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ORIGINAL PAPER

Long-term dietary change in Atlantic and Mediterranean Iberia with the introduction of agriculture: a stable isotope perspective

Miriam Cubas[1,2] · **Rita Peyroteo-Stjerna**[3,4] · **Maria Fontanals-Coll**[1] · **Laura Llorente-Rodríguez**[1,5] · **Alexandre Lucquin**[1] · **Oliver Edward Craig**[1] · **André Carlo Colonese**[1]

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Abstract

The Neolithic expansion in the Iberian Peninsula is marked by the introduction of livestock and domesticated crops which modified subsistence strategies in an unprecedented manner. Bulk collagen stable carbon and nitrogen isotope analysis has been essential to track these changes, which have largely been discussed in relation to particular geographic areas or single case studies. This paper reviews the available isotope literature to provide a regional, long-term synthesis of dietary changes associated with the expansion of the Neolithic and the establishment of farming economy in the Iberian Peninsula. Bulk collagen stable carbon and nitrogen isotope values of 763 human individuals and 283 faunal remains from the Mesolithic to the Late Neolithic period in Iberia (*ca.* 8000–3000 cal BC) were collated and analysed using a Bayesian mixing model. The results show that Mesolithic diets were isotopically diverse in both the Atlantic and Mediterranean regions of the Iberian Peninsula, and that a significant decrease in variability happened with the Neolithisation, culminating with the establishment of farming economies and reliance on terrestrial resources in the Late Neolithic.

Keywords Bulk collagen · Stable carbon and nitrogen isotopes · Palaeodietary reconstructions · Neolithic · Iberian Peninsula

Introduction

The spread of agriculture in Europe during the Early to Middle Holocene constitutes one of the most transformative and controversial socio-cultural processes in Prehistory. Coastal zones and immediate inland areas of the Iberian Peninsula offer attractive geographic contexts to investigate the magnitude and dietary implications of this process. First, the Peninsula was one of the most densely populated regions in Europe during the Mesolithic, especially along the Atlantic coast (Arias 1999). Second, its geographic diversity has demanded distinct adaptive strategies by prehistoric populations, in particular by those living along the Atlantic and the Mediterranean, coastal areas marked by contrasting biological productivity and resource predictability.

Archaeological evidence shows that early farmers from the Near East migrated across the Mediterranean Sea following a coastal route from the Aegean to the Iberian Peninsula, bringing with them pottery, ground stone tools and domesticated plants and animals, which marked the beginning of the Neolithic in these regions (Guilaine 2017). Ancient human DNA has shown a clear Anatolian ancestry of early European farmers (Mathieson et al. 2015; Omrak et al. 2016), as well as strong genetic differentiation between hunter-gatherers and early farmers (Skoglund et al. 2014; Lazaridis et al. 2014), supporting the archaeological model of a maritime colonisation of Iberia in the 6th millennium cal BC (Zilhão 2001; Isern et al. 2014; Martins et al. 2015).

The introduction of farming, however, was not uniform across Iberia. The first domesticates are known for the Mediterranean region of the Peninsula, consisting of cereals and livestock, and

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✉ Miriam Cubas
mcubas.morera@gmail.com

[1] BioArCh-Department of Archaeology, University of York, Wentworth Way, Heslington, York YO10 5DD, UK

[2] Sociedad de Ciencias Aranzadi, Zorroagagaina 11, E-20014 Donostia, San Sebastian, Spain

[3] Human Evolution, Department of Organismal Biology, Uppsala University, Norbyv, 18C, SE-752 36 Uppsala, Sweden

[4] UNIARQ, Faculdade de Letras da Universidade de Lisboa, Alameda da Universidade, University of Lisbon, 1600-214 Lisbon, Portugal

[5] Department of Archaeology, Universiteit Leiden, Van Steenis Building, Einsteinweg 2, 2333 CC Leiden, Netherlands

have been radiocarbon dated to the mid-6th millennium cal BC (Saña 2013; Martins et al. 2015; Pérez-Jordá et al. 2017). Domesticates were introduced to the south-western Atlantic coast in the second half of the 6th millennium cal BC (Zilhão 2001; Davis and Simões 2015; López-Dóriga and Simões 2015), while in the north Atlantic coast of Iberia, such as the Cantabrian region, the earliest domesticated plants and animals were adopted much later, in the 5th millennium cal BC (Cubas et al. 2016).

Moreover, there has been a long, contentious debate about the impact of the expansion of farming upon local forager diets, where the application of stable isotope analysis has been particularly fruitful. Consumer diets can be determined by measuring the stable isotopes of carbon ($^{13}C/^{12}C$) and nitrogen ($^{15}N/^{14}N$) in consumer tissues, such as bone collagen, and comparing these with isotopic baselines for potential food sources (van Klinken et al. 1994; Tykot 2002; Fischer et al. 2007). The $\delta^{13}C$ and $\delta^{15}N$ values of human bone collagen have been successfully used to estimate the relative contribution of marine versus C_3-based terrestrial resources in coastal populations due to distinctive isotopic signatures in these ecosystems, allowing generic discriminations (Jennings et al. 1997; Richards and Hedges 1999). Isotopic analyses across Atlantic coastal areas of Europe have shown a marked dietary difference between Mesolithic foragers, with substantial consumption of marine foodstuffs, and Neolithic farmers, whose diets were essentially based on terrestrial resources (Lubell et al. 1994; Richards and Hedges 1999; Richards et al. 2003; Bonsall et al. 2009; Schulting 2011). Similar results have been reported for the Iberian Peninsula, although considerable variability has been observed at the regional scale (Fontanals-Coll et al. 2014; Guiry et al. 2015; Peyroteo-Stjerna 2016; Salazar-García et al. 2018). Indeed, since the early 2000s, there has been an extraordinary increase in palaeodietary studies based on stable isotope analysis of carbon and nitrogen in human bone collagen from Mesolithic and Neolithic populations in this region (e.g. Cunha and Umbelino 2001; Arias 2006; García-Guixé et al. 2006; Roksandic 2006; Umbelino 2006; Umbelino et al. 2007; Arias and Schulting 2010; Lillios et al. 2010; McClure et al. 2010; Carvalho and Petchey 2013; Fernández-López de Pablo et al. 2013; Jackes et al. 2014; Fontanals-Coll et al. 2014, 2015, 2017; Salazar-García et al. 2014; Gibaja et al. 2015; Gibaja et al. 2016; Guiry et al. 2015, 2016; Umbelino et al. 2015; Alt et al. 2016; Jackes and Lubell 2016; Peyroteo-Stjerna 2016; Remolins et al. 2016; Waterman et al. 2016; Fernández-Crespo and Schulting 2017; Salazar-García et al. 2017; Sarasketa-Gartzia et al. 2018).

This paper reviews the isotope literature reporting $\delta^{13}C$ and $\delta^{15}N$ values of human individuals from archaeological sites dated to the Mesolithic, Early Neolithic, Middle Neolithic and Late Neolithic–Chalcolithic in the Iberian Peninsula. A Bayesian mixing model (FRUITS; Fernandes 2015) was used to estimate the average relative contribution of terrestrial and marine resources to dietary calories for each time period. The aims of this paper are twofold: (i) provide a regional and long-term synthesis of dietary changes associated with the introduction, expansion and establishment of farming economy in this region from *ca.* 8000 to 3000 cal BC; and (ii) offer a comprehensive isotopic database for addressing the dietary implications of early food production in the Iberian Peninsula.

Materials and methods

We analysed the bone collagen $\delta^{13}C$ and $\delta^{15}N$ values currently available for human individuals from archaeological sites dated between *ca.* 8000 and 3000 cal BC in the Iberian Peninsula (SI 1). Archaeological sites were grouped in two main regions (Atlantic, Mediterranean) and in generic chrono-cultural periods: Mesolithic (*ca.* 8000–5500 cal BC), Early Neolithic (*ca.* 5500–4500 cal BC), Middle Neolithic (*ca.* 4500–3500 cal BC) and Late Neolithic–Chalcolithic (*ca.* 3500–3000 cal BC) (Fig. 1). Samples considered in this study are accompanied by their contextual and geographical information, cultural attribution and sample identification (sample code and type, age and sex) (SI 1). Our analysis did not distinguish between coastal and inland sites since in some areas, such as the Atlantic coast of Iberia, the existence of estuarine ecosystems allows marine resources to be exploited at considerable distances from the coast (e.g. Van Der Schriek et al. 2007; Vis et al. 2008). The quality of the published material is extremely variable and data criteria are rarely presented with sufficient detail to allow a critical evaluation of analytical procedures (Roberts et al. 2018). Samples were therefore screened according to established quality criteria for collagen preservation. Samples with C:N ratios outside the 2.9–3.6 range (van Klinken 1999; DeNiro 1985) were discounted as well as samples published without reporting these parameters. For this reason, some geographic areas, such as the Cantabrian region (Arias 2006, 2012), are not well represented in our database.

