Salmo trutta</i>)	Trunk vertebra	5.5	41.4	14.6	3.3	-21.5	9.3
AI18e	Layer <i>b</i> , unnumbered	Trout (<i>Salmo trutta</i>)	Trunk vertebra	6.8	40.3	14.3	3.3	-21.6	9.5
AI18f	Layer <i>b</i> , unnumbered	Trout (<i>Salmo trutta</i>)	Trunk vertebra	3.0	42.1	14.6	3.4	-21.6	9.3
AI18g	Layer <i>b</i> , unnumbered	Trout (<i>Salmo trutta</i>)	Trunk vertebra	1.3	40.7	13.7	3.5	-21.5	9.4
AI18h	Layer <i>b</i> , unnumbered	Trout (<i>Salmo trutta</i>)	Trunk vertebra	8.8	41.8	14.7	3.3	-21.5	9.5
AI19a	Layer <i>b</i> , unnumbered	Barbel (<i>Barbus barbus</i>)	Trunk vertebra	11.0	41.8	14.8	3.3	-21.1	6.2
AI19b	Layer <i>b</i> , unnumbered	Barbel (<i>Barbus barbus</i>)	Trunk vertebra	18.4	40.2	13.7	3.4	-21.5	7.1
AI19c	Layer <i>b</i> , unnumbered	Barbel (<i>Barbus barbus</i>)	Trunk vertebra	8.3	40.5	13.7	3.4	-21.0	7.1
AI19d	Layer <i>b</i> , unnumbered	Barbel (<i>Barbus barbus</i>)	Trunk vertebra	5.2	41.4	14.2	3.4	-22.3	6.8
AI19e	Layer <i>b</i> , unnumbered	Barbel (<i>Barbus barbus</i>)	Trunk vertebra	8.3	42.2	14.8	3.3	-21.7	7.1
AI19f	Layer <i>b</i> , unnumbered	Barbel (<i>Barbus barbus</i>)	Trunk vertebra	5.0	41.4	14.2	3.4	-22.0	7.0
AI19g	Layer <i>b</i> , unnumbered	Barbel (<i>Barbus barbus</i>)	Trunk vertebra	18.3	40.4	13.8	3.4	-24.8	7.8
AI19h	Layer <i>b</i> , unnumbered	Barbel (<i>Barbus barbus</i>)	Trunk vertebra	5.6	42.0	14.9	3.3	-22.4	6.4
AI19i	Layer <i>b</i> , unnumbered	Barbel (<i>Barbus barbus</i>)	Trunk vertebra	13.3	40.3	14.0	3.4	-22.2	6.7

AI19j	Layer <i>b</i> , unnumbered	Barbel (<i>Barbus barbus</i>)	Trunk vertebra	6.0	39.2	13.5	3.4	-22.1	6.4
AI19k	Layer <i>b</i> , unnumbered	Barbel (<i>Barbus barbus</i>)	Trunk vertebra	13.6	41.2	14.7	3.3	-22.4	6.7
AI19l	Layer <i>b</i> , unnumbered	Barbel (<i>Barbus barbus</i>)	Trunk vertebra	8.0	39.5	13.8	3.4	-21.4	7.0
AI19m	Layer <i>b</i> , unnumbered	Barbel (<i>Barbus barbus</i>)	Trunk vertebra	2.7	39.7	13.5	3.4	-20.6	8.1
AI19n	Layer <i>b</i> , unnumbered	Barbel (<i>Barbus barbus</i>)	Trunk vertebra	3.5	41.8	13.8	3.5	-21.6	7.8
AI28	AI.B2	Grey heron (<i>Ardea cinerea</i>)	Femur	9.1	34.8	12.2	3.3	-21.3	11.6
AI33	AI.B.8B.110-120.172	Grey heron (<i>Ardea cinerea</i>)	Long bone	12.0	43.8	15.4	3.3	-21.5	11.3
AI34	AI.B.8B.110-120.173-241	Grey heron (<i>Ardea cinerea</i>)	Long bone	8.2	46.8	16.4	3.3	-21.2	11.0
AI30	AI.B.7A.10-20.65	Barn owl (<i>Tyto alba</i>)	Humerus	14.7	44.3	15.7	3.3	-20.6	9.4
AI31	AI.B.8B.30-40.126	Common buzzard (<i>Buteo</i> sp.)	Left coracoid	14.1	45.2	16.1	3.3	-19.0	8.3
AI32	AI.B.7A.110-120.128	Tawny owl (<i>Strix aluco</i>)	Long bone	9.8	46.6	16.0	3.4	-19.0	8.8
AI35	AI.B.8B.60-70.263.	Wild duck (<i>Anas</i> cf. <i>platyrhynchos</i>)	Femur	11.5	44.7	15.5	3.4	-19.1	7.8
AI36	AI.B.7A.20-30.290	Northern goshawk (<i>Accipiter gentilis</i>)	Long bone	7.2	43.5	15.0	3.4	-18.8	8.5
<i>Rejected</i>									
AI4	Layer <i>b</i> , unnumbered	Red deer (<i>Cervus elaphus</i>)	Calcaneus	0.1	5.4	0.3	19.0	-26.0	2.6
AI7	Layer <i>b</i> , unnumbered	Roe deer (<i>Capreolus capreolus</i>)	Mandible	0.1	2.7	0.3	9.2	-24.5	2.5
AI10	Layer <i>b</i> , unnumbered	Wild goat (<i>Capra pyrenaica</i>)	Calcaneus	0.1	2.7	0.3	10.3	-23.9	4.3
AI16	Layer <i>b</i> , unnumbered	Wild boar (<i>Sus ferus</i>)	Calcaneus	0.8	14.7	4.5	3.8	-21.4	4.6

¹ Anomalous values are shown in italics.

