



Isotopic evidence of strong reliance on animal foods and dietary heterogeneity among Early-Middle Neolithic communities of Iberia

Teresa Fernández-Crespo^{1,2} · Rick J. Schulting¹ · Javier Ordoño³ · Manuel A. Rojo-Guerra⁴ · Jesús Sesma-Sesma⁵ · Jesús García-Gazólaz⁵ · Jesús Altuna⁶ · Koro Mariezkurrena⁶ · Pablo Arias⁷

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Abstract

Stable carbon and nitrogen isotope research on past populations in the Iberian Neolithic has emphasized the Atlantic and Mediterranean coasts. This study provides the first isotopic insights into the diet and subsistence economy of Early and Middle Neolithic populations from open-air sites in interior north-central Iberia. We present bone collagen carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$) isotope ratios for 44 humans and 33 animals recovered from six cemeteries of the Ebro valley and the northern Iberian Plateau. The results obtained are consistent with the C_3 terrestrial diets typical of other contemporary south-western European populations, but the spacing between human and herbivore values from Los Cascajos and Paternanbidea sites is higher than expected, and a significant positive correlation is identified between the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ human values at both. Moreover, the results clearly differ from those of the Late Neolithic/Early Chalcolithic in the same region, which show significantly lower $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values. These findings contribute to an understanding of the implementation of an agro-pastoral economy in interior Iberia, suggesting a stronger reliance on animal foods among the first Neolithic groups of inner Iberia than in subsequent periods as well as differential access to some resources (possibly suckling herbivores) in the diet, which may point to the existence of early social or economic inequalities that do not seem to be linked to age and sex parameters or to mortuary treatment.

Keywords Subsistence · Stable isotopes · Carbon · Nitrogen · Socioeconomic inequality · Early-Middle Neolithic · Interior Iberian Peninsula

Introduction

Stable isotope-based palaeodietary reconstructions have made a series of important contributions to the study of European Neolithic subsistence and the dietary changes

associated with the adoption of an agro-pastoral economy. They have played a pivotal role in challenging notions of a gradual uptake of domesticated resources, identifying a marked shift from marine to terrestrial diets along the Atlantic coastline coinciding with the Mesolithic-

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✉ Teresa Fernández-Crespo
teresa.fernandez-crespo@arch.ox.ac.uk

¹ School of Archaeology, University of Oxford, 1 South Parks Road, Oxford OX1 3TG, UK

² Department of Genetics, Physical Anthropology and Animal Physiology, University of the Basque Country (UPV/EHU), Barrio Sarriena s/n, 48940 Leioa, Spain

³ Department of Archaeology and New Technologies, Arkikus, Pedro de Asúa 63, 01008 Vitoria-Gasteiz, Spain

⁴ Department of Prehistory and Archaeology, University of Valladolid, Plaza del Campus s/n, 47011 Valladolid, Spain

⁵ Dirección General de Cultura, Gobierno de Navarra, Pamplona, Spain

⁶ Arkaios Investigaciones, Mendigain 30, 20014 Donostia-San Sebastián, Spain

⁷ International Institute for Prehistoric Research of Cantabria (IIIPC), University of Cantabria, Government of Cantabria, Avenida de los Castros s/n, 39005 Santander, Spain

Neolithic transition (Richards et al. 2003; Schulting 2013). Equally stable isotope analysis has also been used to confront the idea of dietary homogeneity across Europe, of a single Neolithic way of life (Hedges et al. 2013; Raemaekers 2014; Schulting 2018).

North-central Iberia holds one of the largest Early and Middle Neolithic skeletal populations found in Spain. Their analysis provides an invaluable source for understanding the adoption of a new subsistence economy in the region. Here we present a stable isotope dataset of 44 human and 33 animal remains from six funerary sites, located in the mid-upper Ebro valley (Los Cascajos, Paternanbidea, Llano del Montico and La Lámpara), which constitutes an important corridor for the spread of the Neolithic from the Mediterranean coast into the interior of the Peninsula (Bernabeu et al. 2015; Isern et al. 2017), and the northern Iberian Plateau (Molino de Arriba and Fuente Celada) (Fig. 1). A large number of the human individuals included in the study (23 of 44) have been directly AMS ^{14}C dated (Fig. 2), providing good chronological control, and the faunal remains are closely associated with the burials. The results, the first to be reported for the Early and Middle Neolithic open-air sites of these regions, are discussed in the context of dietary adaptations in the wider Iberian record.

Neolithization and open-air sites in north-central Iberia

Open-air settlements are a key feature in the Early and Middle Neolithic record of north-central Iberia (6th–4th millennia cal. BC). The fact that they were generally situated on or near wetlands, endorheic depressions and shores of lakes, lagoons or marshes, favouring both arable plots and pastures has prompted the suggestion of a ‘leapfrog colonization’ by small Neolithic groups targeting optimal biotopes in the region (Bernabeu et al. 2015; García-Martínez de Lagrán 2015, 2018). These incoming pioneers would have arrived at the Iberian Peninsula around the mid-6th millennium and interacted with local Mesolithic groups, generating new communities that in turn contributed to the spread of farming across the region in the following centuries (Rojo-Guerra et al. 2008; Alday 2012; Rojo-Guerra et al. 2016). Although the contributions of indigenous groups in the process must not be underestimated (Utrilla et al. 1998; Alday 2005), nDNA and mtDNA sequences now available for Iberia show a clear separation in the ancestry of Holocene hunter-gatherers and that of Neolithic population (Gamba et al. 2012; Sánchez-Quinto et al. 2012; Hervella et al. 2014; Olalde et al. 2015; Lazaridis et al. 2016), supporting a greater genetic input of farmers, as observed across Europe.

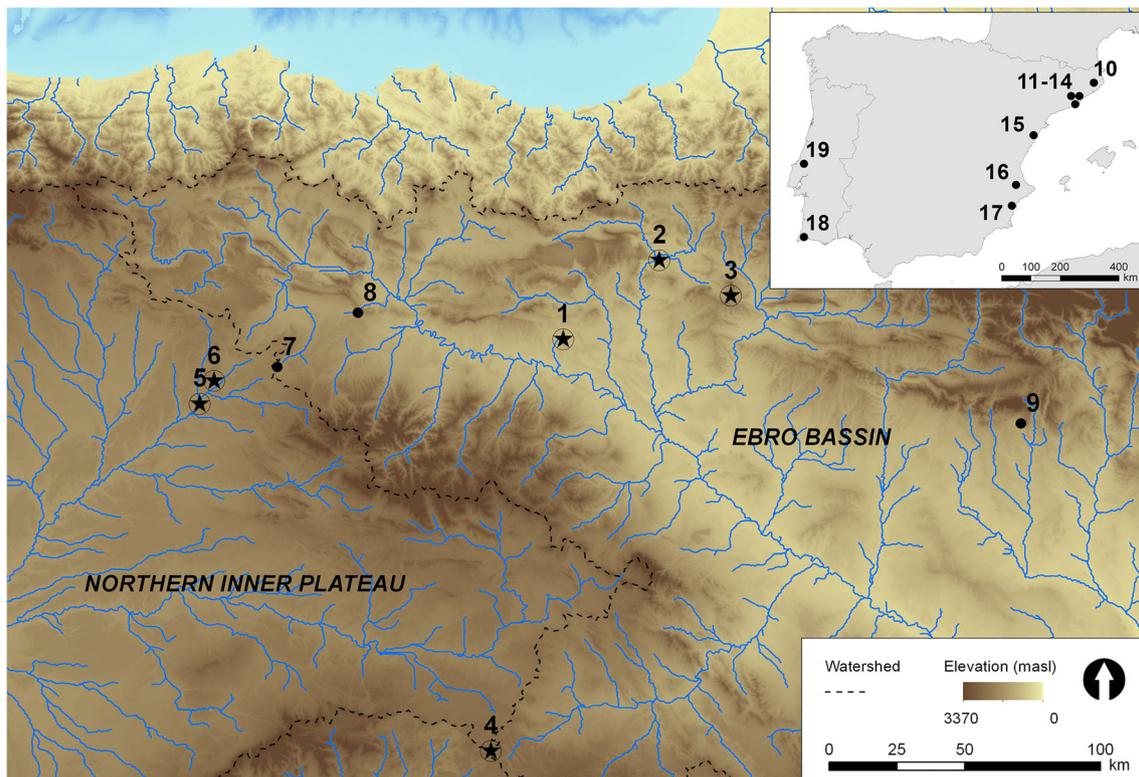
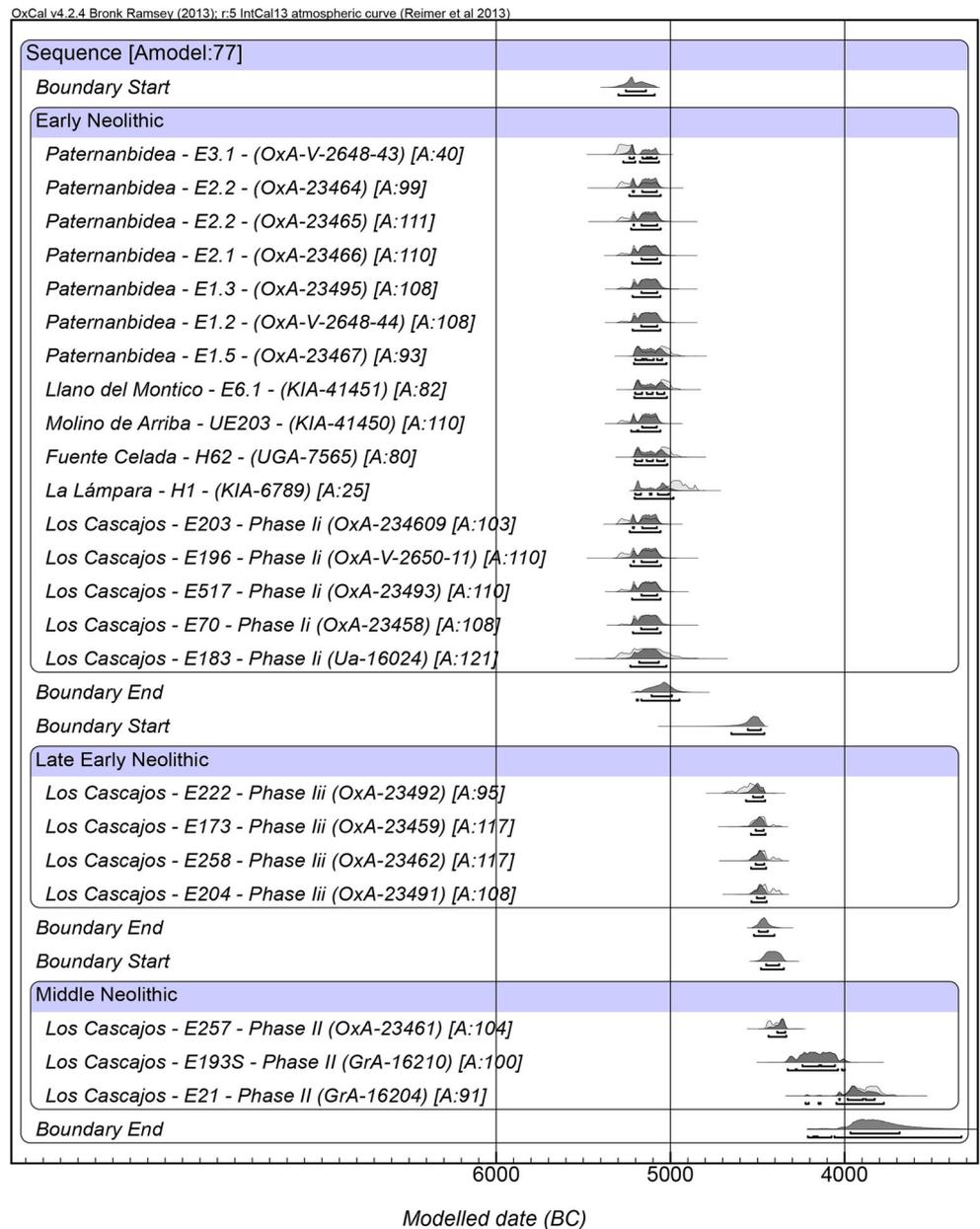