The $\delta^{13}C$ and $\delta^{15}N$ values of faunal remains from prehistoric and historic archaeological sites in the Atlantic and Mediterranean regions were compiled to establish regional stable isotope baselines (SI 2). Fauna $\delta^{13}C$ and $\delta^{15}N$ values were grouped according to their habitat: marine (fish and mammals) and terrestrial (ungulates). Because of the paucity of marine isotope values for the Iberian Peninsula, the $\delta^{13}C$ and $\delta^{15}N$ values of fish and marine mammals from Mesolithic and Early Neolithic contexts from the central Mediterranean (Mannino et al. 2012, 2015), Bronze Age in the Balearic Islands (García-Guixé et al. 2010) and Late Medieval data from the Atlantic (López-Costas and Müldner 2016) have been also included.

Statistical analyses were performed using R package v3.4 (R Development Core Team 2013). Different statistical tests were performed to test the normality of the distributions:

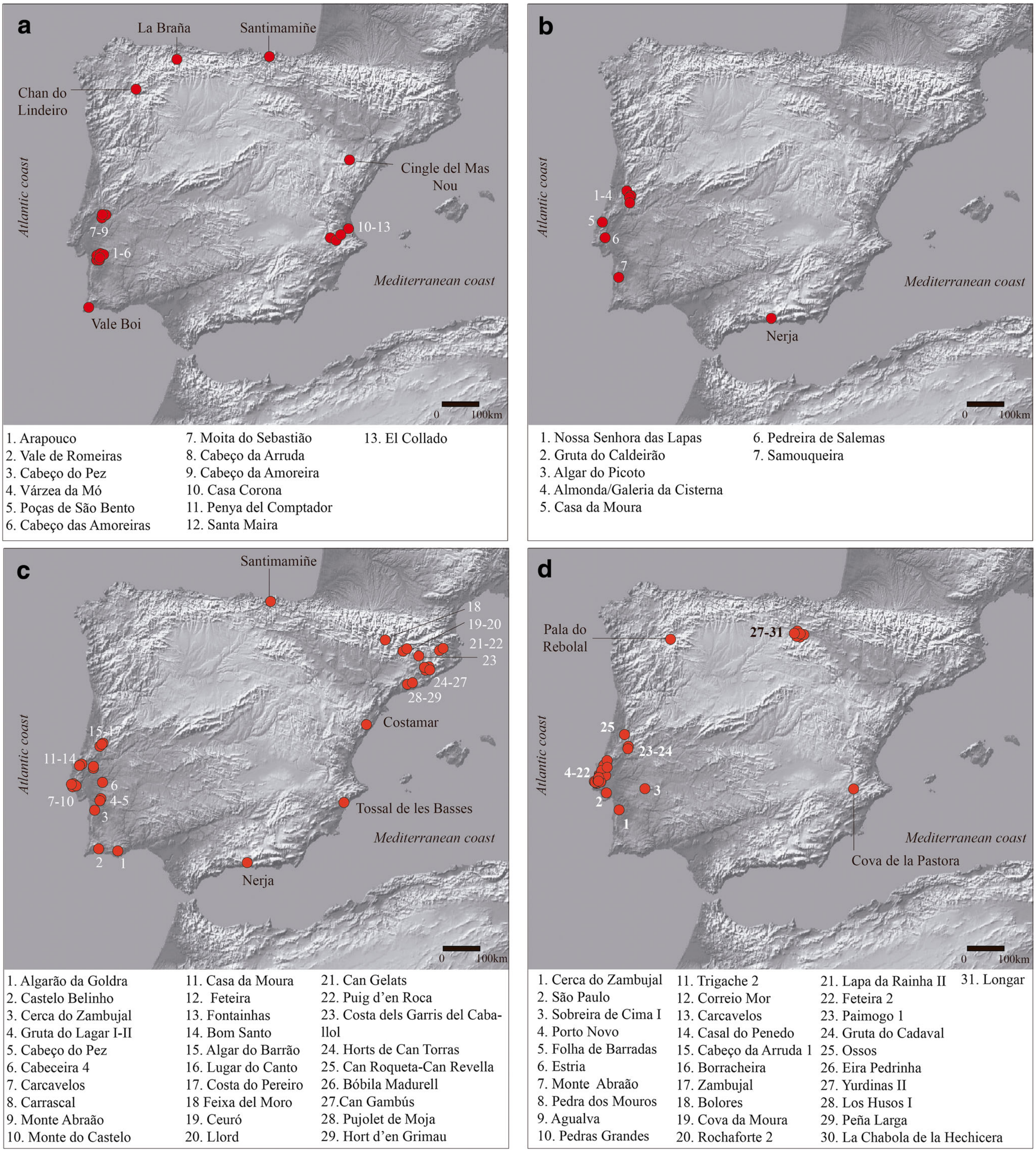


Fig. 1 Iberian Peninsula and the location of archaeological sites with stable isotope measurements of human bone considered in this study. **a** Mesolithic; **b** Early Neolithic; **c** Middle Neolithic; **d** Late Neolithic–Chalcolithic

Shapiro–Wilk (S-W, for statistical populations with less than 50 cases) and Lilliefors corrected Kolmogórov–Smirnov (K-S, for populations with more than 50 individuals). The results show that the isotope data were not normally distributed in all cases (SI 3 and 4). Non-parametric tests were then applied to compare two samples (Wilcoxon-Mann-Whitney, W) or more than two samples (Kruskal-Wallis, K-W). A p value of 0.05 (H_1 acceptance with $p \leq 0.05$) was used as the significance threshold.

For each time period (Mesolithic, Early Neolithic, Middle Neolithic and Late Neolithic-Chalcolithic) and region (Atlantic, Mediterranean), the average percentage of dietary carbon (equivalent to caloric contribution or dry weight contribution) derived from marine and terrestrial resources was estimated using a Bayesian Mixing Model in FRUITS 3.0 (Fernandes et al. 2014). While δ^{15}N values in bone collagen only reflect the sources of dietary proteins and the position of the consumer in the food chain due to relatively predictable dietary isotope fractionations (+ 3–6‰; Jim et al. 2006; O'Connell et al. 2012), the δ^{13}C values may reflect the contribution of different dietary macronutrients, such as proteins, carbohydrates and lipids, to individual diets (Jim et al. 2006; Webb et al. 2017). A routed, concentration-dependent weighted model was used taking into account two dietary proxies (δ^{13}C, δ^{15}N) and two food groups (marine, terrestrial). Isotopic baselines (Mediterranean and Atlantic) were derived from published isotope data from animal bones and are reported in Table 2. Although terrestrial plants were undoubtedly an important portion of the diet of Mesolithic and Neolithic populations (e.g. Umbelino 2006; López-Dóriga et al. 2016; Peña-Chocarro et al. 2018), the absence of isotopic values for both wild and domestic plants in the region prevents their quantification.

The model was developed using the assumptions and uncertainties exactly as described by Fernandes (2015) as this considers the dietary contributions of protein and energy macronutrients. Rather than modelling individuals separately based on their collagen δ^{13}C and δ^{15}N values, we aimed for broad comparisons by using the population means for each region and each period, and by taking the standard deviations of the means as the uncertainties (Fernandes et al. 2015).

Results

Fauna bone collagen

Faunal δ^{13}C and δ^{15}N values are represented by 283 specimens from the Atlantic ($n = 42$) and Mediterranean ($n = 241$) regions (Table 1), with a disproportionate amount of terrestrial mammals (ungulates, 83%) compared to marine animals (fish and mammals, 17%) (García-Guixé et al. 2006; Salazar-García 2009, 2012; Salazar-García et al. 2014, 2017; Fontanals-Coll et al. 2015; Fernández-Crespo and Schulting 2017; Navarrete et al. 2017).