Table 4. Charred wild plant $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values from Aizpea, central part of layer <i>b</i> .									
ID	Inventory no.	Taxon	Element	%C	%N	C/N	$\delta^{13}\text{C}$ (‰) VPDB ¹	$\delta^{15}\text{N}$ (‰) AIR ²	$\Delta^{13}\text{C}$ (‰) ³
AI20	AI.8A.x70-80.n153.(2)	Whitebeam/ Serviceberry (<i>Sorbus aria</i> / <i>Sorbus domestica</i>)	Fruit	63.3	0.9	80.1	-25.3	4.7	19.1
AI21	AI.9A.x95-100.n23-24.(10)	Whitebeam (<i>Sorbus aria</i>)	Fruit	61.7	0.8	89.9	-25.5	-0.6	19.2
AI22	AI.8B.x60-70.n257.(5)	Crab apple/ Serviceberry (<i>Malus sylvestris</i> / <i>Sorbus domestica</i>)	Fruit	57.5	0.5	130.2	-26.8	-1.4	20.6
AI23	AI.(11)	Crab apple/ Serviceberry (<i>Malus sylvestris</i> / <i>Sorbus domestica</i>)	Fruit	59.7	1.4	58.9	-26.8	-5.0	20.7
AI24	AI.8B.x100-110.(7)	Crab apple/ Serviceberry (<i>Malus sylvestris</i> / <i>Sorbus domestica</i>)	Fruit	56.3	0.6	104.8	-25.7	1.2	19.5
AI25	AI.(18)	Crab apple/ Serviceberry tree (<i>Malus sylvestris</i> / <i>Sorbus domestica</i>)	Fruit	59.8	0.6	115.4	-25.9	2.0	19.7
AI26	AI.8 ^a .x60-70.n142	Hazelnut (<i>Corylus avellana</i>)	Pericarp	63.3	0.9	81.2	-23.3	5.3	16.9
AI27	AI.9A/9B.x65-70.n18	Hazelnut (<i>Corylus avellana</i>)	Pericarp	54.2	0.8	80.8	-24.3	8.0	18.0
AI41	AI.9A/9B.x65-70.n19	Hazelnut (<i>Corylus avellana</i>)	Pericarp	66.5	0.7	115.5	-24.8	3.0	18.6

¹ Values corrected for the effect of charring by subtracting 0.11‰ (Nitsch et al. 2015).

² Values corrected for the effect of charring by subtracting 0.31‰ (Nitsch et al. 2015).

³ Values calculated using the equation defined by Farquhar et al. (1989) and both the measured $\delta^{13}\text{C}$ values ($\delta^{13}\text{C}_{\text{plant}}$) and a $\delta^{13}\text{C}_{\text{air}}$ value of -6.71 ‰ approximated by the AIRCO₂_LOESS system (Ferrio et al. 2005) for the chronology of Aizpea's human burial.

Table 5. Human sequential and bulk enamel ⁸⁷ Sr/ ⁸⁶ Sr values from Aizpea’s Mesolithic skeleton upper right second molar.				
Sample ID	Technique	Age represented (years) ¹	⁸⁷ Sr/ ⁸⁶ Sr	2 sigma error
S02.23 Aizpea M2 01	Sequential laser ablation MC-ICP-MS	2.89	0.7086	0.0003
S02.24 Aizpea M2 02		3.68	0.7086	0.0003
S02.25 Aizpea M2 03		4.46	0.7083	0.0003
S02.26 Aizpea M2 04		5.25	0.7084	0.0003
S02.27 Aizpea M2 05		6.04	0.7081	0.0003
S02.28 Aizpea M2 06		6.82	0.7083	0.0003
S02.29 Aizpea M2 07		7.61	0.7085	0.0003
Aizpea (URM2)	Bulk solution analysis	2.5-8 (average)	0.7087	<0.0001

¹ Age was estimated by comparing the dentine sections' anatomical location to the stage of dental development, following AlQahtani et al. 2010.