Fig. 1 Map showing the location of the study area in north-central Spain, with reference to the archaeological sites mentioned in the text: (1) Los Cascajos; (2) Paternanbidea; (3) Llano del Montico; (4) La Lámpara; (5) Molino de Arriba; (6) Fuente Celada; (7) Alto de Rodilla; (8) El Prado; (9)

Chaves; (10) Puig d'en Roca; (11) Horts de Can Torras; (12) Can Roqueta-Can Revella; (13) Can Gambús; (14) La Bòbila Madurell; (15) Costamar; (16) Cova de la Sarsa; (17) Tossal de les Basses; (18) Castelo Belinho; (19) Cadaval

Fig. 2 Bayesian model of the radiocarbon dates available for the human burials of the six Early and Middle Neolithic north-central Iberian sites under study. Radiocarbon dates include those in the published literature (Rojo-Guerra and Kunst 1999; García-Gazólaz and Sesma-Sesma 2007; Palomino et al. 2011; Sesma-Sesma et al. 2009; Alameda et al. 2011), recent measurements obtained from Llano del Montico, Molino de Arriba and Los Cascajos (Rojo-Guerra et al. 2016; Fernández-Crespo et al. 2019) and unpublished results from Paternanbidea. The periods have been modelled as simple phases with single boundaries using OxCal4.2 (Bronk Ramsey 2009; Reimer et al. 2013)



Within the context of Holocene climatic fluctuations, the Early-Middle Neolithic period in north-central Iberia experienced a Continental or Continental/Mediterranean temperate phase, with a landscape dominated by meso-thermophilic mixed forests, principally composed of hazel, birch and to a lesser degree oak, and some shrubs together with humid meadows (Rofes et al. 2013). The emergence of anthropogenic pastures, supported by the presence of nitrophilous species and coprophilous fungi in the palynological records, has been interpreted as a progressive depletion of forests and their substitution by open areas (Fernández-Eraso et al. 2015; Pérez-Díaz et al. 2015). The available local palaeobotanical record shows the cultivation of naked and hulled varieties of both wheat (emmer: *Triticum dicoccum*; einkorn: *Triticum*

monococcum; bread wheat: *Triticum aestivum/durum*) and barley (*Hordeum vulgare*), while legumes such as lentil (*Lens culinaris*), bitter and common vetch (*Vicia ervilia/sativa*), and other typically early Neolithic domesticates, such as flax (*Linum usitatissimum*) or opium poppy (*Papaver somniferum*), are almost absent (Zapata et al. 2004; Stika 2005; Iriarte 2009). The main evidence for the exploitation of wild plants comes from hazelnut (*Corylus avellana*) shells and acorn (*Quercus* sp.) cotyledons. Although relatively less abundant, fruit remains, such as crab apple (*Malus sylvestris*), whitebeam, wild service tree or rowan (*Sorbus* sp.), dogwood (*Cornus sanguinea*) and wild grape (*Vitis* sp.), have also been identified (Zapata 2000; Peña-Chocarro et al. 2005; Peña-Chocarro et al. 2013). Moreover, some nearby Cantabrian

sites highlight the importance of wild plant exploitation not only as potential food but also for medicinal, fuel and technological uses (Cubas et al. 2016).

As regards animal husbandry, the evidence in open-air settlements of the mid-upper Ebro valley displays a clear predominance of cattle, followed by domestic ovicaprines, swine and a few wild animals (mainly red deer, roe deer, horse and wild boar) (e.g. La Renke (Altuna and Mariezkurrena 2001), Los Cascajos (Altuna and Mariezkurrena 2009)). By contrast, caves and rockshelters of the region either do not have domestic livestock, suggesting their use as logistical hunting camps (e.g. Mendandia (Castaños 2005)), or their faunal record is dominated by ovicaprines, suggesting their use as pens (e.g. Chaves (Castaños 2004), Los Husos II (Polo and Fernández-Eraso 2008), Els Trocs (Rojo-Guerra et al. 2013)). But, even in the latter case, caves and rockshelters usually show a notable exploitation of wild ungulates (Altuna 1980), especially deer (e.g. Peña Larga (Castaños 1997), Chaves (Castaños 2004)). In the open-air settlements of the northern Iberian Plateau, however, the large number of remains of domestic sheep and goat (in comparison with those of cattle) found suggests that ovicaprid flocks would have played a major role in the economy of this region (e.g. La Lámpara, La Revilla (Montero and Liesau 2008; García-Martínez de Lagrán 2012)).

Together with open-air sites, pit-grave cemeteries have been considered an important feature of the Early and Middle Neolithic in Iberia (Rojo-Guerra et al. 2016), though caves are also used for burial (e.g. Chaves (Utrilla et al. 2008)) or ritualized skeletal deposits (e.g. Els Trocs (Rojo-Guerra et al. 2013)).

The exceptional collection of pit graves at *Los Cascajos* (Navarre) was found within an impressive Neolithic open-air settlement. Excavations uncovered a wide range of features, including post-holes for oval or circular huts/houses and fences for enclosing livestock, storage and combustion structures, enclosures and burial pits. A total of 36 individuals, with a predominance of adult and juvenile males (64%), were recovered from 30 single and three double graves grouped in a cemetery comprising 22 graves, with the remaining 11 graves found scattered across the site (García-Gazólaz and Sesma-Sesma 2007). Skeletons were normally laid out in lateral (60%) and supine (30%) positions and facing SE-SW. Grave goods were generally scarce and, when present, consisted of pottery vessels, flint tools, milling stones, polished axes and shell and bone beads. The presence of domestic fauna, wheat and barley, as well as grinding stones and storage features, confirms the agrarian nature of the settlement (García-Gazólaz and Sesma-Sesma 2001; Peña-Chocarro et al. 2005). Available archaeological data and radiocarbon dates indicate two different Neolithic phases of funerary use: the earliest, phase I, belongs to the Early Neolithic and is divided into two subphases, one spanning 5300–5000 cal. BC (subphase Ii) and the other 4650–4400 cal. BC (subphase Iii), whereas the latest or phase II is attributed to the Middle Neolithic, 4200–3500 cal. BC (Fernández-Crespo et al. 2019) (cf. Fig. 2).

Paternanbidea (Navarre) is another important cemetery located some 45 km from Los Cascajos with a single Early Neolithic phase of funerary use dated to the late 6th millennium cal. BC (ca. 5300–5000 cal. BC). It held a minimum of 13 individuals in three double graves and one multiple pit grave grouped in an area of 50 m² (García-Gazólaz 2007). There is a clear predominance of adults (85%) but more parity between the sexes (four males vs. three females and two probable females). Skeletons, when articulated, were in supine (38%) or lateral (15%) positions and facing SE-NW, E-W or NE-SW. Grave goods are rich, particularly in pendants and shells, bone and green stone beads for necklaces and bracelets, together with some pottery bowls, geometric microliths, flint blades and rock crystal prisms. Very limited faunal remains were recovered, though the excavation did not extend to a possible settlement area.

In addition, a number of Early Neolithic burials exhibiting similar funerary patterns have been documented in north-central Iberia. The majority has been excavated as a result of rescue campaigns and, despite belonging to potential open-air settlements or necropolises of different sizes, usually only one or two pit graves have been identified. This is the case with *Llano del Montico* in Navarre (Rojo-Guerra et al. 2016); *Molino de Arriba* (Palomino et al. 2011), *Fuente Celada* (Alameda et al. 2011), *El Prado* (Alonso and Jiménez 2014) and *Alto de Rodilla* (Alonso and Jiménez 2015) in Burgos; and *La Lámpara* (Rojo-Guerra and Kunst 1999) in Soria. The interred are usually adults (7 of 8) of both sexes (4 males, 3 females), laid out in mainly lateral or supine positions, facing preferentially SE and with scarce grave goods (Rojo-Guerra et al. 2016). The principal exception is *La Lámpara*, interpreted as a storage structure repurposed as a tomb, in which a mature woman was buried together with an elaborately decorated ceramic bottle and a flint blade. Also found in the tomb were 246 pottery fragments, 92 flint elements, three bone tools and a few faunal remains, suggesting a relatively complex funeral ceremony (Rojo-Guerra et al. 2008).