Terrestrial faunal remains from the Mediterranean region have significantly higher δ^{13}C ($W = 2006$; p value = 5.614e−05) and δ^{15}N ($W = 1862$; p value = 1.012e−05) values compared to animals from the Atlantic region (Table 1). While no significant differences were observed for the δ^{13}C values of the marine animals between these regions ($W = 94$; p value = 0.1737), the fish and sea mammals from the Atlantic region have δ^{15}N values significantly higher than those of specimens from the Mediterranean ($W = 244$; p value = 0.002). This presumably reflects fundamental differences in food webs between the Mediterranean Sea compared to the Atlantic Ocean (Stambler 2014).

The significant variability observed in the isotope values of faunal remains from the Mediterranean and the Atlantic regions emphasises the importance of building local to regional baselines to estimate the contribution of each food source. The average δ^{13}C and δ^{15}N values of terrestrial and marine resources for each region were used to establish the isotopic composition of macronutrients of each food group and the parameters required for modelling (Table 2).

Human bone collagen

A total of 763 individuals were analysed from sites in the Atlantic ($n = 481$) and Mediterranean regions ($n = 282$) (Fig. 1 and Table 3). Most individuals were dated to the Middle Neolithic ($n = 315$), followed by the Late Neolithic–Chalcolithic ($n = 276$), Mesolithic ($n = 150$) and Early Neolithic ($n = 22$). Information about age and sex were not always available, preventing further analysis across populations.

The δ^{13}C and δ^{15}N values show significant variability over time within and between regions (Fig. 2a, b). The largest range of δ^{13}C and δ^{15}N values is observed among Mesolithic individuals of the Atlantic region. Although the paucity of isotope values from the Early Neolithic prevents robust comparisons

Table 1 Faunal δ^{13}C and δ^{15}N values grouped into two categories: terrestrial (ungulates), marine (fish and mammals)

		δ^{13}C (‰)				δ^{15}N (‰)				*N*
		Mean	SD	Max	Min	Mean	SD	Max	Min	
Atlantic	Terrestrial	− 20.8	1	− 18.9	− 22.1	4.3	1.6	9.6	2.1	35
	Marine	− 12	0.6	− 11.5	− 13	12.5	2.03	15.1	9.2	7
Mediterranean	Terrestrial	− 20	1.1	− 11.4	− 21.9	5.3	1.4	9	2.6	200
	Marine	− 11.6	1.6	− 8.9	− 15.2	9.2	2.1	12.1	3.6	41

Table 2 Average and standard deviations of terrestrial and marine faunal collagen isotope values. The estimated protein and lipid isotope values and the macronutrient composition (%dry weight carbon content) were calculated according to Fernandes (2015)

	δ^{13}C dietary protein (‰)	δ^{15}N dietary protein (‰)	δ^{13}C dietary lipids (‰)	Protein (%C)	Lipids (%C)
Atlantic					
Terrestrial	−22.8 ± 1	6.2 ± 1	−28.8 ± 1	30 ± 2.5	70 ± 2.5
Marine	−13 ± 1	14.5 ± 1	−19 ± 1	65 ± 5	35 ± 5
Mediterranean					
Terrestrial fauna	−22 ± 1	7.3 ± 1	−28 ± 1	30 ± 2.5	70 ± 2.5
Marine fauna	−12.6 ± 1	11.2 ± 1	−18.6 ± 1	65 ± 5	35 ± 5

across regions for this time period (e.g. Mediterranean), there is a decrease in δ^{13}C and δ^{15}N variability in the Atlantic region. The narrow isotopic variability continued through the Middle to Late Neolithic–Chalcolithic, and these differences were statistically significant for both δ^{13}C (K-W = 172.81, df = 3, p value < 2.2e−16) and δ^{15}N values (K-W = 130.53, df = 3, p value < 2.2e–16). In the Mediterranean region, Mesolithic and Middle Neolithic populations had the most variable δ^{13}C and δ^{15}N values, while considerably narrower isotopic distributions were recorded during the Late Neolithic–Chalcolithic. These differences were also statistically significant for both δ^{13}C (K-W = 120.25, df = 3, p value < 2.2e–16) and δ^{15}N values (K-W = 7.9449, df = 3, p value = 0.04716). Worth noting is the lower variability in δ^{13}C and δ^{15}N values of Mesolithic populations in the Mediterranean region compared to the Atlantic. These differences could be a consequence of sample size, but most likely reflect differences in the isotope ecology and diet of populations between these regions, with considerable consumption of marine resources by some Atlantic foragers, as also estimated by Bayesian calculations.

Mesolithic (*ca.* 8000–5500 cal BC)

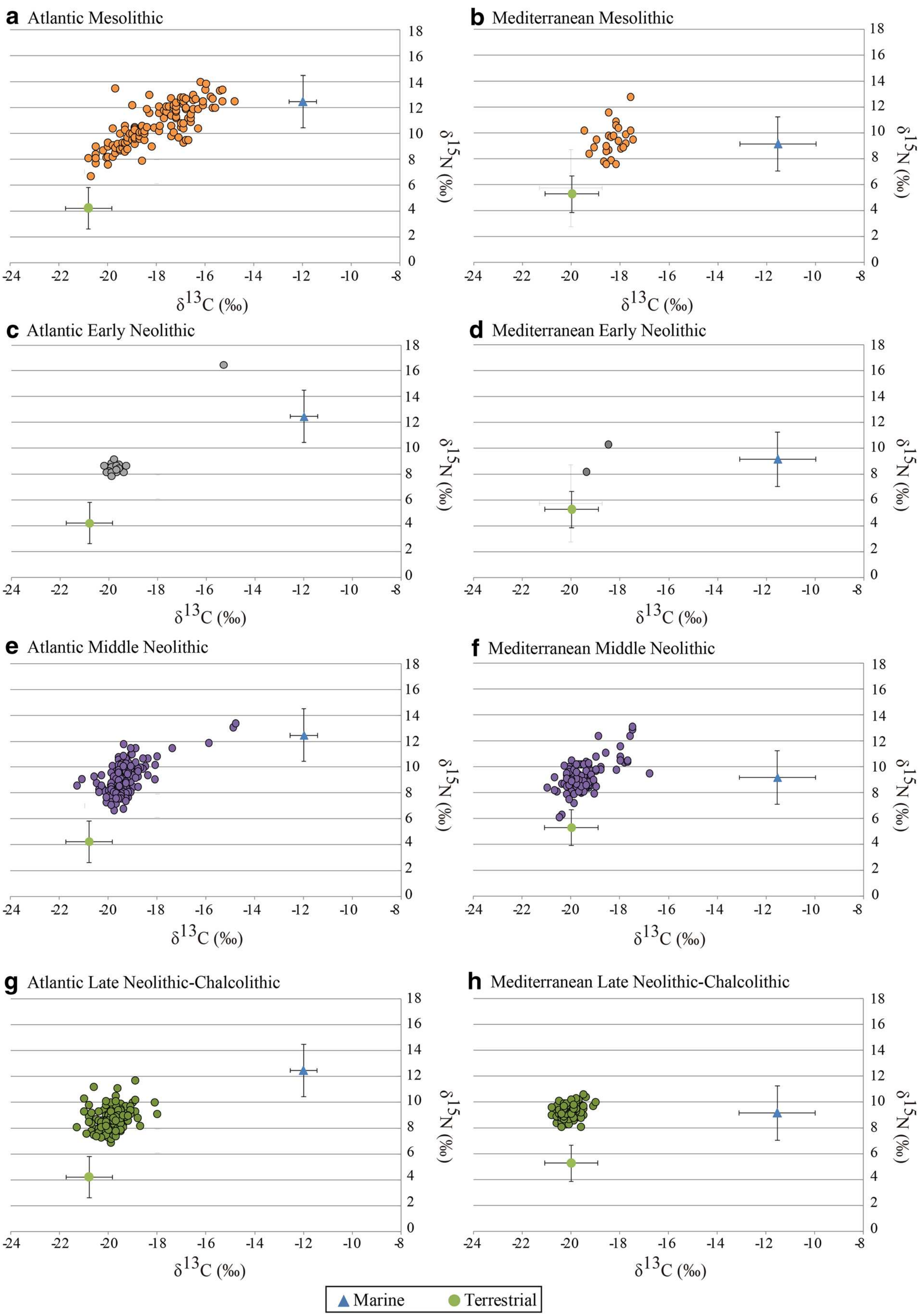
Stable isotope values of Mesolithic populations indicate diets based mainly on C_3-terrestrial foods in both regions of the peninsula (Fig. 2a, b; Fig. 3a; Table 4). For the Atlantic region, Bayesian modelling estimates that terrestrial and marine resources provided average contributions to dietary calories of 91.8 ± 6.2% and 8.2 ± 6.2%, respectively. However, marine resources may have contributed as much as *ca.* 23% of dietary calories in some areas. Indeed, considerable intake of marine resources has been reported for individuals from sites such as Cabeço do Pez, Cabeço da Amoreira, Cabeço da Arruda and Moita do Sebastião in Portugal (e.g. Lubell et al. 1994; Fontanals-Coll et al. 2014; Guiry et al. 2015; Peyroteo-Stjerna 2016). The wide range of δ^{13}C values in the Atlantic region also suggests that distinct terrestrial ecological niches were exploited (e.g. Waterman 2012; Fontanals-Coll et al. 2014). For the Mediterranean region, the Bayesian model estimates average contributions of terrestrial and marine resources of 95.5 ± 3.7% and 4.5 ± 3.7%, respectively, to dietary calories. The maximum estimated contribution of marine resources to diet was *ca.* 14% (Table 4). A higher consumption of marine resources in this region was found at the sites of El Collado, Santa Maira and some individuals from Cingle del Mas Nou (García-Guixé et al. 2006; Salazar-García et al. 2014).