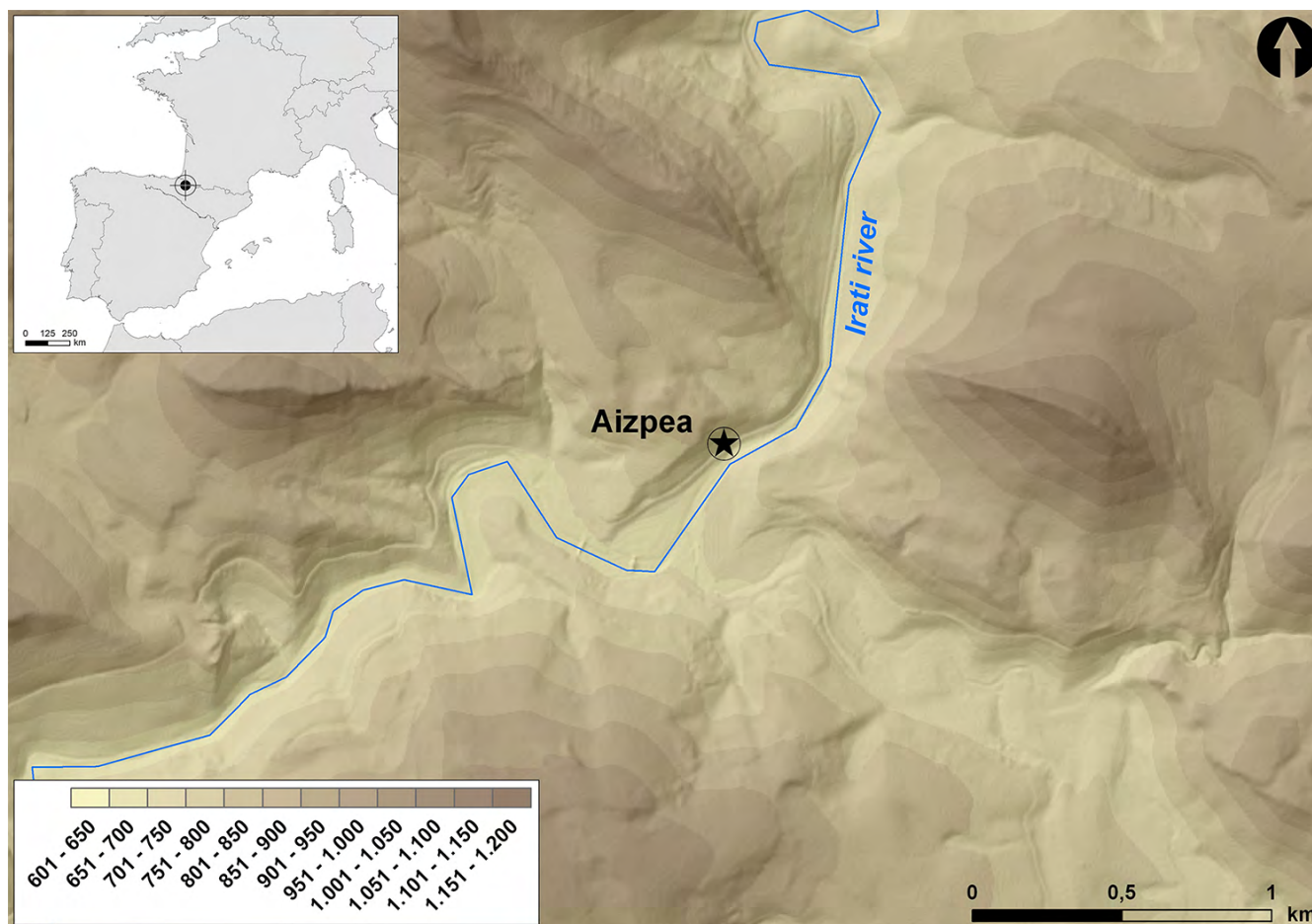


Fig. 1. Map showing the location of Aizpea rockshelter (Navarra, Spain) in Western Europe and its immediate region.

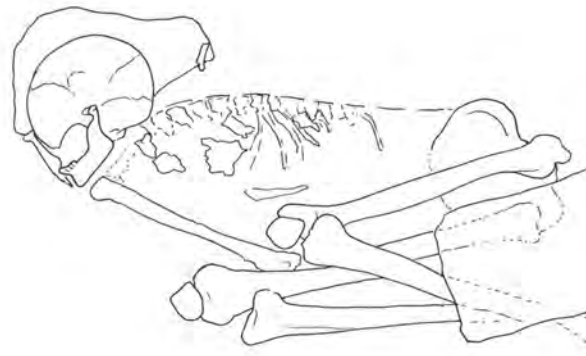
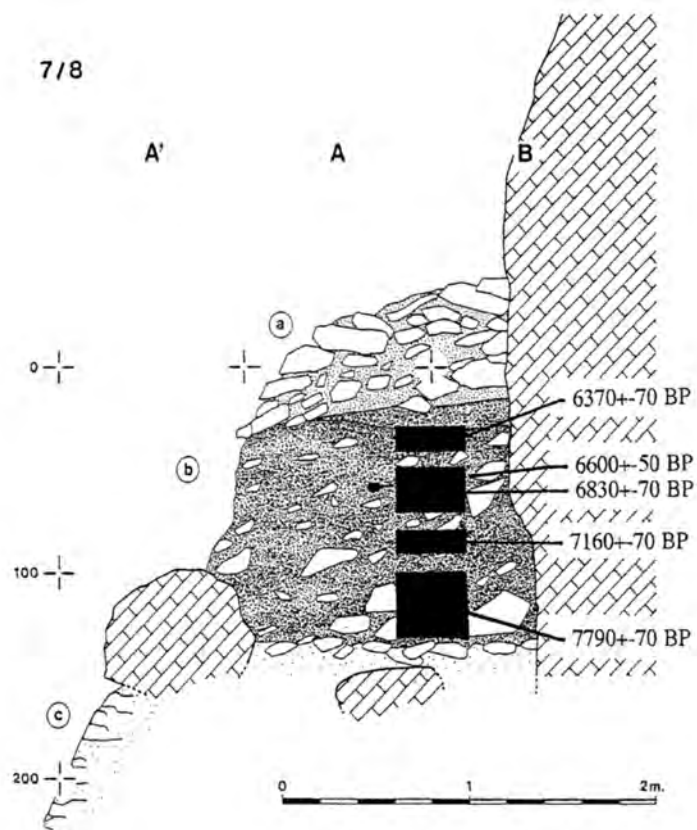