Material and methods

A total of 50 human samples were selected for analysis. They derive from Los Cascajos ($n = 35$), Paternanbidea ($n = 10$), Llano del Montico ($n = 2$), Fuente Celada ($n = 1$), Molino de Arriba ($n = 1$) and La Lámpara ($n = 1$). Skeletal remains are relatively well preserved, although some were found partially commingled and fragmented due to different taphonomic processes as well as to ritual practices. In the case of multiple graves, sampling was carried out ensuring that each sample corresponded to a unique individual.

In addition, 38 faunal samples from terrestrial herbivores and omnivores were included in the study to ascertain variability in baseline isotopic signatures in the region. They were closely associated with the human burials (i.e. recovered either

from the same grave or from other pits dated to the same period) and come from Los Cascajos ($n = 27$), Paternanbidea ($n = 10$) and La Lámpara ($n = 1$). Of these, at least nine are non-adult specimens and another five may show a non-adult isotopic signal since the sample was taken from tooth dentine. The sample size is relatively small and biased towards the two large sites due to the absence of animal remains in most of the small sites.

Samples of between 500 and 800 mg were exclusively taken from bone in humans, and from bone or dentine in fauna. Collagen extraction was carried out following a modified Longin (1971) method as described by Richards and Hedges (1999). Some samples from Los Cascajos and Paternanbidea that had previously been radiocarbon dated underwent a 30-kD ultrafiltration step (Brock et al. 2010). Extracted collagen was measured in duplicate in a Sercon 20/22 continuous flow isotope ratio mass spectrometer coupled with an elemental analyzer at the Research Laboratory for Archaeology and the History of Art, University of Oxford. Analytical precision is $\pm 0.2\text{‰}$ (1σ) for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ based on repeated analysis of standards. Results were calibrated using a two-point calibration with internal cow and seal bone collagen standards bracketing the range of archaeological samples (cf. Coplen et al. 2006). Collagen quality was assessed according to several preservation criteria: collagen yield $> 1\%$, $\%C = 30\text{--}44\%$, $\%N = 11\text{--}16\%$ and $C:N = 2.9\text{--}3.6$ (DeNiro 1985; Ambrose 1990; van Klinken 1999; Harbeck and Grupe 2009).

Statistical analyses were performed using IBM SPSS software for Windows v17. Z -scores were initially calculated to detect the presence of outliers. Shapiro-Wilk tests were used to test whether or not the data were normally distributed. Student's t tests were employed to compare means between two sample groups when the data did not depart significantly from a normal distribution, and Mann-Whitney's U test when they did. Finally, Pearson's r^2 and Spearman's rho coefficients were both used to assess correlations, with the latter being more appropriate for non-linear relationships. A significance level of $\alpha = 0.05$ was used for all statistical tests.

Results

Collagen preservation

The majority of the human samples analyzed provided well-preserved collagen according to the abovementioned quality criteria (Tables 1 and 2). However, six samples from Los Cascajos did not yield any collagen, and another three, despite having C:N ratios within the accepted range, gave collagen yields lower than 1%. This seems to have had a small but significant impact on $\delta^{13}\text{C}$ values, providing an average of $-19.7 \pm 0.4\text{‰}$ for these three samples compared with that of $-19.3 \pm 0.3\text{‰}$ for the remaining 26 individuals at the site ($t =$

2.22 , $df = 27$, $p = 0.035$). The effects of including or excluding these samples have been considered, and they have been retained in subsequent analyses, since observed differences (a) are relatively small, on the order of 0.5‰ or less; (b) do not affect any patterns with regard to age, sex, location or chronology among the individuals; and (c) affect $\delta^{13}\text{C}$ values only, showing no divergences in $\delta^{15}\text{N}$. Moreover, 13 samples (eight from Los Cascajos, two from Paternanbidea and one each from Llano del Montico, Molino de Arriba and Fuente Celada) exhibit $\%C$ and/or $\%N$ values slightly below or above the generally accepted limits but have acceptable C:N ratios and collagen yields. Since they were found not to substantially alter the results (individual Z -scores generally < 1.0 ; Student's t tests, $p > 0.05$), they were also retained. Comparison between samples including the 30-kD ultrafiltration step and those that do not shows no significant difference, which is consistent with previous studies (Hull 2008; Sealy et al. 2014). The faunal collagen quality indicators show more variable preservation, particularly for Los Cascajos, seemingly linked to the considerable taphonomic deterioration documented in the faunal remains (Altuna and Mariezkurrena 2019), which was probably caused by their deposition in relatively shallow features compared with the funerary pits. Five faunal samples yielded C:N ratios above 3.6 and were excluded from the analysis. Sixteen samples exhibiting collagen yields, $\%C$ and/or $\%N$ values below the generally accepted limits were retained, given that their $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ average values proved not to be significantly different from those samples showing acceptable collagen preservation (e.g. t test for Los Cascajos domestic herbivores: $\delta^{13}\text{C}$: $t = 1.05$, $df = 15$, $p = 0.313$; $\delta^{15}\text{N}$: $t = 0.28$, $df = 15$, $p = 0.784$). In summary, a total of 11 samples were therefore excluded, leaving 44 humans and 33 fauna for further analysis.

Faunal isotope data

The $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ ratios for herbivores and omnivores are consistent with expectations for a temperate C_3 ecosystem (DeNiro and Epstein 1978; Schwarcz and Schoeninger 1991) (Table 1). No significant differences are found in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values between domestic bovines and ovicaprids, providing a combined average of $\delta^{13}\text{C} = -20.6 \pm 0.3\text{‰}$ and $\delta^{15}\text{N} = 5.7 \pm 1.4\text{‰}$ at Los Cascajos and of $\delta^{13}\text{C} = -20.3 \pm 0.2\text{‰}$ and $\delta^{15}\text{N} = 5.0 \pm 0.7\text{‰}$ at Paternanbidea. The higher standard deviation for $\delta^{15}\text{N}$ results is due to the presence of a nursing signal in some samples belonging to immature individuals or being obtained from tooth dentine at Los Cascajos ($\delta^{15}\text{N}$ ca. $6\text{--}8\text{‰}$), yielding higher values than those of adult specimens, though only in the case of Bovidae does the difference attain statistical significance (Table A.1). The only values for auroch and wild horse are similar to those from adult domestic herbivores. The results for suids, whether wild (wild boar) or domestic (pig), are significantly higher than the

Table 1 Faunal isotopic values available for the six Early and Middle Neolithic open-air sites of north-central inner Spain studied

Site	ID	Pit	Phase	Species	Age ¹	Element	%Col ²	%C	%N	C:N	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)
Los Cascajos	CAS39	150	I	<i>Bos primigenius</i>	A	Metacarpal	0.6	29.5	10.7	3.2	-21.0	4.5
Los Cascajos	CAS34	25	I	<i>Bos taurus</i>	A?	Long bone	0.8	29.2	10.3	3.3	-20.5	4.7
Los Cascajos	CAS35	150	I	<i>Bos taurus</i>	A?	Long bone	1.6	35.3	12.7	3.2	-20.7	4.9
Los Cascajos	CAS36	96	II	<i>Bos taurus</i>	A	Metatarsal	1.7	41.8	14.5	3.4	-20.3	8.7
Los Cascajos	CAS37	199	II	<i>Bos sp.</i>	?	Long bone	0.9	28.6	9.9	3.4	-20.3	7.5
Los Cascajos	AtNeo-172	214	I	<i>Bos taurus</i>	A?	Bone collagen	*	11.8	3.9	3.5	-21.2	5.5
Los Cascajos	AtNeo-174	64	I	<i>Bos taurus</i>	?	Bone collagen	*	7.0	2.2	3.7	-21.1	4.4
Los Cascajos	AtNeo-175	572	I	<i>Bos taurus</i>	A	Scapula	0.1	1.3	0.2	7.4	-22.5	5.4
Los Cascajos	AtNeo-176	572	I	<i>Bos taurus</i>	A	Metacarpal	3.0	32.3	11.2	3.4	-20.7	4.4
Los Cascajos	AtNeo-177	572	I	<i>Bos taurus</i>	A	Mandible	5.3	27.8	9.4	3.4	-20.5	4.1
Los Cascajos	AtNeo-178	214	I	<i>Bos taurus</i>	A ³	Tooth	1.2	29.6	10.0	3.5	-20.7	5.8
Los Cascajos	AtNeo-179	214	I	<i>Bos taurus</i>	A?	Long bone	3.3	26.7	8.9	3.5	-21.1	5.7
Los Cascajos	AtNeo-189	572	I	<i>Bos taurus</i>	N? ³	Tooth	2.0	26.4	9.3	3.3	-20.5	7.4
Los Cascajos	AtNeo-173	265	II	<i>Ovis aries</i>	A?	Bone collagen	*	21.3	7.2	3.5	-20.2	4.5
Los Cascajos	AtNeo-185	214	I	<i>Ovis aries/Capra hircus</i>	A ³	Tooth	1.9	42.8	14.8	3.4	-20.2	6.5
Los Cascajos	AtNeo-180	572	I	<i>Ovis aries/Capra hircus</i>	A	Metatarsal	4.0	38.7	13.8	3.3	-20.4	3.8
Los Cascajos	AtNeo-181	572	I	<i>Ovis aries/Capra hircus</i>	?	Mandible	0.2	12.5	3.4	4.2	-21.3	5.3
Los Cascajos	AtNeo-182	572	I	<i>Ovis aries/Capra hircus</i>	A?	Phalanx	3.3	34.9	12.0	3.4	-20.7	5.0
Los Cascajos	AtNeo-183	572	I	<i>Ovis aries/Capra hircus</i>	N?	Humerus	1.1	19.3	5.9	3.8	-21.0	5.2
Los Cascajos	AtNeo-184	572	I	<i>Ovis aries/Capra hircus</i>	N?	Radius	0.1	15.5	3.9	4.6	-22.4	6.9
Los Cascajos	AtNeo-187	572	I	<i>Ovis aries/Capra hircus</i>	N? ³	Tooth	0.8	23.5	8.1	3.4	-20.3	6.9
Los Cascajos	AtNeo-188	572	I	<i>Ovis aries/Capra hircus</i>	A?	Radius	2.5	19.8	6.4	3.6	-20.7	5.1
Los Cascajos	CAS38	166	II	<i>Equus caballus</i>	?	Long bone	2.9	37.1	13.5	3.2	-20.6	4.2
Los Cascajos	AtNeo-186	214	I	<i>Sus domesticus</i>	A ³	Tooth	1.0	23.6	8.0	3.4	-20.7	8.4
Los Cascajos	CAS33	199	II	<i>Sus domesticus</i>	A	Mandible	0.3	24.1	8.4	3.3	-19.4	9.9
Los Cascajos	CAS31	96	II	<i>Sus scrofa</i>	N	Mandible	0.9	27.7	9.8	3.3	-19.4	9.5
Los Cascajos	CAS32	159	II	<i>Sus scrofa</i>	A	Mandible	0.5	29.3	9.8	3.5	-19.3	8.6
Paternanbidea	PAT10	E1		<i>Bos sp.</i>	A	Phalanx	4.1	39.5	14.3	3.2	-20.2	5.6
Paternanbidea	PAT13	E2		<i>Bos sp.</i>	N?	Long bone	10.4	42.5	15.4	3.2	-20.1	6.1
Paternanbidea	PAT16	E3		<i>Bos sp.</i>	A	Long bone	8.2	40.8	14.7	3.2	-20.2	4.7
Paternanbidea	PAT20	E4		<i>Bos sp.</i>	N?	Long bone	3.6	41.0	14.6	3.3	-20.6	6.1
Paternanbidea	PAT12	E1		<i>Ovis aries/Capra hircus</i>	A	Phalanx	10.2	44.0	15.9	3.2	-20.3	4.6
Paternanbidea	PAT14	E2		<i>Ovis aries/Capra hircus</i>	A	Vertebra	5.1	40.0	14.4	3.2	-20.4	4.2
Paternanbidea	PAT15	E2		<i>Ovis aries/Capra hircus</i>	N	Calcaneus	10.6	41.2	14.9	3.2	-20.3	4.9
Paternanbidea	PAT17	E3		<i>Ovis aries/Capra hircus</i>	N	Carpal	1.4	35.8	12.5	3.3	-20.4	4.2
Paternanbidea	PAT21	E4		<i>Ovis aries/Capra hircus</i>	N?	Tibia	7.3	38.4	13.9	3.2	-20.2	4.9
Paternanbidea	PAT19	E3		<i>Sus sp.</i>	A	Mandible	3.2	39.3	13.9	3.3	-20.8	5.8
La Lámpara	LAM3	E1(2)		<i>Ovis aries/Capra hircus</i>	A	Skull	4.2	43.6	15.0	3.4	-20.1	5.4