Early Neolithic (*ca.* 5500–4500 cal BC)

Isotopic values from the Atlantic and Mediterranean regions are consistent with diets based on C_3-terrestrial

Table 3 Human δ^{13}C and δ^{15}N values grouped by period

		δ^{13}C (‰)				δ^{15}N (‰)			
	Period	Mean	SD	Max	Min	Mean	SD	Max	Min
Atlantic	Mesolithic (n = 124)	−18	1.4	−14.8	−20.8	10.7	1.6	14	6.7
	Early Neolithic (n = 20)	−19.6	1	−15.3	−20.2	8.9	1.8	16.5	7.9
	Middle Neolithic (n = 174)	−19.4	0.8	−14.8	−21.3	9.1	1.2	13.4	6.7
	Late Neolithic–Chalcolithic (n = 163)	−19.9	0.5	−18	−21.3	8.6	0.8	11.7	6.9
Mediterranean	Mesolithic (n = 26)	−18.4	0.5	−17.5	−19.5	9.5	1.2	12.8	7.6
	Early Neolithic (n = 2)	−19	0.6	−18.5	−19.4	9.3	1.5	10.3	8.2
	Middle Neolithic (n = 141)	−19.5	0.7	−16.8	−21	9.2	1	13.1	6.1
	Late Neolithic–Chalcolithic (n = 113)	−20.1	0.3	−19	−20.8	9.3	0.5	10.6	8.1


a Atlantic Mesolithic
b Mediterranean Mesolithic
c Atlantic Early Neolithic
d Mediterranean Early Neolithic
e Atlantic Middle Neolithic
f Mediterranean Middle Neolithic
g Atlantic Late Neolithic-Chalcolithic
h Mediterranean Late Neolithic-Chalcolithic
δ13C (‰)
-24
-22
-20
-18
-16
-14
-12
-10
-8
δ15N (‰)
0
2
4
6
8
10
12
14
16
18
▲ Marine
● Terrestrial

◀ **Fig. 2** $\delta^{13}C$ and $\delta^{15}N$ variation in human bone collagen and faunal remains in the Atlantic and Mediterranean regions of the Iberian Peninsula from the Mesolithic to the Late Neolithic

resources, with an overall decline in marine intake (Fig. 2c, d; Fig. 3a, b). For the Atlantic region, Bayesian estimations indicate that terrestrial and marine resources provided average contributions of 95.7 ± 3.7% and 4.3 ± 3.7% of dietary calories respectively (Table 4). The model estimates that the maximum amount of carbon from marine resources was *ca*. 14% (Table 4). One individual has considerably higher $\delta^{13}C$ and $\delta^{15}N$ values (Fig. 2c; Samouqueira 1 in Portugal; Lubell et al. 1994), but its cultural attribution is controversial (Zilhão 2000). Similar results were obtained for Early Neolithic individuals from the Mediterranean sites, where Bayesian model estimates that terrestrial and marine resources accounted for averages of 96.1 ± 3.3% and 3.9 ± 3.3% of dietary calories, respectively, while the maximum contribution of marine resources was ca. 13% (Tab. 4).

Middle Neolithic (*ca.* 4500–3500 cal BC)

Again, most of the samples have isotopic compositions consistent with C_3-terrestrial resources. This is supported by Bayesian estimations of the terrestrial mammal contribution to dietary calories with average values of 96.8 ± 2.7% for the Atlantic and 97.4 ± 2.4% for the Mediterranean (Table 4). Although the Middle Neolithic shows a clear shift toward a terrestrial-based diet, marine resources were consumed at a detectable level in several areas of the Peninsula (Fig. 2e, f). The average contribution of marine resources to dietary calories was 3.2 ± 2.7% and 2.6 ± 2.4% in the Atlantic and Mediterranean regions respectively, but intakes of marine products up to 9–10% of the diet may have occurred in both regions (Table 4, Fig. 3a, b). These values are represented by individuals from Cerca do Zambujal and Lagar I (Guiry et al. 2016; Jackes and Lubell 2016) in the Atlantic region, and two individuals from Tossal de les Basses (Salazar-García et al. 2016) and one individual from Can Gambús (Fontanals-Coll et al. 2015) in the Mediterranean area (SI 1).

Late Neolithic–Chalcolithic (*ca.* 3500–3000 cal BC)

The $\delta^{13}C$ and $\delta^{15}N$ values from the Atlantic and Mediterranean regions are narrowly distributed and fall at the end-point of C_3-terrestrial resources (Fig. 2g, h). The Bayesian model estimates average contributions of terrestrial resources to dietary calories of 98.1 ± 1.08% for the Atlantic and 98.4 ± 1.5% for the Mediterranean. Marine resources contributed less than 6–7% in both regions (Table 4, Fig. 3a, b).

Discussion

The results show significant differences in human diets over time, from the Mesolithic to the Late Neolithic–Chalcolithic, while they also varied geographically across the Atlantic and Mediterranean regions of the Iberian Peninsula. The distribution of $\delta^{13}C$ and $\delta^{15}N$ values and Bayesian estimations for Mesolithic populations reveal diets largely dominated by C_3-terrestrial resources, here represented by ungulates. Terrestrial resources including both animals and plants were the most significant component of the diet, in agreement with other lines of evidence (Umbelino et al. 2007; Marín 2013; López-Dóriga et al. 2016). The noticeable isotopic variability also indicates highly diversified diets, with groups exploiting a variety of ecological patches and environments (Arias 2006; Fontanals-Coll et al. 2014; Salazar-García et al. 2014; Peyroteo-Stjerna 2016). Marine

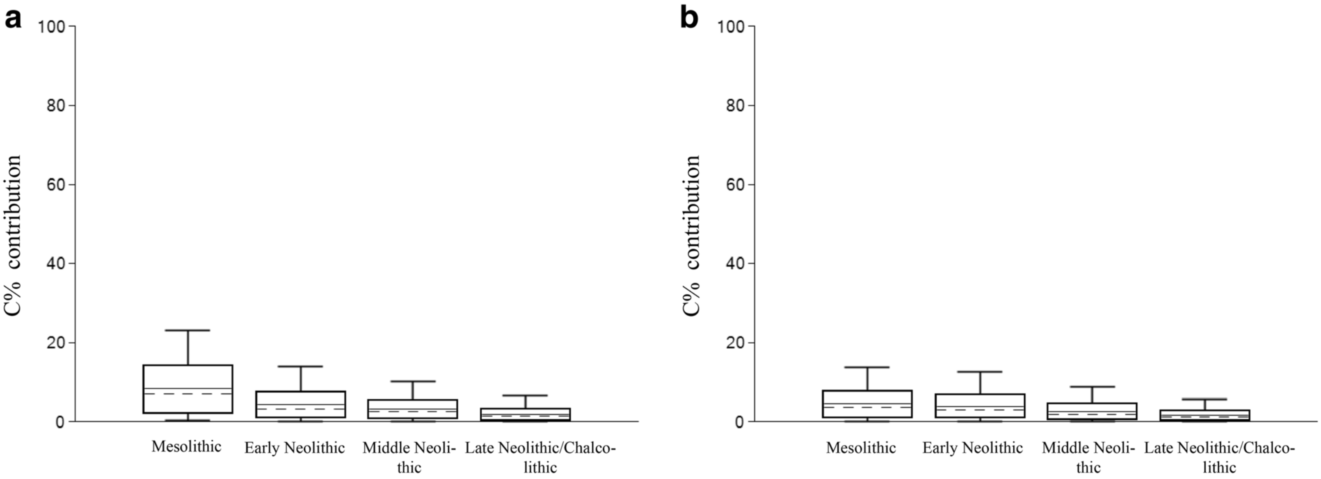


Fig. 3 Estimated marine calorie intake for the Atlantic (**a**) and Mediterranean (**b**) populations in each chronological period. Boxes represent a 68% credible interval while the whiskers represent a 95% credible interval. The horizontal continuous line represents the estimated mean and the horizontal discontinuous line represents the estimated median