Fig. 2. Aizpea rockshelter's prehistoric record. *Left*) Section of the stratigraphy documented, with reference to the location of the five bone samples that were radiocarbon dated for layer *b*, including that obtained from the Mesolithic human burial (modified from Barandiarán and Cava, 2001). *Right*) Photograph and plan of the Mesolithic human burial (after Barandiarán and Cava, 2001).

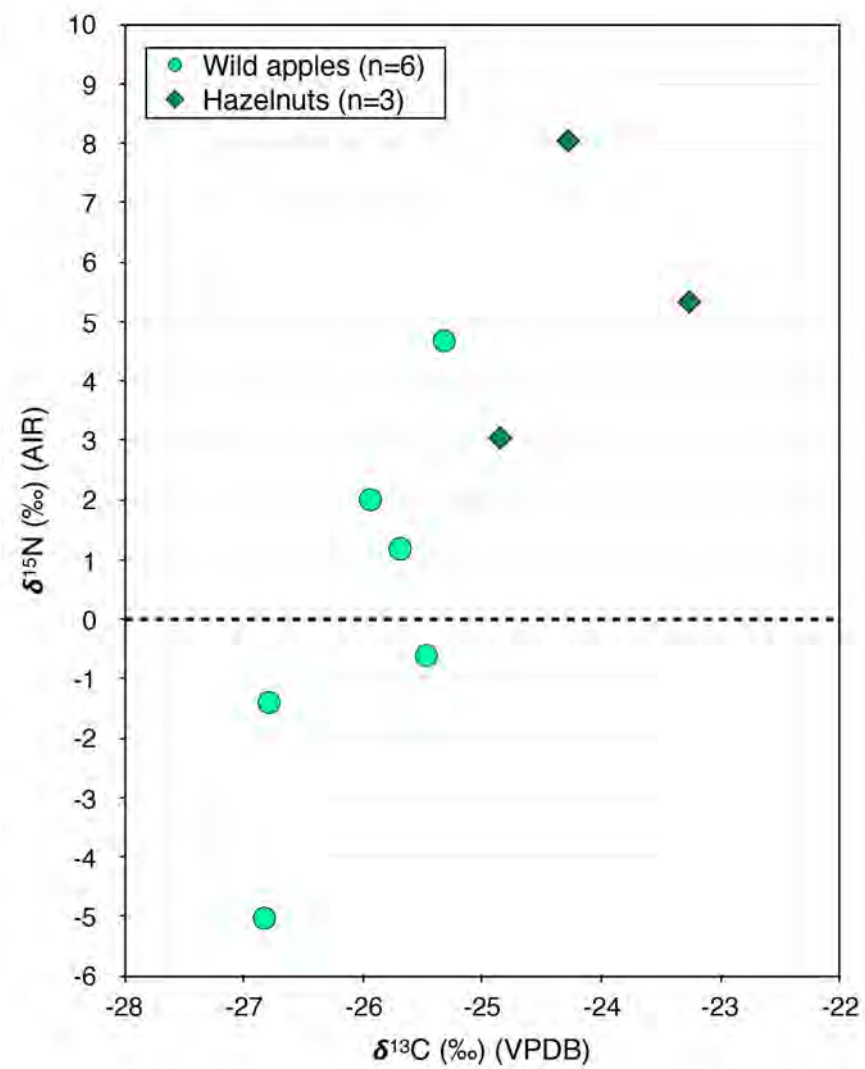


Fig. 3. Dispersion of Mesolithic charred plant $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values from Aizpea.