¹ N, non-adult; N?, probable non-adult; A, adult; A?, probable adult; ?, indeterminate

² Results shown in bold are those excluded from analyses for providing too high C:N ratios. The asterisks at the '%col' column indicate the impossibility of calculating the collagen yield for those samples coming from other laboratories (for having previously been used for radiocarbon dating)

³ Note that, in these cases, the isotopic measures correspond not to the age of death of the specimen but to the age where the sampled tooth was formed (i.e. non-adulthood)

Table 2 Isotopic values and radiocarbon dates available for the human burials of the six Early and Middle Neolithic open-air sites of north-central inner Spain studied

Site	ID	Pit	Phase	Age ¹	Sex ²	Element	%Col ³	%C	%N	C:N	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)	¹⁴ C date ⁴	± cal BC (95%)	Lab. ref.	
Los Cascajos	P27821	204	I	C (8–9)	I	Tibia	4.8	44.0	15.9	3.2	-18.6	11.2	5630	31	4531	OxA-23,491
Los Cascajos	CAS16	193I	II	C (12±3)	I	Mandible	0.8	29.2	9.9	3.5	-19.8	10.9				
Los Cascajos	P27827	203	I	J (13–14)	F	Tibia	5.4	44.9	16.1	3.3	-19.3	10.8	6221	33	5301	OxA-23,460
Los Cascajos	CAS24	206	I/II	J (15±3)	M	Mandible	-	-	-	-	-	-				
Los Cascajos	CAS15	193S	II	J (15±3)	M?	Mandible	5.2	39.6	14.3	3.2	-19.2	11.1	5330	60	4327	GrA-16,210
Los Cascajos	CAS26	254	I/II	J (15±3)	I	Skull	-	-	-	-	-	-				
Los Cascajos	CAS17	194	I	YA	M	Mandible	2.3	40.3	14.3	3.3	-19.2	10.2				
Los Cascajos	P27824	70	I	YA	M	Tibia	5.2	47.9	17.2	3.3	-19.5	9.8	6187	33	5282	OxA-23,458
Los Cascajos	P27825	173	I	YA	M	Tibia	1.8	42.8	15.2	3.3	-19.1	11.6	5655	33	4552	OxA-23,459
Los Cascajos	CAS7	90	I/II	YA	M	Mandible	1.9	34.8	12.4	3.3	-19.3	10.1				
Los Cascajos	CAS9	179	I/II	YA	M	Mandible	1.9	44.8	16.2	3.2	-18.9	11.5				
Los Cascajos	CAS10	180	I/II	YA	M	Mandible	1.8	34.1	12.2	3.3	-19.0	11.6				
Los Cascajos	CAS14	191	I/II	YA	M	Mandible	1.0	33.7	11.8	3.3	-19.7	9.9				
Los Cascajos	CAS22	202	I/II	YA	M	Mandible	2.6	36.8	14.1	3.1	-19.3	10.3				
Los Cascajos	CAS25	216	I/II	YA	M	Mandible	2.8	33.9	12.3	3.2	-19.4	10.9				
Los Cascajos	CAS2	21	II	YA	M	Mandible	-	-	-	-	-	-	5100	60	4039	GrA-16,204
Los Cascajos	CAS3	33	II	YA	M	Mandible	2.7	37.3	13.3	3.3	-19.1	11.1				
Los Cascajos	P27823	517	I	YA	M?	Tibia	5.5	49.6	18.0	3.2	-18.8	11.4	6199	33	5290	OxA-23,493
Los Cascajos	CAS12	182	I	YA	F	Mandible	-	-	-	-	-	-				
Los Cascajos	CAS27	258	I	YA	F	Mandible	3.1	37.7	13.4	3.3	-19.4	11.4	5643	33	4545	OxA-23,462
Los Cascajos	P27828	257	II	YA	F	Tibia	4.8	47.9	17.3	3.2	-18.9	11.1	5541	32	4450	OxA-23,461
Los Cascajos	CAS23	205	I/II	YA	I	Mandible	2.0	36.9	13.1	3.3	-19.3	11.3				
Los Cascajos	CAS13	183	I	MA	M	Skull	2.0	41.2	14.5	3.3	-19.0	11.3	6185	75	5311	Ua-16,024
Los Cascajos	CAS19	196	I	MA	M	Maxilla	1.6	33.3	11.7	3.3	-19.4	10.7	6214	39	5299	OxA-V-2650-11
Los Cascajos	P27822	222	I	MA	M	Tibia	5.5	45.2	16.5	3.2	-19.6	10.3	5711	32	4677	OxA-23,492
Los Cascajos	CAS4	48.1	I/II	MA	M	Mandible	3.2	35.9	12.7	3.3	-19.3	10.0				
Los Cascajos	CAS11	181	I/II	MA	M	Mandible	3.4	60.4	22.0	3.2	-18.8	12.0				
Los Cascajos	CAS30	341	I/II	MA	M	Mandible	0.3	18.4	5.9	3.6	-20.0	9.1				
Los Cascajos	CAS5	48.2	I	MA	F?	Mandible	1.0	24.2	8.1	3.5	-19.9	9.9				
Los Cascajos	CAS21	201	I/II	MA	F?	Mandible	-	-	-	-	-	-				
Los Cascajos	CAS6	73	I	IA	M	Fibula	0.3	21.5	7.3	3.4	-19.3	11.0				
Los Cascajos	CAS18	195	I/II	IA	M	Tibia	1.9	39.4	14.2	3.2	-19.7	9.6				
Los Cascajos	CAS8	148	I/II	IA	F?	Skull	-	-	-	-	-	-				
Los Cascajos	CAS28	262	I/II	IA	I	Long bone	2.4	40.5	14.4	3.3	-19.2	10.3				
Los Cascajos	CAS29	263	I/II	IA	I	Tibia	1.6	33.8	12.1	3.3	-19.8	9.0				

Table 2 (continued)