Table 4 Carbon contribution (%) of terrestrial and marine resources to the diet for each population

			Terrestrial vs. marine total carbon contribution to diet (%)						
			Mean	SD	2.5pc	Median	97.5pc	16pc	84pc
Atlantic	Terrestrial	Mesolithic (*n* = 124)	91.8	6.2	76.8	93.1	99.7	85.6	97.9
		Early Neolithic (*n* = 20)	95.7	3.7	86.2	96.7	99.9	92.4	99.1
		Middle Neolithic (*n* = 174)	96.8	2.7	90	97.5	99.9	94.3	99.3
		Late Neolithic–Chalcolithic (*n* = 163)	98.1	1.8	93.4	98.6	100	96.6	99.6
	Marine	Mesolithic (*n* = 124)	8.2	6.2	0.3	6.9	23.2	2.2	14.4
		Early Neolithic (*n* = 20)	4.3	3.7	0.1	3.3	13.8	0.9	7.6
		Middle Neolithic (*n* = 174)	3.2	2.7	0.1	2.5	10	0.7	5.7
		Late Neolithic–Chalcolithic (*n* = 163)	1.9	1.8	0.1	1.4	6.6	0.4	3.4
Mediterranean	Terrestrial	Mesolithic (*n* = 26)	95.5	3.7	86.3	96.4	99.8	92.1	99
		Early Neolithic (*n* = 2)	96.1	3.3	87.5	96.9	99.9	93.1	99.1
		Middle Neolithic (*n* = 141)	97.4	2.4	91.3	98.1	99.9	95.3	99.5
		Late Neolithic–Chalcolithic (*n* = 113)	98.4	1.5	94.4	98.8	100	97	99.7
	Marine	Mesolithic (*n* = 26)	4.5	3.7	0.2	3.6	13.8	1	7.9
		Early Neolithic (*n* = 2)	3.9	3.3	0.1	3.1	12.5	0.9	7
		Middle Neolithic (*n* = 141)	2.6	2.4	0.1	1.9	8.7	0.5	4.7
		Late Neolithic–Chalcolithic (*n* = 113)	1.6	1.5	0	1.2	5.6	0.3	3

resources contributed up to 23% of dietary calories, particularly along the Atlantic coast. Consumption of marine resources by Mesolithic populations in the Atlantic region was possibly facilitated by the higher marine productivity and the larger tidal zones for shellfish gathering compared to the Mediterranean (Fa 2008).

A decline in the consumption of marine foods took place with the introduction of farming in the Early Neolithic, which is particularly noticeable in the Atlantic region, although it is important to highlight the low number of human remains dated in the Early Neolithic in the Iberian Peninsula in comparison to those dated to the Mesolithic and later periods (Fig. 1b). The paucity of data from Mediterranean regions prevents a meaningful comparison with the Atlantic, but we can expect a similar pattern (Salazar-García et al. 2018), even though archaeozoological records show that marine resources were still exploited as food in some areas (e.g. Benito 2015). Middle Neolithic individuals show the consumption of marine resources within economic contexts dominated by C_3-based terrestrial diets. Higher human $\delta^{15}N$ values during the Middle Neolithic in both Atlantic and Mediterranean Iberia have also been attributed to the consumption of freshwater resources (Carvalho et al. 2016; Fontanals-Coll et al. 2017), but these might alternatively indicate protein intake from livestock raised intensively on food leftovers (such as pigs) and/or manured plants (Albarella et al. 2007; Bogaard et al. 2007, 2013; Navarrete et al. 2017).

A definitive rupture with foraging subsistence strategies appears to have occurred during the Late Neolithic–Chalcolithic. The narrow isotopic distribution of individual diets, in particular in the Mediterranean region, suggests an intensification of farming practices in an increasingly anthropogenic landscape where productive cycles (crops and livestock) were fully integrated. While this meta-analysis does not provide qualitative information on which resources were consumed, the interpretations are generally supported by archaeozoological records showing an increasing frequency of domesticated animals from the Early to the Late Neolithic–Chalcolithic in the Iberian Peninsula (e.g. Altuna and Mariezkurrena 2009; Valente and Carvalho 2014). The isotopic distribution of the Late Neolithic–Chalcolithic therefore probably reflects the establishment and intensification of food production systems as indirectly evidenced by structural changes in settlement patterns, intensification of regional exchange networks and enhanced technological capacity (Bernabeu et al. 2013).

Conclusions

Built on a large dataset of $\delta^{13}C$ and $\delta^{15}N$ values of human and faunal remains in the available literature, this study offers a long-term, regional synthesis of the transition from foraging to farming in the Iberian Peninsula. From the Mesolithic to the Late Neolithic–Chalcolithic, humans have largely relied on C_3-based terrestrial resources for food complemented, in some coastal areas, with marine organisms. Considerable isotopic variability among Mesolithic individuals could be associated with versatile and diversified subsistence strategies, adapted to the mosaic of environmental conditions in the Iberian Peninsula. The onset of farming triggered the replacement of heterogeneous diets based on a broad spectrum of resources—including terrestrial animals from different ecological niches, marine resources and wild plants—to fully terrestrial diets dominated by farming products (crops and livestock) under increasing human control of their production cycles.

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References

Albarella U, Manconi F, Vigne JD, Rowley-Conwy P (2007) The ethnoarchaeology of traditional pig husbandry in Sardinia and Corsica. In: Albarella U, Dobney K, Ervynck A, Rowley-Conwy P (eds) Pigs and humans. 10,000 years of interactions. Oxford University Press, Oxford, pp 285–307

Alt KW, Zesch S, Garrido-Pena R, Knipper C, Szécsényi-Nagy A, Roth C, Tejedor-Rodríguez C, Held P, García-Martínez-de-Lagrán Í, Navitainuck D, Arcusa H, Rojo-Guerra MA (2016) A Community in Life and Death: The Late Neolithic Megalithic Tomb at Alto de Reinoso (Burgos, Spain). PLOS ONE 11, e0146176. https://doi.org/10.1371/journal.pone.0146176

Altuna J, Mariezkurrena K (2009) Tipos de cabañas ganaderas durante el Neolítico en el País Vasco y zonas próximas. Archaeofauna 18:137–157

Arias P (1999) The origins of the Neolithic along the Atlantic coast of continental Europe: a survey. J World Prehist 13:403–464

Arias P (2006) Determinaciones de isótopos estables en restos humanos de la Región Cantábrica Aportación al estudio de la dieta de las poblaciones del Mesolítico y del Neolítico. Munibe (Antropologia-Arkeologia) 57(3):359–374

Arias P (2012) Después de Los Azules. Las prácticas funerarias en las sociedades mesolíticas de la región cantábrica. In: Muñiz JR (ed) Ad Orientem Del final del Paleolítico en el norte de España a las primeras civilizaciones del Oriente Próximo. Universidad de Oviedo, Oviedo, pp 253–274

Arias P, Schulting RJ (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 JM, Prada ME (eds) Los hombres mesolíticos de la cueva de La Braña-Arintero (Valdelugueros León). Junta de Castilla y León (Estudios y catálogos 18), León, pp 130–137

Benito JLP (2015) El consumo de moluscos marinos durante el Neolítico antiguo en la región central del Mediterráneo peninsular. Archaeofauna 23:207–222

Bernabeu J, Moreno A, Barton M (2013) Complex systems, social networks, and the evolution of social complexity in the east of Spain from the Neolithic to pre-Roman times. In: Berrocal MC, García-Sanjuán L, Gilman A (eds) The prehistory of Iberia. Debating Early Social Stratification and the State. Routledge, New York, pp 53–73