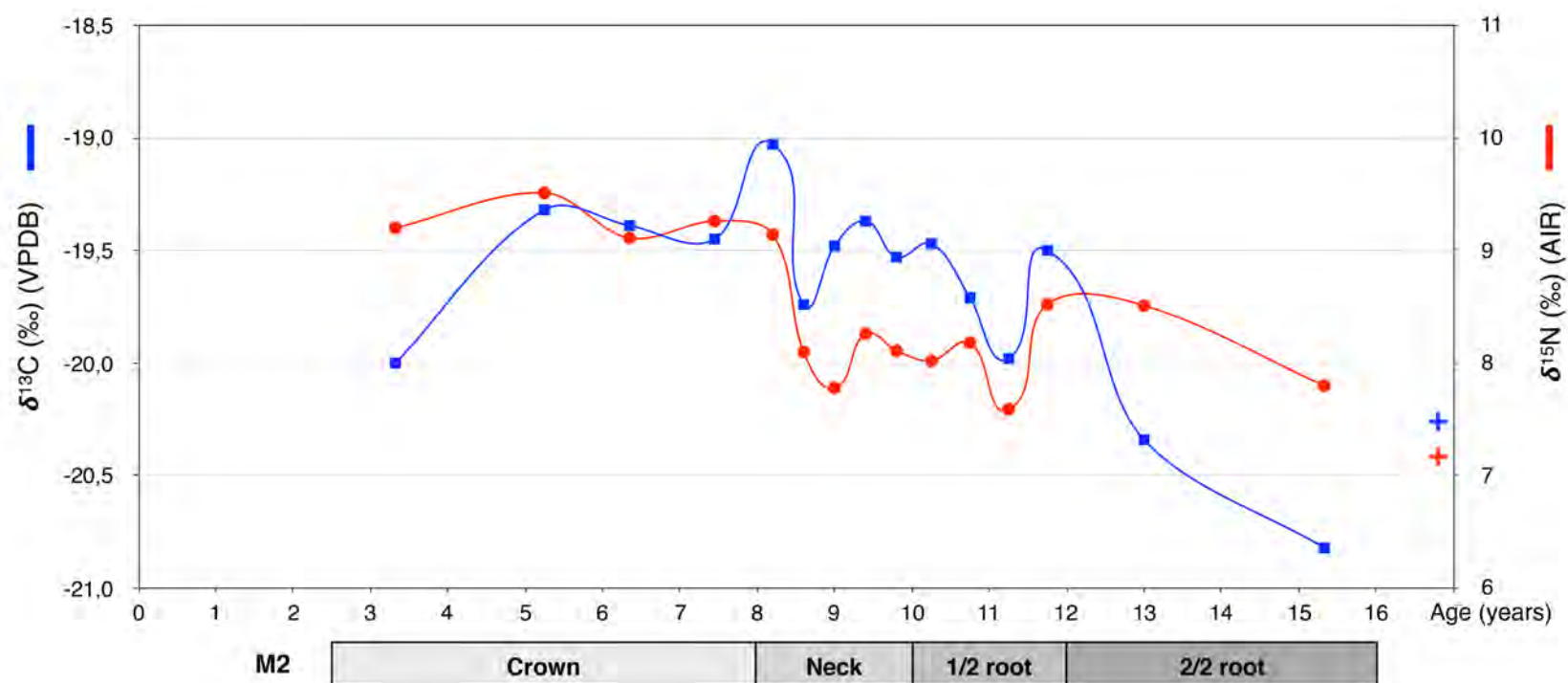


Fig. 4. Sequential dentine collagen $\delta^{13}\text{C}$ (blue squares) and $\delta^{15}\text{N}$ (red circles) results obtained from the permanent maxillary right second molar of Aizpea's Mesolithic skeleton. Isotope values obtained on the bone collagen of the same individual at adulthood are shown for reference (blue cross for $\delta^{13}\text{C}$ and red cross for $\delta^{15}\text{N}$). A schematic graph of tooth anatomy has been included at the bottom to illustrate age alignment of dentine samples (AlQahtani et al., 2010).