Site	ID	Pit	Phase	Age ¹	Sex ²	Element	%Col ³	%C	%N	C:N	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)	¹⁴ C date ⁴	± cal BC (95%)	Lab. ref.	
Paternambídea	P27838	E1.5		C (8±2)	I	\bar{x} (n = 29)	2.7	38.3	13.7	3.3	-19.3	10.7	6130	33	5211	OxA-23,467
	PAT6	E2.1		J (13–15)	F?	σ	1.6	8.7	3.3	0.1	0.3	0.8	6198	34	5291	OxA-23,466
Paternambídea	P27835	E2.2		J (13–15)	I	Min.	0.3	18.4	5.9	3.1	-20.0	9.0	6211	36	5296	OxA-23,465
	PAT3	E1.2		YA	M	Max.	5.5	60.4	22.0	3.6	-18.6	12.0	6191	33	5287	OxA-V-2648-44
Paternambídea	P27831	E4.1		YA	M		2.3	44.3	16.0	3.2	-19.3	10.3	6192	33	5288	OxA-23,463
Paternambídea	PAT4	E1.3		YA	F		2.5	34.2	12.3	3.3	-19.4	10.8	6192	33	5288	OxA-23,495
Paternambídea	P27834	E3.2		YA	F		6.5	43.5	15.8	3.2	-19.1	11.5	6224	35	5302	OxA-23,464
Paternambídea	PAT9	E4.2		YA	F		2.3	39.2	13.9	3.3	-19.5	11.7				
Paternambídea	PAT5	E1.4		YA	F?		3.0	35.8	12.8	3.3	-19.2	10.7				
Paternambídea	PAT8	E3.1		MA	M		3.0	37.7	13.2	3.3	-19.4	11.3	6267	33	5321	OxA-V-2648-43
						\bar{x} (n = 10)	3.2	38.0	13.6	3.3	-19.4	10.6				
						σ	1.4	5.4	2.1	0.1	0.2	0.8				
						Min.	1.6	26.3	8.9	3.2	-19.8	9.3				
						Max.	6.5	44.3	16.0	3.5	-19.1	11.7				
Llano del Montico	MON2	E6		MA	M		1.6	29.0	10.2	3.3	-19.5	10.2	6124	28	5209	4986
Llano del Montico	MON3	E6		MA	M		3.4	36.4	13.0	3.3	-19.4	10.3				KIA-41451
						\bar{x} (n = 2)	2.5	32.7	11.6	3.3	-19.4	10.2				
						σ	1.2	5.3	2.0	0.0	<0.1	0.1				
						Min.	1.6	29.0	10.2	3.3	-19.5	10.2				
						Max.	3.4	36.4	13.0	3.3	-19.4	10.3				
Molino de Arriba	MOL2	UE203		J (ca.18)	M		1.6	24.5	8.5	3.4	-19.8	9.3	6210	30	5293	5057
Fuente Celada	FUE2	H62		OA	M		2.3	30.5	10.7	3.3	-19.4	10.0	6120	30	5208	4961
La Lámpara	LAM2	H1		MA	F		1.4	33.6	11.6	3.4	-19.6	9.8	6055	34	5047	4848

¹ C, child; J, adolescent; YA, young adult; MA, mature adult; OA, older adult; IA, indeterminate adult. Non-adult age was determined based on dental development (Ubelaker 1989). Adult age was classified based on the pubic symphyseal and auricular surfaces (Brooks and Suchey 1990; Lovejoy et al. 1985) and tooth wear (Brothwell 1989)

² M, male; M?, probable male; F, female; F?, probable female; Indet., indeterminate. Sex estimation focused on the combination of coxal and cranial morphological indicators (Buikstra and Ubelaker 1994; Ferembach et al. 1980)

³ Isotopic results shown in bold are those samples excluded from further analyses for yielding no collagen

⁴ Radiocarbon dates include those published in the literature so far (Rojo-Guerra and Kunst 1999; García-Gazólaz and Sesma-Sesma 2007; Palomino et al. 2011; Sesma-Sesma et al. 2009; Alameda et al. 2011), recent measurements obtained from Llano del Montico, Molino de Arriba and Los Cascajos (Rojo-Guerra et al. 2016; Fernández-Crespo, Schulting and Arias 2019) and the unpublished results from Paternambídea. They have been calibrated using OxCal4.2 (Bronk Ramsey 2009; Reimer et al. 2013)

herbivores in both isotopes, as would be expected for an omnivorous diet (e.g. Los Cascajos: $\delta^{13}\text{C} \bar{x} = -19.7 \pm 0.6\text{‰}$; $\delta^{15}\text{N} \bar{x} = 9.1 \pm 0.7\text{‰}$).

Human isotope data

The $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ human values cluster reasonably tightly (Los Cascajos ($n=29$): $\delta^{13}\text{C} \bar{x} = -19.3 \pm 0.3$, $\delta^{15}\text{N} \bar{x} = 10.7 \pm 0.8$; Paternanbidea ($n=10$): $\delta^{13}\text{C} \bar{x} = -19.4 \pm 0.2$, $\delta^{15}\text{N} \bar{x} = 10.6 \pm 0.8$; Llano del Montico ($n=2$): $\delta^{13}\text{C} \bar{x} = -19.4 \pm 0.1$, $\delta^{15}\text{N} \bar{x} = 10.2 \pm 0.1$; Molino de Arriba ($n=1$): $\delta^{13}\text{C} = -19.8$, $\delta^{15}\text{N} = 9.3$; Fuente Celada ($n=1$): $\delta^{13}\text{C} = -19.4$, $\delta^{15}\text{N} = 10.0$; La Lámpara ($n=1$): $\delta^{13}\text{C} = -19.6$, $\delta^{15}\text{N} = 9.8$) (Table 2). However, there are certain additional aspects that are worth exploring.

Los Cascajos is the only site where the human and faunal results combined with archaeological and chronological data allow an intra-site analysis. That being said, no statistically significant differences are observed with regard to chronology (phases and subphases), location (necropolis or isolated) or type of pit-grave (single or double), body position (lateral or supine) and orientation, or the presence/absence of grave goods (Table A.2), nor are there any differences in the isotopic values concerning the sex of the interred. This is also the case at Paternanbidea, the other site whose sample size allows comparisons in this respect. Grouping the data from all the funerary contexts also reveals no significant sex-based differences (Table A.3). Regarding age, however, Los Cascajos non-adults (8–20 years old) exhibit values that are significantly higher than those of adults in $\delta^{15}\text{N}$ ($t=2.14$, $df=27$, $p=0.043$) though not in $\delta^{13}\text{C}$ (Table A.4). This trend is reversed in the nearby site of Paternanbidea, where non-adults show lower values than adults not only in $\delta^{15}\text{N}$ ($t=3.63$, $df=8$, $p=0.007$) but also in $\delta^{13}\text{C}$ ($t=3.45$, $df=8$, $p=0.009$).

Finally, we note the existence of a marked positive correlation between human $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values both at Los

Cascajos ($r^2=0.521$, $p<0.001$; $\rho=0.768$, $p<0.001$) and Paternanbidea ($r^2=0.503$, $p=0.022$; $\rho=0.488$, $p=0.153$). The correlation at Los Cascajos is also seen in the fauna ($r^2=0.452$, $p=0.001$; $\rho=0.475$, $p=0.026$) (Fig. 3) and persists even when the data are divided into the Early and Middle Neolithic phases. The small sample sizes of the other funerary contexts analyzed prevent the detection (or rejection) of such a correlation.

Discussion

The human $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values are broadly consistent with C_3 plant-based diets typical of the European Neolithic (Hedges et al. 2013; Schulting 2011) (Fig. 4), though this does still leave scope for intra- and inter-site variability. With regard to differences within sites, the only significant findings relate to age. It is possible that higher or lower non-adult $\delta^{15}\text{N}$ values seen in Los Cascajos and Paternanbidea, respectively, reflect compromised health status due to nutritional deficiencies or infectious diseases (Beaumont and Montgomery 2016), since these children and adolescents did not reach adulthood (cf. the ‘Osteological Paradox’ (Wood et al. 1992; DeWitte and Stojanowski 2015)). Moreover, it must be considered that bone collagen turnover rates are high in early infancy but decrease over the course of childhood into adolescence (Tsutsaya and Yoneda 2013), hence reflecting different time spans. Thus, periods of stress and starvation would be expected to have much greater isotopic visibility in non-adults than in adults. In any case, both the small samples of non-adults available (four at Los Cascajos and three at Paternanbidea) and the fact that no skeletal evidence for a higher prevalence of disease has been observed among these warrants caution in interpreting the observed isotopic differences. Although variability in climate factors at a local scale may be driving some small inter-site differences in isotopic values, especially with

Fig. 3 Positive correlation between $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values observed in both human and faunal samples at Los Cascajos

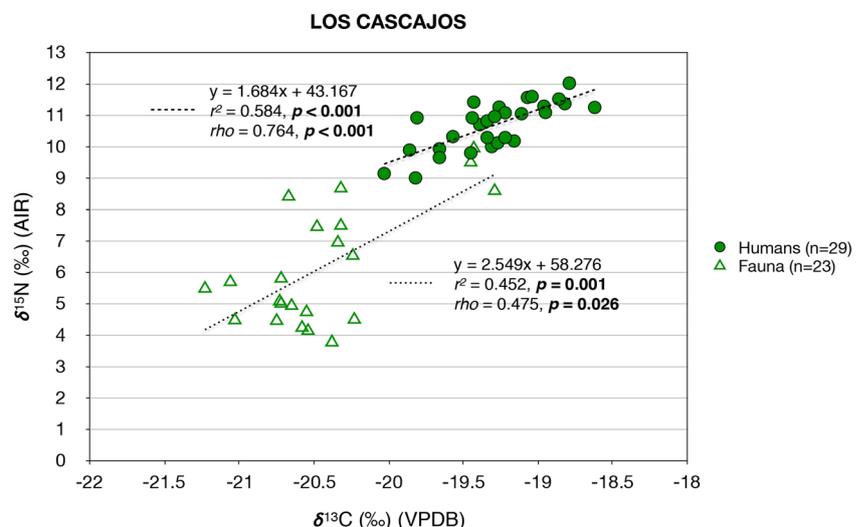
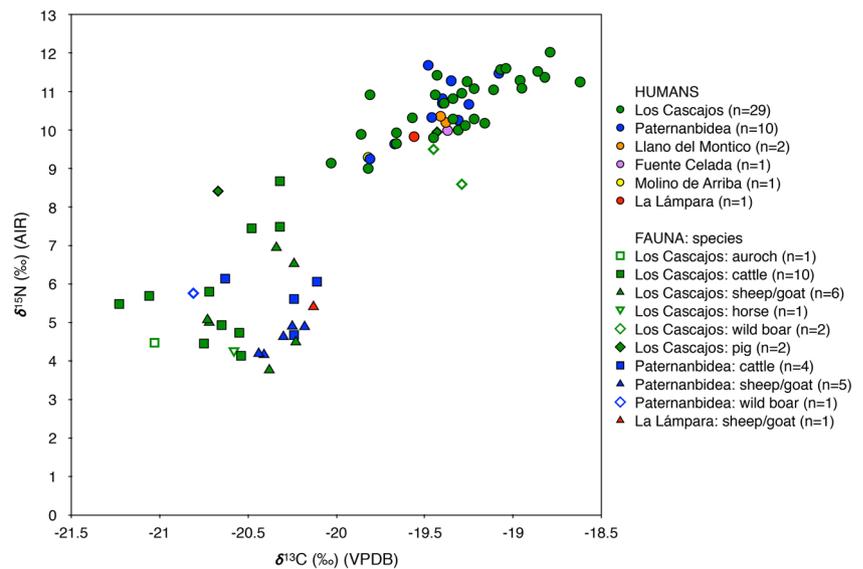


Fig. 4 Dispersion of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ human and faunal values of the sites studied



regard to $\delta^{13}\text{C}$ values, where a weak correlation ($r^2 = 0.225$, $p = 0.142$; $\rho = 0.321$, $p = 0.039$) (Fig. 5) is seen with present mean annual temperature (Ninyerola et al. 2005), the similarity of the results from the six sites, and from the two periods represented—Early and Middle Neolithic, extending over a millennium—suggests similar dietary and plant/animal management practices. Apart from these considerations, there are three major findings that are worth discussing in detail.