Bogaard A, Heaton THE, Poulton P, Merbach I (2007) The impact of manuring on nitrogen isotope ratios in cereals: archaeological implications for reconstruction of diet and crop management practices. J Archaeol Sci 34:335–343. https://doi.org/10.1016/j.jas.2006.04.009

Bogaard A, Frase R, Heaton T, Wallace M, Vaiglova P, Charles M, Jones G, Evershed R, Styring A, Andersen N, Arbogast RM, Bartosiewicz L, Gardeisen A, Kanstrup M, Maier U, Marinova E, Ninov L, Schäfer M, Stephan E (2013) Crop manuring and intensive land management by Europe's first farmers. Proc Natl Acad Sci 110:12589–12594. https://doi.org/10.1073/pnas1305918110

Bonsall C, Cook GT, Pickard C, McSweeney K, Bartosiewicz L (2009) Dietary trends at the Mesolithic-Neolithic transition in North-West Europe. In: Crombé P, Van Strydonck M, Sergant J, Bioudin M, Bats M (eds) Chronology and evolution within the Mesolithic of North-West Europe. Cambridge Scholars Publishing, Newcastle upon Tyne, pp 539–562

Carvalho AF, Petchey F (2013) Stable isotope evidence of Neolithic paleodiets in the coastal regions of southern Portugal. J Isl Coast Archaeol 8:361–383

Carvalho AF, Alves-Cardoso F, Gonçalves D, Granja R, Cardoso JL, Dean RM, Gibaja JF, Masucci MA, Arroyo-Pardo E, Fernández-Domínguez E, Petchey F, Douglas Price T, Mateus JE, Queiroz PF, Callapez P, Pimenta C, Regala FT (2016) The Bom Santo Cave (Lisbon, Portugal): catchment, diet, and patterns of mobility of a middle Neolithic population. Eur J Archaeol 19:187–214. https://doi.org/10.1179/1461957115Y.0000000014

Cubas M, Altuna J, Álvarez-Fernádez E, Armendariz A, Fano MA, López-Dóriga I, Mariezkurrena K, Tapia J, Teira LC, Arias P (2016) Re-evaluating the Neolithic: the impact and the consolidation of farming practices in the Cantabrian region (northern Spain). J World Prehist 29:79–116. https://doi.org/10.1007/s10963-016-9091-2

Cunha E, Umbelino C (2001) Mesolithic people from Portugal: an approach to Sado osteological series. Antropologie XXXIX:125–132

Davis SJM, Simões T (2015) The velocity of Ovis in prehistoric times: the sheep bones from Early Neolithic Lameiras Sintra Portugal. In: O Neolítico em Portugal antes do Horizonte 2020: perspectivas em debate. Associação dos Arqueólogos Portugueses, Lisboa, pp 51–66

DeNiro MJ (1985) Postmortem preservation and alteration of in vivo bone collagen isotope ratios in relation to palaeodietary reconstruction. Nature 317:806–809. https://doi.org/10.1038/317806a0

Fa DA (2008) Effects of tidal amplitude on intertidal resource availability and dispersal pressure in prehistoric human coastal populations: the Mediterranean-Atlantic transition. Quat Sci Rev 27:2194–2209. https://doi.org/10.1016/j.quascirev.2008.07.015

Fernandes R (2015) A simple(R) model to predict the source of dietary carbon in individual consumers. Archaeometry 58:500–512. https://doi.org/10.1111/arcm12193

Fernandes R, Millard AR, Brabec M, Nadeau M-J, Grootes P (2014) Food reconstruction using isotopic transferred signals (FRUITS): a Bayesian model for diet reconstruction. PLoS One 9:e87436. https://doi.org/10.1371/journal.pone.0087436

Fernandes R, Grootes P, Nadeau M-J, Nehlich O (2015) Quantitative diet reconstruction of a Neolithic population using a Bayesian mixing model (FRUITS): the case study of Ostorf (Germany). Am J Phys Anthropol 158:325–340. https://doi.org/10.1002/ajpa.22788

Fernández-Crespo T, Schulting RJ (2017) Living different lives: early social differentiation identified through linking mortuary and isotopic variability in Late Neolithic/ Early Chalcolithic north-central Spain. PLoS One 12:e0177881. https://doi.org/10.1371/journal.pone.0177881

Fernández-López de Pablo J, Salazar-García DC, Subirà ME, Roca de Togores C, Gómez-Puche M, Richards MP, Esquembre-Bebiá MA (2013) Late Mesolithic burials at Casa Corona (Villena Spain): direct radiocarbon and palaeodietary evidence of the last forager populations in Eastern Iberia. J Archaeol Sci 40:671–680. https://doi.org/10.1016/j.jas.2012.09.005

Fischer A, Olsen J, Richards MP, Heinemeier J, Sveinbjornsdottir A, Bennike P (2007) Coast-inland mobility and diet in the Danish Mesolithic and Neolithic: evidence from stable isotope values of humans and dogs. J Archaeol Sci 34:2125–2150. https://doi.org/10.1016/j.jas.2007.02.028

Fontanals-Coll M, Subirà ME, Marín-Moratalla N, Ruiz J, Gibaja JF (2014) From Sado Valley to Europe: Mesolithic dietary practices through different geographic distributions. J Archaeol Sci 50:539–550. https://doi.org/10.1016/j.jas.2014.07.028

Fontanals-Coll M, Subirà ME, Díaz-Zorita MF, Duboscq S, Gibaja JF (2015) Investigating palaeodietary and social differences between two differentiated sectors of a Neolithic community La Bòbila Madurell-Can Gambús (north-east Iberian Peninsula). J Archaeol Sci Rep 3:160–170. https://doi.org/10.1016/j.jasrep.2015.06.013

Fontanals-Coll M, Subirà ME, Díaz-Zorita M, Gibaja JF (2017) First insight into the Neolithic subsistence economy in the north-east Iberian Peninsula: paleodietary reconstruction through stable isotopes. Am J Phys Anthropol 162:36–50. https://doi.org/10.1002/ajpa.23083

García-Guixé E, Richards MP, Subirà ME (2006) Palaeodiets of human and fauna at the Spanish Mesolithic site of El Collado. Curr Anthropol 47:549–556. https://doi.org/10.1086/504170

García-Guixé E, Subirà ME, Marlasca R, Richards MP (2010) δ^{13}C y δ^{15}N in ancient and recent fish bones from the Mediterranean Sea. Journal of Nordic Archaeological Science 17:83–92

Gibaja JF, Subirá E, Terradas X, Santos FJ, Agulló L, Gómez-Martínez I, Allièse F, Fernández-López de Pablo J (2015) The emergence of mesolithic cemeteries in SW Europe: insights from El Collado (Oliva, Valencia, Spain) radiocarbon record. PLoS One 1–18. https://doi.org/10.1371/journal.pone.0115505

Gibaja JF, Fontanals-Coll M, Dubosq S, Oms FX, Augé A, Santos FJ, Morell B, Subirà ME (2016) Human diet and the chronology of Neolithic societies in the north-east of the Iberian Peninsula: the necropolises of Puig d'en Roca and Can Gelats (Girona Spain). Archaeol Anthropol Sci 1–11. https://doi.org/10.1007/s12520-015-0311-y

Guilaine J (2017) The Neolithic transition: from the Eastern to the Western Mediterranean. In: García-Puchol O, Salazar-García D (eds) Times of Neolithic transition along the Western Mediterranean. Springer (Fundamental Issues in Archaeology), Switzerland, pp 15–32

Guiry EJ, Hillier M, Richards MP (2015) Mesolithic dietary heterogeneity on the European Atlantic coastline. Curr Anthropol 56:460–470

Guiry EJ, Hillier M, Boaventura R, Silva AM, Oosterbeek L, Tomé T, Valera A, Cardoso JL, Hepburn JC, Richards MP (2016) The transition to agriculture in south-western Europe: new isotopic insights from Portugal's Atlantic coast. Antiquity 90:604–616. https://doi.org/10.15184/aqy.2016.34

Isern N, Fort J, Carvalho AF, Gibaja JF, Ibáñez Estévez JJ (2014) The Neolithic transition in the Iberian Peninsula: data analysis and modelling. J Archaeol Method Theory 21:447–460. https://doi.org/10.1007/s10816-013-9193-4

Jackes M, Lubell D (2016) New information on Melides stable isotopes. Antiquity 90(351):617–619. https://doi.org/10.15184/aqy.2016.37