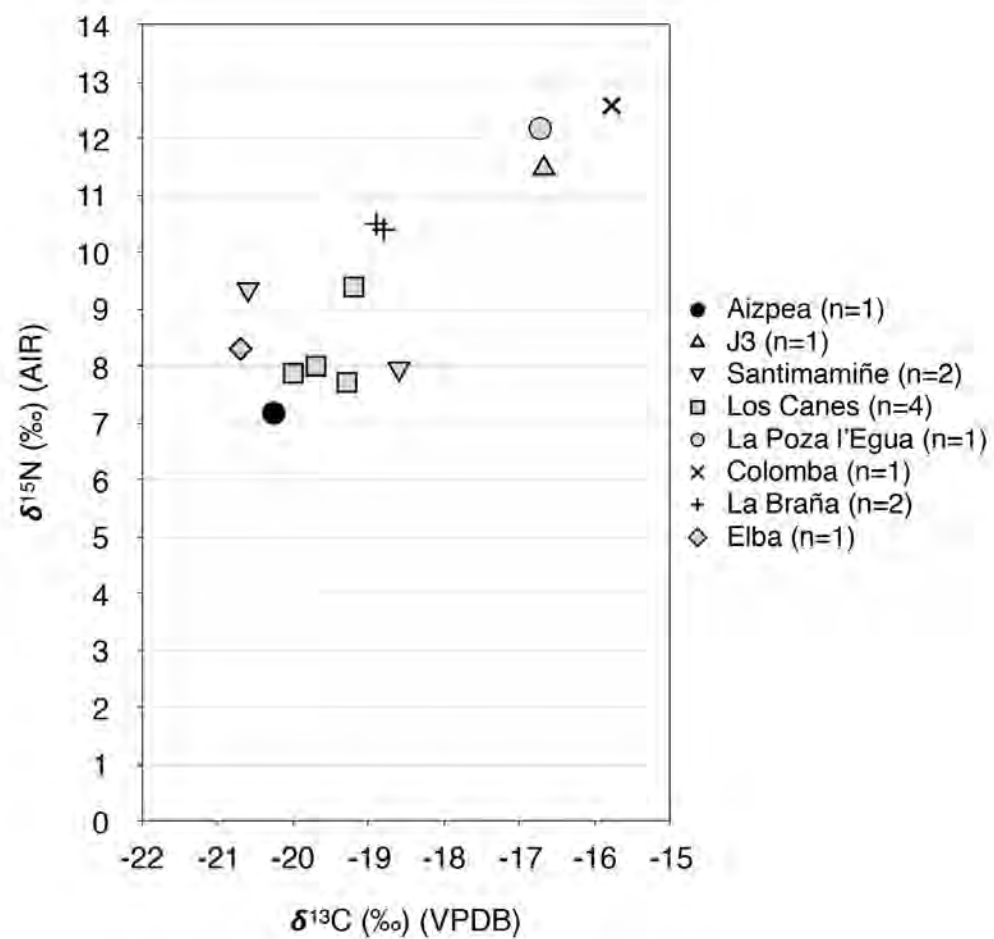


Fig. 5. Dispersion of bone collagen $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values from Mesolithic individuals of northern Iberia. Values other than Aizpea's were obtained from available literature ([Arias, 2005](#); [Arias and Schulting, 2010](#); [Grandal and Amalia, 2017](#); [Sarasketa-Gartzia et al., 2018](#)).



Fig. 6. Caries documented in the mandibular right third molar and second premolar, and left first premolar and second molar of Aizpea's Mesolithic skeleton. Other caries have been documented in the mandibular right first, right second and left third molars, and in the maxillary left second premolar and both left and right second molars ([de-la-Rúa, 2001](#)).

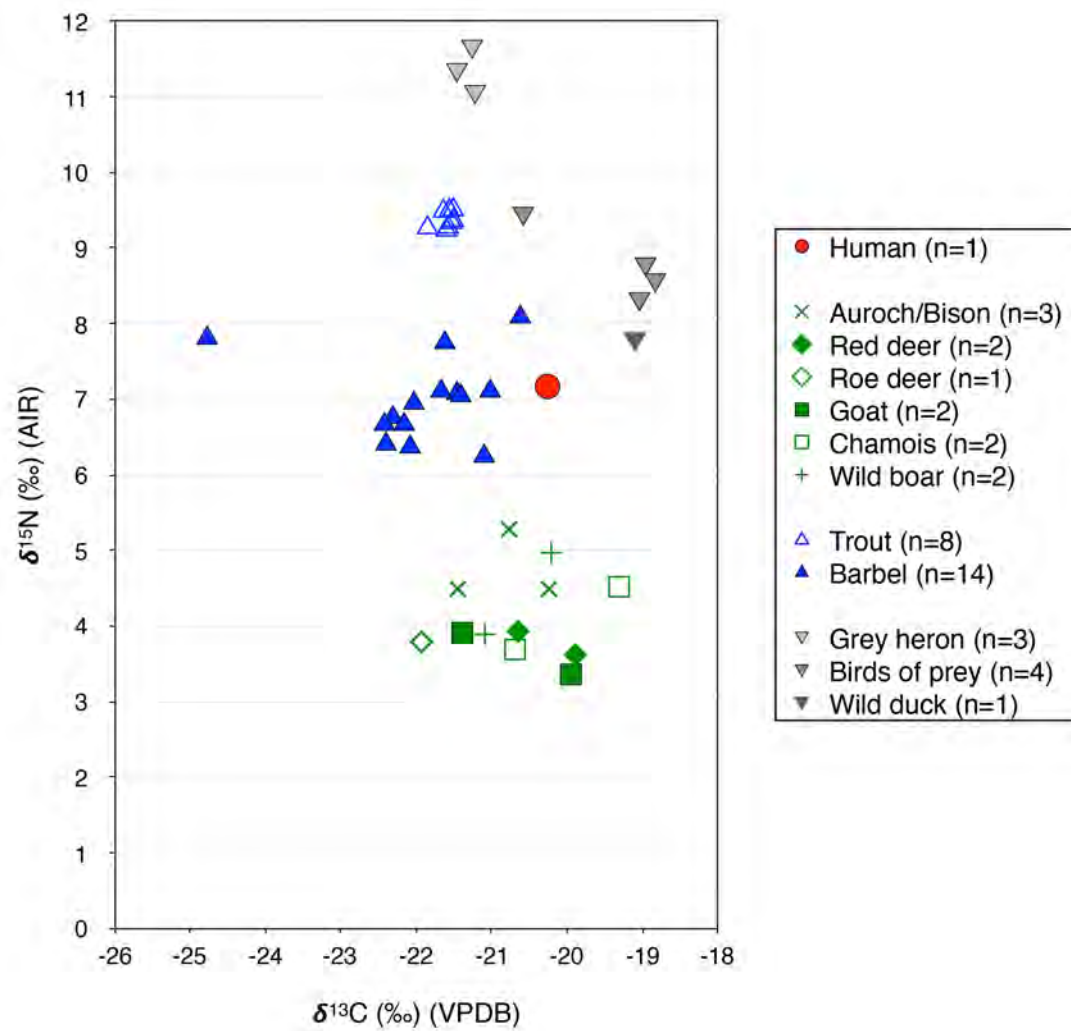


Fig. 7. Dispersion of Mesolithic human and animal bone collagen $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values from Aizpea, sorted by species.