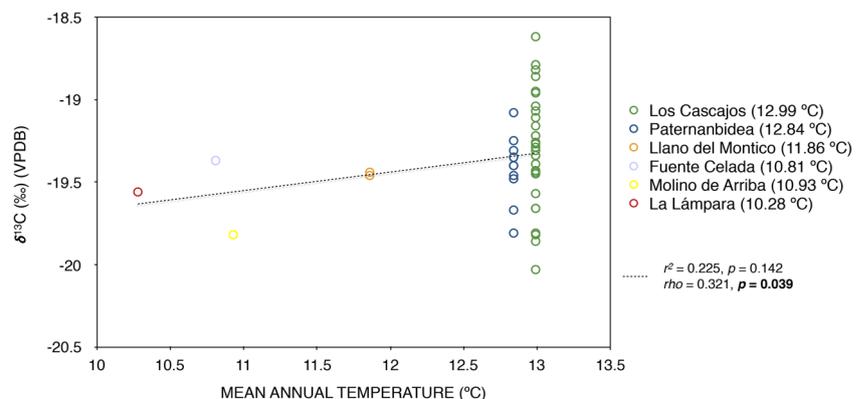
Trophic level offsets between humans and herbivores

There are relatively consistent offsets between the herbivore terrestrial fauna and human isotope values ($\Delta_{\text{human-herbivore}}$) at both Los Cascajos (1.3‰ for $\delta^{13}\text{C}$ and 5.2‰ for $\delta^{15}\text{N}$) and Paternanbidea (0.9‰ for $\delta^{13}\text{C}$ and 5.6‰ for $\delta^{15}\text{N}$). Comparing these data with those from other Neolithic Iberian major sites, it can be observed that this pattern is not exclusive to the mid-upper Ebro valley, since the site of La Bòbila Madurell, Catalonia, shows a similar spacing (0.9‰ for $\delta^{13}\text{C}$ and 5.4‰ for $\delta^{15}\text{N}$). This may also be the case for the nearby (1 km apart) coeval site of Can Gambús: although

faunal isotopic values are lacking there, the spacing with regard to the herbivore values of La Bòbila Madurell is comparable (1.1‰ for $\delta^{13}\text{C}$ and 5.2‰ for $\delta^{15}\text{N}$) (Fontanals-Coll et al. 2015). Unfortunately, it is difficult to assess whether or not this pattern is present in other Early-Middle Neolithic Iberian sites given the small sample sizes (e.g. Costamar (Salazar-García 2009), Cova de la Sarsa (Salazar-García 2010), Can Roqueta-Can Revella, Horts de Can Torras (Fontanals-Coll et al. 2017), Cadaval (Guiry et al. 2016), Chaves (Villalba-Mouco et al. 2018a), La Lámpara (this paper) and/or the absence of fauna in many case-studies (e.g. Castelo Belinho (Carvalho and Petchey 2013), Puid d'en Roca (Gibaja et al. 2017), Tossal de les Basses (Salazar-García et al. 2016)).

Assuming the range typically accepted for trophic level enrichments in the archaeological literature (ca. 0.8–1.3‰ for $\delta^{13}\text{C}$ and 3–5‰ for $\delta^{15}\text{N}$), the observed human-herbivore shifts of ca. 1‰ $\delta^{13}\text{C}$ and ca. 5‰ for $\delta^{15}\text{N}$ would require that terrestrial mammalian fauna contributed essentially 100% of the protein in the diet. But, of course, this is unlikely given the limited degree to which protein can

Fig. 5 Correlation observed between $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ human values obtained at each site and mean annual temperature (°C) (Ninyerola et al. 2005)



contribute to the body's energy requirements (Speth and Spielmann 1983). The shortfall needs to be made up by lipids and/or carbohydrates, and cereals and other plants would generally contribute significantly lower $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values to human diets. Even assuming a larger offset of ca. 6‰ for $\delta^{15}\text{N}$, as recently proposed by O'Connell et al. (2012), the isotopic values would still require an unusually high animal protein intake for European Neolithic farmers (for comparison, it can be noted that the vast majority of LBK sites from Central Europe never reach such a shift (Hedges et al. 2013)). Therefore, the observed isotopic human-herbivore offsets suggest the regular consumption of other higher trophic level foods underrepresented or missing in the sample studied and/or in the archaeological record. Considering that neither cereals (generally expected to have $\delta^{13}\text{C}$ values ca. 1‰ lower than those of herbivores even if $\delta^{15}\text{N}$ is raised by moderate levels of manuring), nor C_4 plants (archaeologically absent anywhere in Iberia at this time (Moreno-Larrazabal et al. 2015)) nor marine foods (given the considerable distance of these sites from the sea, and the absence of any evidence for marine foods) are likely to explain enrichment in both ^{13}C and ^{15}N , two possibilities seem more feasible to us.

First, it is possible that protein intake included a significant proportion of non-adult domestic herbivores (represented by 11 of the 33 successfully measured samples (Table 1)), which show higher $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ presumably because of the nursing signal (which would persist for some months even in the flesh in young, fully weaned specimens (Sponheimer et al. 2006)). Unfortunately, the zooarchaeological sample in our sites is too small to assess the extent to which the exploitation of these prevailed in the livestock economy (Altuna and Mariezkurrena 2019; Montero and Liesau 2008). However, the predominance of infant (i.e. nursing) and young (i.e. recently weaned) ovicaprids is seen in the coeval faunal assemblage from Chaves cave, also in the Ebro valley (Castaños 2004). Pigs might also have raised the isotopic values in human consumers due to their omnivorous diet, but based on their limited presence among the ungulates in our sites (Fig. 6) (Table 3), they do not seem to have been a major food source. A second possibility is that the consumption of freshwater resources, which are archaeologically almost absent, was more important than suspected. However, stable carbon isotopes in freshwater aquatic systems, though highly variable, are usually ^{13}C -depleted (Dufour et al. 1999), as observed in a study of modern fish from the Flix reservoir on the Ebro river (Soto et al. 2011). The exploitation of migratory birds consuming a mix of freshwater and marine foods and inhabiting the wetlands where the sites are located could also have shifted the human values in the direction observed, but again, their remains have been scarcely archaeologically documented, let alone in the numbers that would be required to make a notable impact on human diets. These two possibilities have also been suggested to explain high protein intake and

unusual $\Delta_{\text{human-herbivore}}$ spacing in some central and northern French Neolithic sites (Goude and Fontugne 2016), as well as elsewhere in the European Neolithic (Hedges and Reynard 2007; Hedges et al. 2008). However, the contribution of non-adult domestic animals fits better in the context of Early-Middle Neolithic north-central Spain, given the zooarchaeological evidence. In addition, Bayesian diet modelling using FRUITS (Fernandes et al. 2014) does not suggest any significant role for freshwater resources here (see Appendix B). Although these models do not provide either a definitive answer on the possible nature of the terrestrial food source/s producing the observed $\Delta_{\text{human-herbivore}}$ isotope enrichment, a relatively high consumption of non-adult herbivores remains, in our opinion, as a viable explanation.

The seasonal slaughter of calves and lambs may be seen here as management strategy by Early and Middle Neolithic groups. The culling of nursing animals would have optimized dairy production by removing unwanted surplus (particularly of males) before the animals were weaned, as well as facilitated the future supply of fodder, water and shelter for overwintering animals by controlling herd size. Culling of fully weaned young specimens, by contrast, it is considered to be a practice aimed at promoting meat production (Gillis et al. 2014). Whichever practice predominated in the sites studied, this evidence raises questions about the capacity of these communities to keep the balance between the exploitation of herds and the cost of maintaining them.