Jackes M, Alvim P, Anacleto JA, Roksandic M (2014) New photographic evidence on the 1954 excavations at Moita do Sebastião Muge Portugal. In: Roksandic M (ed) The cultural dynamics of shell middens matrix. University of New Mexico Press, New Mexico, pp 131–150

Jennings S, Reñones O, Morales-Nin B, Polunin NVC, Moranta J, Coll J (1997) Spatial variation in ^{15}N and ^{13}C stable isotope composition of plants invertebrates and fishes on Mediterranean reefs: implications for the study of trophic pathways. Mar Ecol Prog Ser 146:109–116

Jim S, Jones V, Ambrose SH, Evershed RP (2006) Quantifying dietary macronutrient sources of carbon for bone collagen biosynthesis using natural abundance stable carbon isotope analysis. Br J Nutr 95:1055–1062

Lazaridis I, Patterson N, Mittnik A, Renaud G, Mallick S, Kirsanow K, Sudmant P, Schraiber JG, Castellano S, Lipson M, Berger B, Economou C, Bollongino R, Fu Q, Bos KI, Nordenfelt S, Li H, de Filippo C, Prufer K, Sawyer S, Posth C, Haak W, Hallgren F, Fornander E, Rohland N, Delsate D, Francken M, Guinet JM, Wahl J, Ayodo G, Babiker HA, Bailliet G, Balanovska E, Balanovsky O, Barrantes R, Bedoya G, Ben-Ami H, Bene J, Berrada F, Bravi CM, Brisighelli F, Busby GB, Cali F, Churnosov M, Cole DE, Corach D, Damba L, van Driem G, Dryomov S, Dugoujon JM, Fedorova SA, Gallego Romero I, Gubina M, Hammer M, Henn BM, Hervig T, Hodoglugil U, Jha AR, Karachanak-Yankova S, Khusainova R, Khusnutdinova E, Kittles R, Kivisild T, Klitz W, Kucinskas V, Kushniarevich A, Laredj L, Litvinov S, Loukidis T, Mahley RW, Melegh B, Metspalu E, Molina J, Mountain J, Nakkalajarvi K, Nesheva D, Nyambo T, Osipova L, Parik J, Platonov F, Posukh O, Romano V, Rothhammer F, Rudan I, Ruizbakiev R, Sahakyan H, Sajantila A, Salas A, Starikovskaya EB, Tarekegn A, Toncheva D, Turdikulova S, Uktveryte I, Utevska O, Vasquez R, Villena M, Voevoda M, Winkler CA, Yepiskoposyan L, Zalloua P, Zemunik T, Cooper A, Capelli C, Thomas MG, Ruiz-Linares A, Tishkoff SA, Singh L, Thangaraj K, Villems R, Comas D, Sukernik R, Metspalu M, Meyer M, Eichler EE, Burger J, Slatkin M, Paabo S, Kelso J, Reich D, Krause J (2014) Ancient human genomes suggest three ancestral populations for present-day Europeans. Nature 513:409–413. https://doi.org/10.1038/nature13673

Lillios KT, Waterman AJ, Artz JA, Josephs RL (2010) The Neolithic-Early Bronze Age mortuary rockshelter of Bolores, Torres Vedras, Portugal. J Field Archaeol 35:19–39. https://doi.org/10.1179/009346910X12707320296630

López-Costas O, Müldner G (2016) Fringes of the empire: diet and cultural change at the Roman to post-Roman transition in NW Iberia. Am J Phys Anthropol 161:141–154. https://doi.org/10.1002/ajpa.23016

López-Dóriga I, Simões T (2015) Los cultivos del Neolítico Antiguo de Sintra: Lapiás das Lameiras y São Pedro de Canaferrim: resultados preliminares. In: Gonçalves V, Diniz M, Sousa AC (eds) Actas do 5° Congresso do Neolitico Peninsular. Centro da Arqueologia da Universidade de Lisboa, Lisboa, pp 96–105

López-Dóriga I, Diniz M, Arias P (2016) Macrobotanical remains and shell-midden formation processes are they related? The case of Poças de São Bento (Portugal). Archaeol Anthropol Sci 1–13. https://doi.org/10.1007/s12520-016-0429-6

Lubell D, Jackes M, Schwarcz H, Knyf M, Meiklejohn C (1994) The Mesolithic-Neolithic transition in Portugal: isotopic and dental evidence of diet. J Archaeol Sci 21:201–216. https://doi.org/10.1006/jasc.1994.1022

Mannino MA, Catalano G, Talamo S, Mannino G, Di Salvo R, Schimmenti V, Lalueza-Fox C, Messina A, Petruso D, Caramelli D, Richards M, Sineo L (2012) Origin and diet of the prehistoric hunter-gatherers on the Mediterranean Island of Favignana (Ègadi Islands Sicily). PLoS One 7:e49802. https://doi.org/10.1371/journal.pone.0049802

Mannino MA, Talamo S, Tagliacozzo A, Fiore I, Nehlich O, Piperno M, Tusa S, Collina C, Di Salvo R, Schimmenti V, Richards MP (2015) Climate-driven environmental changes around 8200 years ago favoured increases in cetacean strandings and Mediterranean hunter-gatherers exploited them. Sci Rep 5:16288. https://doi.org/10.1038/srep16288

Marín AB (2013) Human response to Holocene warming on the Cantabrian Coast (northern Spain): an unexpected outcome. Quat Sci Rev 81:1–11. https://doi.org/10.1016/j.quascirev.2013.09.006

Martins H, Oms FX, Pereira L, Pike AWG, Rowsell K, Zilhão J (2015) Radiocarbon dating the beginning of the Neolithic in Iberia: new results new problems. J Mediterr Archaeol 28(1):105–131. https://doi.org/10.1558/jmea.v28i1.27503

Mathieson I, Lazaridis I, Rohland N, Mallick S, Patterson N, Roodenberg SA, Harney E, Stewardson K, Fernandes D, Novak M, Sirak K, Gamba C, Jones ER, Llamas B, Dryomov S, Pickrell J, Arsuaga JL, de Castro JMB, Carbonell E, Gerritsen F, Khokhlov A, Kuznetsov P, Lozano M, Meller H, Mochalov O, Moiseyev V, Guerra MAR, Roodenberg J, Vergès JM, Krause J, Cooper A, Alt KW, Brown D, Anthony D, Lalueza-Fox C, Haak W, Pinhasi R, Reich D (2015) Genome-wide patterns of selection in 230 ancient Eurasians. Nature 528:499. https://doi.org/10.1038/nature16152

McClure SB, García-Puchol O, Culleton B (2010) AMS dating of human bone from Cova de la Pastora: new evidence of ritual community in the prehistory of eastern Spain. Radiocarbon 52:25–32

Navarrete V, Colonese A, Tornero C, Antolín F, Von Tersch M, Subirà ME, Comes P, Rossell-Melé A, Saña M (2017) Feeding management strategies among the Early Neolithic pigs in the NE of the Iberian Peninsula. Int J Osteoarchaeol 27:839–852. https://doi.org/10.1002/oa.2598

O'Connell TC, Kneale CJ, Tasevska N, Kuhnle GGC (2012) The diet-body offset in human nitrogen isotopic values: a controlled dietary study. Am J Phys Anthropol 149:426–434. https://doi.org/10.1002/ajpa.22140

Omrak A, Gunther T, Valdiosera C, Svensson EM, Malmstrom H, Kiesewetter H, Aylward W, Store J, Jakobsson M, Gotherstrom A (2016) Genomic evidence establishes Anatolia as the source of the European Neolithic gene pool. Curr Biol 26:270–275. https://doi.org/10.1016/j.cub.2015.12.019

Peña-Chocarro L, Pérez-Jordà G, Morales J (2018) Crops of the first farming communities in the Iberian Peninsula. Quat Int 470:369–382. https://doi.org/10.1016/j.quaint.2017.06.002

Pérez-Jordá G, Peña-Chocarro L, Morales Mateos J, Zapata L (2017) Evidence for early crop management practices in the Western Mediterranean: latest data new developments and future perspectives. In: García-Puchol O, Salazar-García D (eds) Times of Neolithic transition along the Western Mediterranean. Springer (Fundamental Issues in Archaeology), Switzerland, pp 171–197