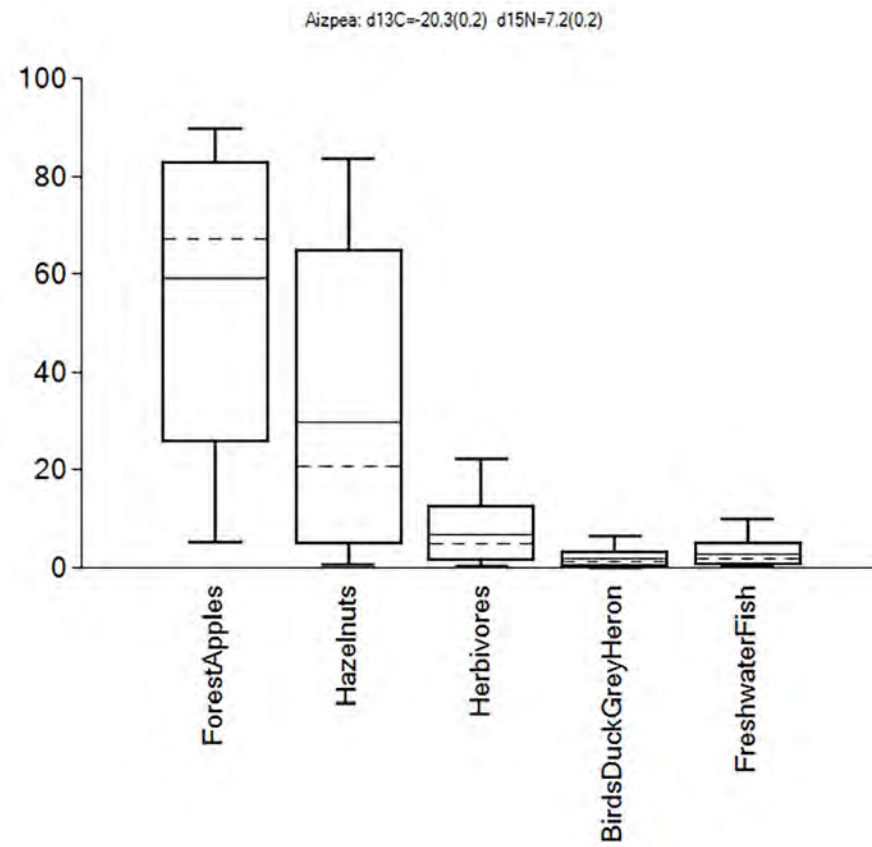


Fig. 8. Box plot results obtained from using Bayesian mixing model software FRUITS to model the Aizpea individual's diet.