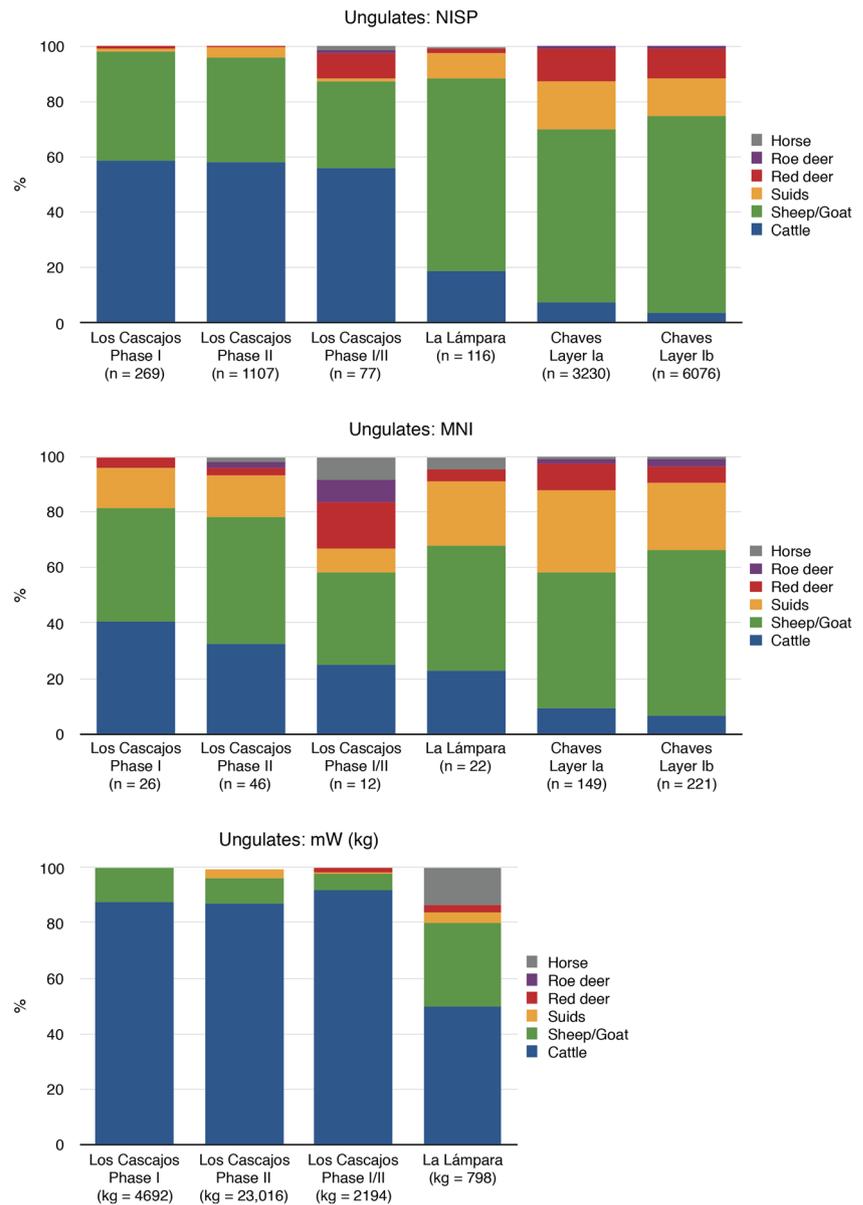
Positive correlation between $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ human values

Explaining the significant positive correlation between the human $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values in both phases of Los Cascajos and at Paternambidea is a separate issue from that of their high trophic level offsets. In a review of the published data, comparable correlations can be found in other Middle Neolithic Iberian open-air sites including Can Gambús ($r^2 = 0.113$, $p = 0.035$; $\rho = 0.303$, $p = 0.069$) (Fontanals-Coll et al. 2015) and Tossal de les Basses ($r^2 = 0.442$, $p = 0.026$; $\rho = 0.600$, $p = 0.051$) (Salazar-García et al. 2016). A similar trend may apply to other contemporary sites, although the typically small size of the available human sample often precludes statistical testing (Fig. 7).

In other contexts, similar correlations have been found when comparing sites within a region and these have been attributed to environmental factors, specifically precipitation gradients (Hollund et al. 2010). While, as noted above, there are hints that climate is relevant even within the small region encompassed by the present study, the correlation being discussed here is found within sites, rather than between them, so that another explanation is required.

Again, the use of FRUITS agent-based Bayesian models does not resolve the issue, as the results (cf. Appendix B in the

Fig. 6 Number of identified specimens (NISP), minimum number of individuals (MNI) and meat weight estimation (mW) of the ungulate remains recovered from Los Cascajos, La Lámpara and Chaves Early and Middle Neolithic phases/layers, displayed as percentages (data obtained from Altuna and Mariezcurrera 2019; Montero and Liesau 2008; Castaños 2004, respectively)



ESM) do not provide any clearer identification of carbon- and nitrogen-enriched terrestrial food source/s producing the observed correlation. The problem here is the relatively small isotopic and nutritional differences between the key food sources (especially adult vs. non-adult herbivores). Each of the food groups is modelled as contributing between 0 and 48% of the diet (other than cereals—between 32 and 86%—but this is because of the model parameter specifying that no more than 40% of energy requirements be met by protein). In this case, the model only shows what was already apparent from a consideration of the plotted values, i.e. the existence of differences in the relative proportion of plants and animals consumed between individuals at both extremes of the correlation. What is particularly problematic here is the absence of direct isotopic values for cereals and legumes.

It may be that the higher-trophic-level food source (i.e. non-adult domestic herbivores) behind the human-herbivore spacing played an important role in the creation of the correlations observed. Perhaps a section of the community had a diet emphasizing the consumption of terrestrial animal protein and, in some cases (i.e. those individuals with higher carbon and nitrogen isotopic values), primarily from domesticated nursing or recently weaned herbivores due to their socio-political status or, alternatively, to their economic practices.

On the one hand, the slaughter of nursing calves and lambs has been considered to be a far less economical practice than the culling of weaned non-adults and adults for prioritizing dairy over meat production (Saña 2000), and thus might implicate that their consumption was more frequent among the ‘elite’, assuming that differential access depended on social

Table 3 Number of identified specimens (NISP), minimum number of individuals (MNI) and, when available, meat weight estimation (mW) of the ungulate remains recovered from Los Cascajos, La Lámpara and Chaves E/M Neolithic phases (data obtained from Altuna and Maríquezkurrena 2019; Montero and Liesau 2008; Castaños 2004, respectively)

Site	Los Cascajos									La Lámpara			Chaves			
	Phase I			Phase II			Phases I and II			Pit no. 1			Layer Ia		Layer Ib	
Species	NISP	MNI	mW (kg)	NISP	MNI	mW (kg)	NISP	MNI	mW (kg)	NISP	MNI	mW (kg)	NISP	MNI	NISP	MNI
<i>Bos primigenius</i>	2	1	128	16	2	2329	–	–	–	3	1	137	5	2	7	1
<i>Bos taurus</i>	156	10	3979	627	13	17,629	43	3	2015	15	3	128	235	12	200	14
<i>Bos sp.</i>	–	–	–	–	–	–	–	–	–	4	1	132	–	–	–	–
<i>Ovis aries</i>	5	2	70	40	4	361	2	2	20	5	2	16	–	–	–	–
<i>Capra hircus</i>	1	1	4	–	–	–	–	–	–	1	1	70	55	5	123	11
<i>Ovis/Capra</i>	100	8	495	374	17	1815	22	2	115	74	7	157	1967	68	4196	120
<i>Sus ferus</i>	–	–	–	9	3	316	–	–	–	–	–	–	46	7	108	13
<i>Sus domesticus</i>	1	2	11	29	3	349	1	1	10	–	–	–	504	37	713	41
<i>Sus sp.</i>	2	2	5	7	1	51	–	–	–	11	5	27	–	–	–	–
<i>Cervus elaphus</i>	2	1	*	3	1	67	7	2	26	2	1	24	393	14	664	13
<i>Capreolus capreolus</i>	–	–	–	1	1	*	1	1	*	–	–	–	20	3	58	6
<i>Equus caballus</i>	–	–	–	1	1	99	1	1	8	1	1	107	5	1	7	2
Total	269	26	4692	1107	46	23,016	77	12	2194	116	22	798	3230	149	6076	221

*Meat weight was not calculated since the available remains consisted of antler fragments

standing. If this were the case, we might expect some concomitant differences in mortuary treatment or age/sex-related divergences, like those detected in other Neolithic sites such as Can Gambús in Catalonia, where the results show a significant enrichment in both $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ among men, especially older individuals, who not only were buried in monumental funerary structures but also were associated with qualitatively and quantitatively superior grave goods (Fontanals-Coll et al. 2015). However, these are not observed in our sample: all are pit graves, no associations between the presence/absence of grave goods and the isotopic data are found (cf. Table A.2) and, while some age-related differences are present (cf. Table A.4), they do not account for the observed correlation. Thus, while not excluding the possibility of the existence of status-related dietary distinctions, the lack of archaeological correlates does undermine this interpretation, at least pending further investigation.

On the other hand, it may be that some specialization in subsistence activities—such as livestock herding and crop farming—existed. For example, in the Languedoc region of southern France, those interred in stone cists and those deposited in pit graves show statistically distinct isotopic values, interpreted as reflecting differing emphases on herding and arable farming, respectively (Le Bras-Goude et al. 2013). No such a link between funerary and isotopic variability has been found here. Of course, this need not imply the absence of some degree of economic differentiation. Indeed, the existence of economic specializations among the first Neolithic groups has been proposed for the middle Ebro valley. Here,

seasonal transhumant herders could have moved cyclically to the mountains with their livestock, while the rest of the community would remain in valley settlements (e.g. Rojo-Guerra et al. 2013: 45). Other studies, conversely, suggest that most of the Neolithic sites in north-eastern Iberia, including those in upland areas, would have been settled by more or less permanent mixed farming communities, where herding was probably limited to short-distance movements (Antolín et al. 2018). Although in this model the existence of such an economic specialization would be not so obvious, it still may exist. In any case, it is clear that, whether for questions relating to social differentiation or to economic specialization, not all the people interred at Los Cascajos and Paternanbidea consumed the same amounts and/or quality of animal protein.

A further question arises as to whether the origins of the positive correlation between human $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values at Los Cascajos and Paternanbidea are diachronic. The available radiocarbon dates provide no suggestion of any temporal trends at the currently available resolution, given the modest number of determinations (cf. Fig. 2). But this does not exhaust the possibilities, as only persistent directional shifts in subsistence practices would be discernible isotopically at this resolution. Short-term oscillations on the order of decades could be sufficient to result in isotopic differences in adult bone collagen, but insufficient to be detected in the radiocarbon chronology, even with Bayesian modelling, unless data were available for many more individuals, if then. Underlying such a scenario would be a shifting emphasis on the consumption of cereals versus animal foods, particularly young animals

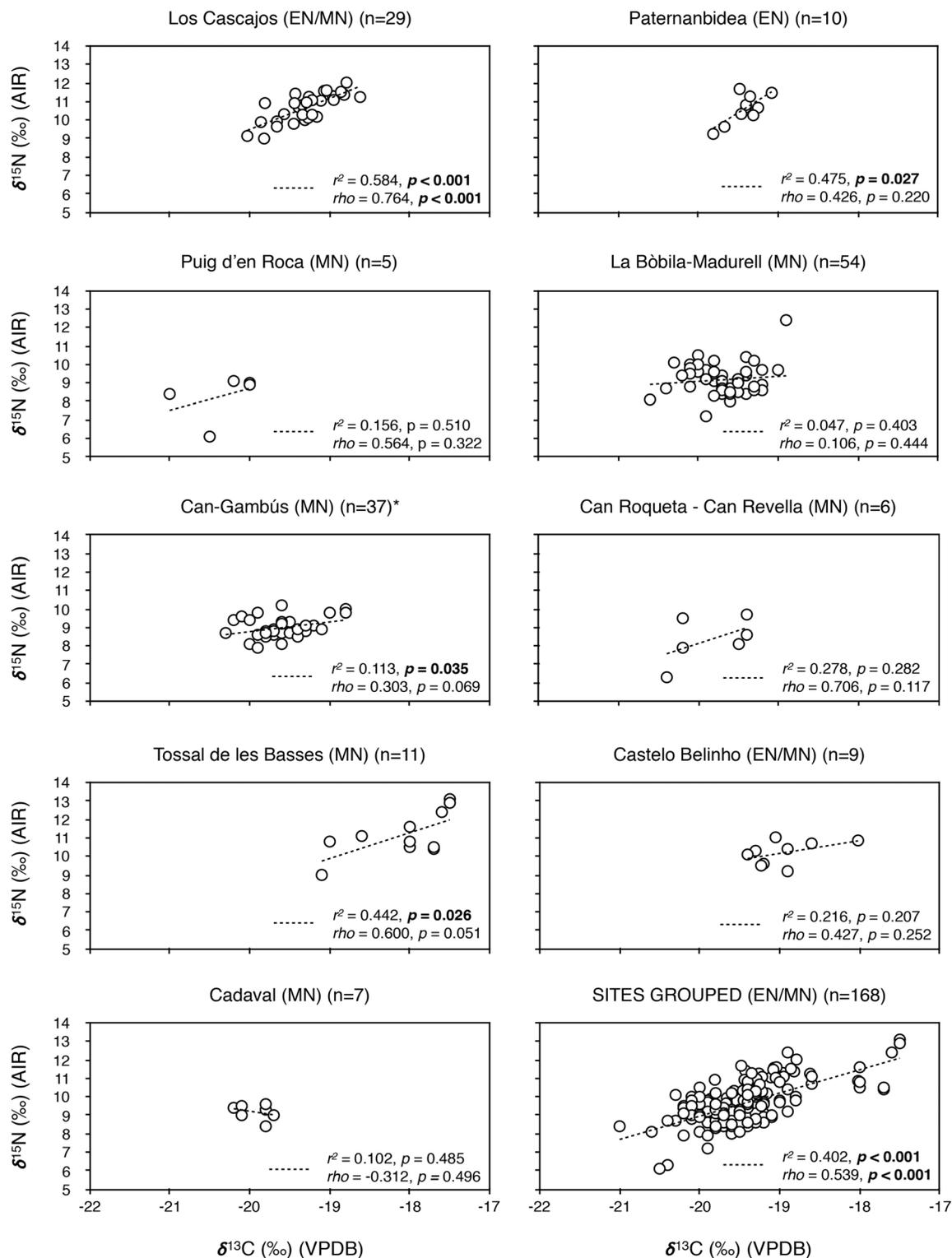
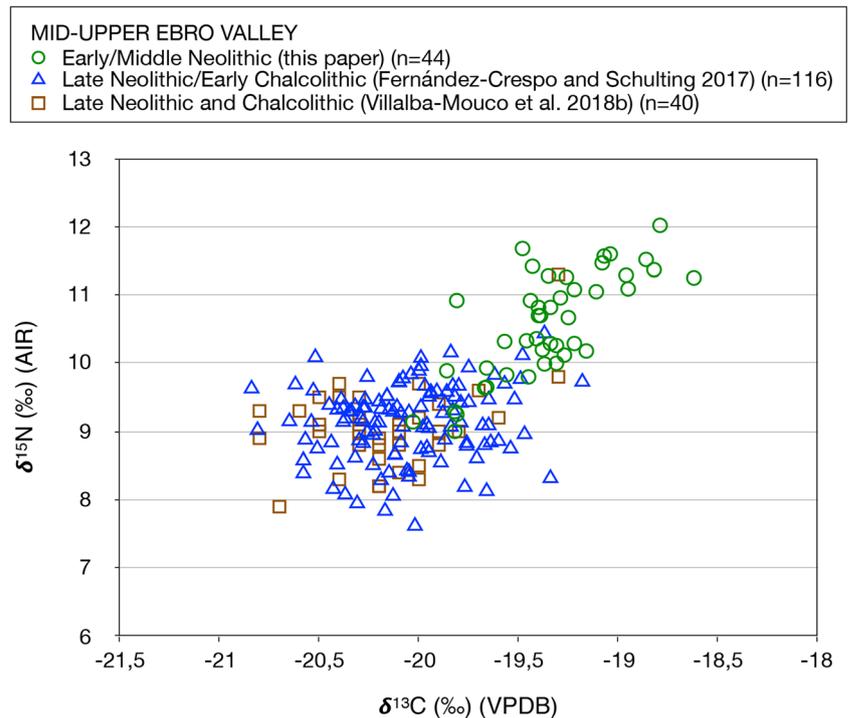


Fig. 7 Correlations between $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ human values at Los Cascajos and Paternanbidea, compared with those from other Early and Middle Neolithic Iberian sites (Puig d'en Roca (Gibaja et al. 2017); La Bòbila Madurell and Can Gambús (Fontanals-Coll et al. 2015); Can Roqueta-Can Revella (Fontanals-Coll et al. 2017); Tossal de les Basses (Salazar-García et al. 2016); Castelo Belinho (Carvalho and Petchey 2013); Cadaval (Guiry et al. 2016)). Iberian sites with less than five

human samples with acceptable values have not been included in the comparison. Single asterisk indicates that one individual has been excluded from the correlation model in the case of Can-Gambús, for being a clear outlier in $\delta^{13}\text{C}$ (-16.8‰) compared with the rest of the samples (Fontanals-Coll et al. 2015); in any case, its inclusion only increases the strength of the correlation

Fig. 8 Comparison between Early/Middle Neolithic and Late Neolithic/Early Chalcolithic $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ human values of the Ebro Valley (Fernández-Crespo and Schulting 2017; Villalba-Mouco et al. 2018b; this paper)



retaining elements of a nursing signal. Such shifts would need to persist for a decade or so in order to be visible isotopically, and could be the result of a combination of a series of failed crops (e.g. a number of poor rainfall years, or domestic stock falling prey to disease or to human predation). This would be far from unexpected in an agro-pastoral economy, the question then becoming why such a pattern has not been detected more widely across Europe, where similar considerations would presumably apply. This would bear revisiting, but the current impression is that this pattern is not repeated with anything approaching the consistency seen in the present study area.

Shift in human isotope values between the Early-Middle and the Late Neolithic/Early Chalcolithic

Widening the comparison, the Early-Middle Neolithic human isotope values discussed in this paper differ substantially from those of the Late Neolithic/Early Chalcolithic in the same region, which show notably lower carbon and, especially, nitrogen isotope values (Fig. 8), a far weaker positive correlation between $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ and smaller human-herbivore offsets in those sites with enough faunal data (e.g. Los Husos I: 0.5‰ for $\delta^{13}\text{C}$ and 4.2‰ for $\delta^{15}\text{N}$; Abauntz: 1.2‰ for $\delta^{13}\text{C}$ and 4.8‰ for $\delta^{15}\text{N}$) (Fernández-Crespo and Schulting 2017; Villalba-Mouco et al. 2018b). This shift in subsistence, described here for the first time, may tentatively be related to the stronger emphasis on pastoralism increasingly being attributed to the earliest Neolithic communities of interior Iberia (e.g. Carvalho 2015; Guerra-Doce et al. 2017), which is consistent with the local palynological (e.g. López-García

and López-Sáez 2000; Pérez-Díaz et al. 2015) and zooarchaeological records (Castaños 2004). Similar subsistence models characterized by a high reliance on animal resources have been proposed in other western European regions, including Britain, where $\delta^{15}\text{N}$ values are also relatively high compared with Central Europe (Schulting and Boric 2017). Unfortunately, it remains unknown whether this potentially greater commitment to a herding economy attributed to the first north-central Iberian Neolithic groups would involve a significant degree of mobility (transhumance, transterminance) or not (e.g. 'from dawn till dusk'). In any case, it is possible that, rather than a fully arable economy, Early and Middle Neolithic subsistence practices in the region emphasized intensive dairying and domestic herbivore meat exploitation complemented by the hunting of ungulates (Altuna 1980; Castaños 1997; Castaños 2004), gathering of wild plants and a small-scale intensive and diversified agriculture based on the cultivation of small cereal plots (Zapata et al. 2004; Zapata et al. 2008). This model could be the precursor to more extensive cereal-based farming from the Late Neolithic onwards, as both the isotope evidence (Fernández-Crespo and Schulting 2017; Villalba-Mouco et al. 2018b) and the environmental and archaeological records suggest (Fernández-Eraso et al. 2015; Pérez-Díaz et al. 2015).

Conclusion

The human and faunal isotopic results from the Early-Middle Neolithic pit-grave cemeteries of interior north-central Iberia

analyzed are consistent with an isotopically similar C₃ plant- and terrestrial animal-based diet. However, the spacing between the humans and herbivores is higher than expected for both isotopes. This is observable here and in other large coeval Iberian sites and suggests that an important food source may not be accurately represented in the isotope studies and in the archaeological record. Although it is unclear at present what this might be, we propose a high consumption of non-adult domestic herbivores as the most likely hypothesis, at least for the study region. In addition, a positive correlation observed between carbon and nitrogen isotopic values in Los Cascajos and Paternambidea, also detected in other coeval Iberian sites, is seen. This may indicate consumption of different foods within the community, with relevant implications for the understanding of the subsistence strategies (e.g. economic specialization) and/or social practices (e.g. differential diets based on status) followed by Iberian early farming societies. Finally, the results also show a significant shift in diet between the Early/Middle Neolithic and the Late Neolithic in north-central Iberia, which possibly relates to a subsistence change from mainly pastoral to mixed economies.

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