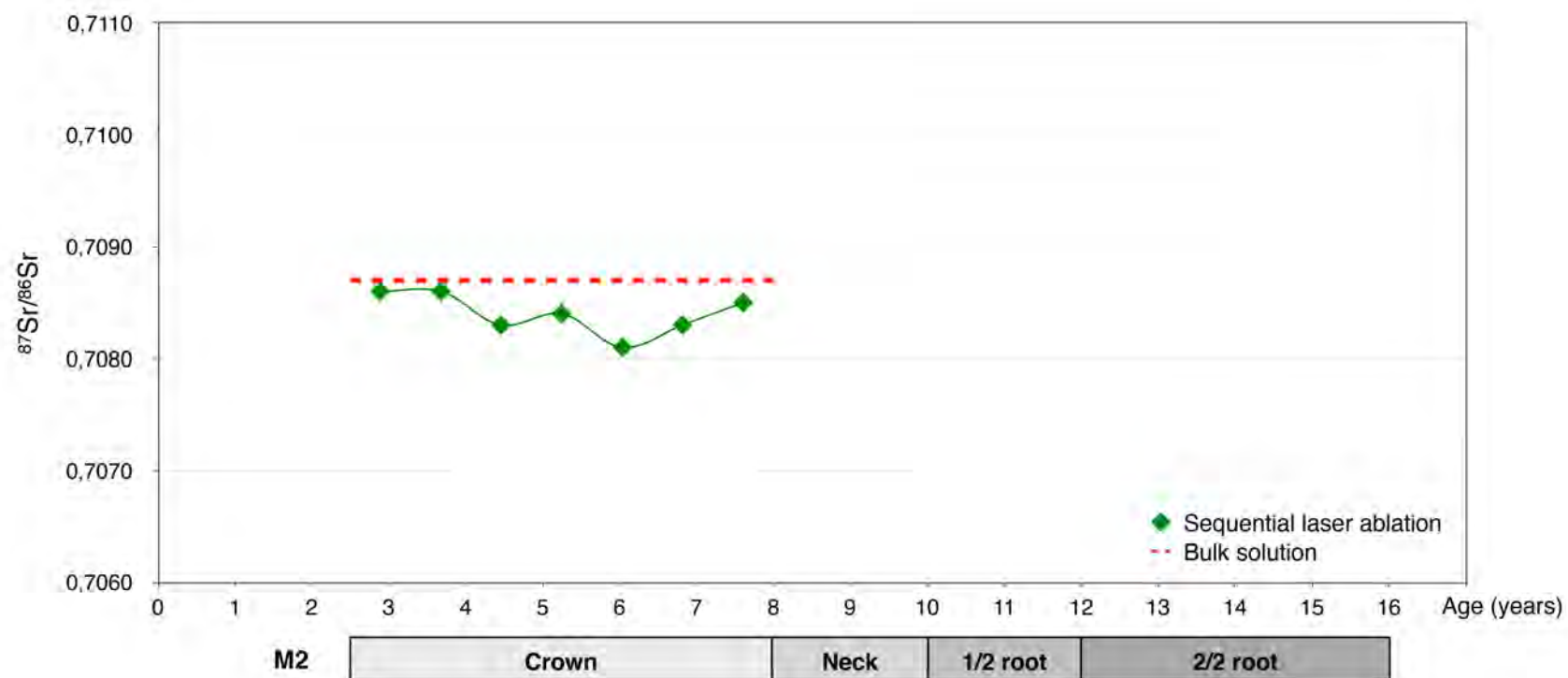


Fig. 9. Sequential and bulk enamel apatite $^{86}\text{Sr}/^{88}\text{Sr}$ results obtained from the crown of the permanent maxillary right second molar of Aizpea's Mesolithic skeleton. A schematic graph of tooth anatomy has been included at the bottom to illustrate age alignment of dentine samples ([AlQahtani et al., 2010](#)).

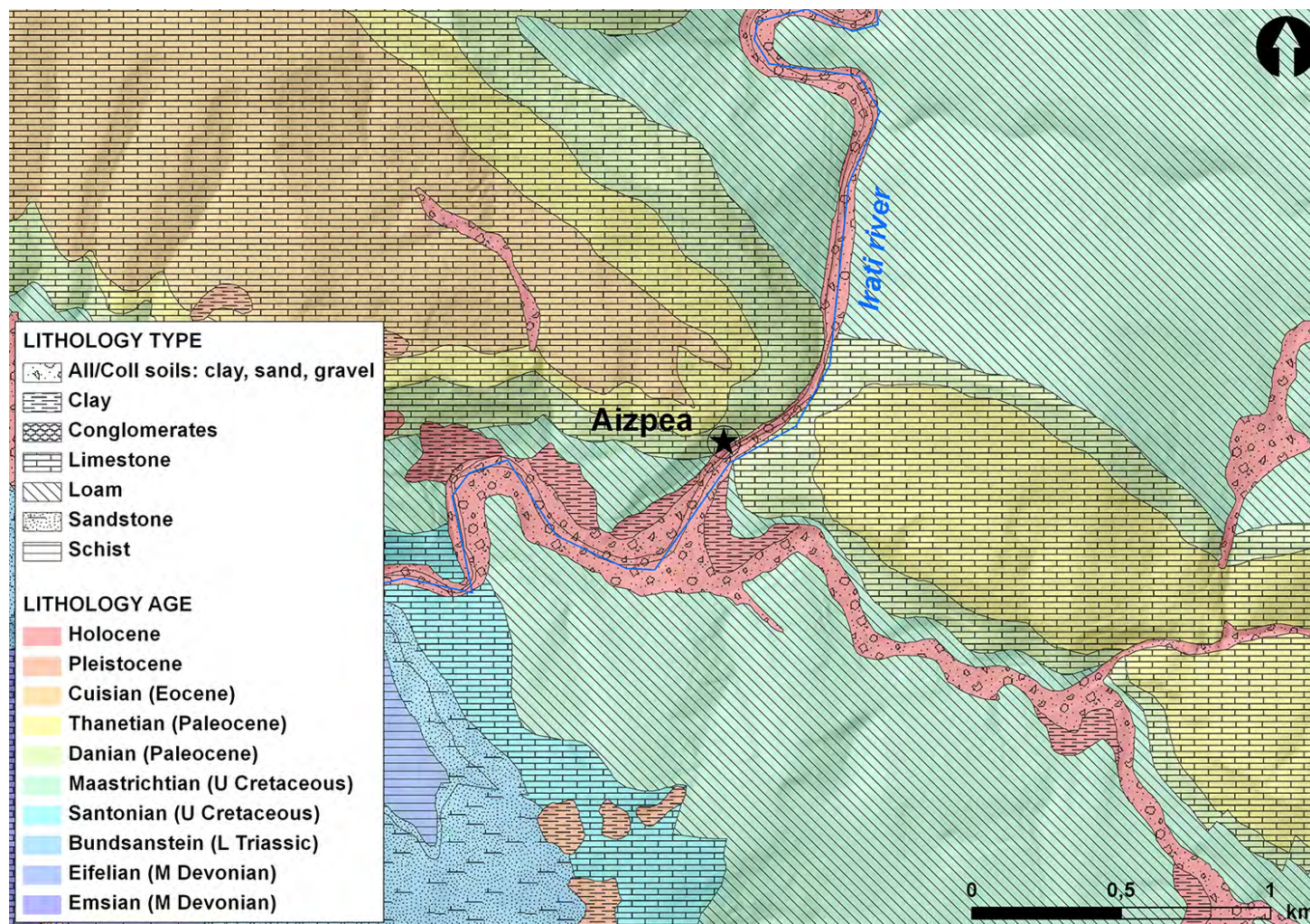


Fig. 10. Geological formations of Aizpea rockshelter's immediate region, sorted by type and age.