Peyroteo-Stjerna R (2016) On death in the Mesolithic: or the mortuary practices of the last hunter-gatherers of the South-Western Iberian Peninsula 7th–6th millennium BCE. Department of Archaeology and Ancient History, Uppsala

R Development Core Team (2013) R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna

Remolins G, Gibaja JF, Allièse F, Fontanals M, Martin P, Masclans A, Mazzucco N, Mozota M, Oliva M, Oms X, Santos FJ, Terradas X, Subirà ME, Llovera J (2016) The Neolithic necropolis of La Feixa del Moro (Juberri, Andorra): new data on the first farming communities in the Pyrenees. C R Palevol 15:537–554. https://doi.org/10.1016/j.crpv.2015.11.005

Richards MP, Hedges REM (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. https://doi.org/10.1006/jasc.1998.0387

Richards MP, Schulting RJ, Hedges REM (2003) Archaeology: sharp shift in diet at onset of Neolithic. Nature 425:366–366. https://doi.org/10.1038/425366a

Roberts P, Fernandes R, Craig OE, Larsen T, Lucquin A, Swift J, Zech J (2018) Calling all archaeologists. Guidelines for terminology,methodology, data handling and reporting when undertaken and reviewing stable isotope applications in Archaeology. Rapid Communications in Mass Spectrometry 32:361–372. https://doi.org/10.1002/rcm.8044

Roksandic M (2006) Analysis of burials from the new excavations of the sites Cabeço da Amoreira and Cabeço da Arruda (Muge Portugal). In: Bicho N, Veríssimo H (eds) Do Epipaleolítico ao Calcolítico na Península Ibérica (Actas do IV Congresso de Arqueologia Peninsular). Centro de estudios de Patrimonio, Algarve, pp 43–54

Salazar-García DC (2009) Estudio de la dieta en la población neolítica de Costamar Resultados preliminares de análisis de isótopos estables de carbono y nitrógeno. In: Flors E (ed) Torre de la Sal (Ribera de Cabanes Castellón) Evolución del paisaje antrópico desde la Prehistoria hasta el medioevo. Servei d'Investigacions Arqueològiques i Prehistòriques, Castellón, pp 411–418

Salazar-García DC (2012) Aproximación a la dieta de la población calcolítica de La Vital a través del análisis de isótopos estables del carbono y del nitrógeno sobre restos óseos. In: Pérez G, Bernabeu J, Carrión Y, García-Puchol O, Molina L, Gómez M (eds) La Vital (Gandía Valencia) Vida y muerte en la desembocadura del Serpis durante el III y el I milenio a C. Servicio de Investigación Prehistórica del Museo de Prehistoria de Valencia (Serie de Trabajos Varios 113), Valencia, pp 139–143

Salazar-García D, Aura JE, Olaria C, Talamo S, Morales JV, Richards DA (2014) Isotope evidence for the use of marine resources in the eastern Iberian Mesolithic. J Archaeol Sci 42:231–240. https://doi.org/10.1016/j.jas.2013.11.006

Salazar-García DC, Pérez-Ripoll M, García-Borja P, Jordá Pardo J, Aura JE (2017) A terrestrial diet close to the coast: a case of study from the Neolithic levels of Nerja cave (Málaga Spain). In: García-Puchol O, Salazar-García D (eds) Times of Neolithic transition along the Western Mediterranean. Springer (Fundamental Issues in Archaeology), Switzerland, pp 281–310

Salazar-García DC, Fontanals-Coll M, Goude G, Subirà ME (2018) "To 'seafood' or not to 'seafood'?" An isotopic perspective on dietary preferences at the Mesolithic-Neolithic transition in the Western Mediterranean. Quat Int 470(B):497–510. https://doi.org/10.1016/j.quaint.2017.12.039

Saña M (2013) Domestication of animals in the Iberian Peninsula. In: Colledge S, Conolly J, Dobney K, Manning K, Shennan S (eds) The origins and spread of domestic animals in Southwest Asia and Europe. Left Coast Press, United States, pp 195–220

Sarasketa-Gartzia I, Villalba-Mouco V, le Roux P, Arrizabalaga Á, Salazar-García DC (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. https://doi.org/10.1016/j.quaint.2017.05.049

Schulting R (2011) Mesolithic-Neolithic transitions: an isotopic tour through Europe. In: Pinhasi R, Stock JT (eds) Human bioarchaeology of the transition to agriculture. Wiley-Blackwell, Oxford, pp 17–42

Skoglund P, Malmström H, Omrak A, Raghavan M, Valdiosera C, Günther T, Hall P, Tambets K, Parik J, Sjögren KG, Apel J, Willerslev E, Storå J, Götherström A, Jakobsson M (2014) Genomic diversity and admixture differs for stone-age Scandinavian foragers and farmers. Science 24:1253448. https://doi.org/10.1126/science.1253448

Stambler N (2014) The Mediterranean Sea—primary productivity. In: Goffredo S, Dubinsky Z (eds) The Mediterranean Sea. Its history and present challenges. Springer, Heidelberg, pp 113–121

Tykot RH (2002) Contribution of stable isotope analysis to understanding dietary variation among the Maya. In: Jakes K (ed) Archaeological chemistry: materials, methods, and meaning. American Chemical Society, Washington DC, pp 214–230

Umbelino C (2006) Outros sabores do Passado as análisis de oligoelementos e de isótopos estáveis na reconstituição da dieta das comunidades humanas do Mesolítico final e do Neolítico final/Calcolítico portugués. Universidade de Coimbra, Coimbra

Umbelino C, Pérez-Pérez A, Cunha E, Hipólito C, Freitas MC, Cabral JP (2007) Outros sabores do passado: um novo olhar sobre as comunidades humanas mesolíticas de Muge e do Sado através de análises químicas dos ossos. Promontoria 5:45–90

Umbelino C, Gonçalves C, Figueiredo O, Pereira T, Cascalheira J, Marreiros J, Évora M, Cunha E, Bicho N (2015) Life in the Muge Shell Middens: inferences from the new skeletons recovered from Cabeço da Amoreira. In: Bicho N, Detry C, Price DT, Cunha E (eds) Muge 150th. The 150th anniversary of the discovery of Mesolithic shellmiddens. Cambridge Scholars Publishing, Newcastle, pp 209–224

Valente MJ, Carvalho AF (2014) Zooarchaeology in the Neolithic and Chalcolithic of southern Portugal. Environ Archaeol 19:226–224. https://doi.org/10.1179/1749631414Y.0000000022

Van Der Schriek T, Passmore DG, Stevenson AC, Rolao J (2007) The palaeogeography of Mesolithic settlement-subsistence and shell midden formation in the Muge valley, Lower Tagus Basin, Portugal. Holocene 17:369–385. https://doi.org/10.1177/0959683607075839

van Klinken GJ (1999) Bone collagen quality indicators for palaeodietary and radiocarbon measurements. J Archaeol Sci 26:687–695

van Klinken GJ, Van der Plicht J, Hedges REM (1994) Bone 13C/12C ratios reflect (palaeo) climatic variations. Geophys Res Lett 21:445–448

Vis GJ, Kasse C, Vandenberghe J (2008) Late Pleistocene and Holocene palaeogeography of the Lower Tagus Valley (Portugal): effects of relative sea level, valley morphology and sediment supply. Quat Sci Rev 27:1682–1709. https://doi.org/10.1016/j.quascirev.2008.07.003

Waterman AJ (2012) Marked in life and death: identifying biological markers of social differentiation in late prehistoric Portugal. PhD Thesis, University of Iowa

Waterman AJ, Tykot RH, Silva AM (2016) Stable isotope analysis of diet-based social differentiation at Late Prehistoric Collective burials in south-western Portugal. Archaeometry 58:131–151. https://doi.org/10.1111/arcm.12159

Webb E, Lewis J, Shain A, Kastrisianaki-Guyton E, Honch N, Stewart A, Miller B, Tarlton J, Evershed RP (2017) The influence of varying proportions of terrestrial and marine dietary protein on the stable carbon-isotope compositions of pig tissues from a controlled feeding experiment. Science & Technology of Archaeological Research 3:36–52. https://doi.org/10.1080/20548923.2016.1275477

Zilhão J (2000) From the Mesolithic to the Neolithic in the Iberian Peninsula. In: Price D (ed) Europe's first farmers. Cambridge University Press, Cambridge, pp 144–182

Zilhão J (2001) Radiocarbon evidence for maritime pioneer colonization at the origins of farming in west Mediterranean Europe. Proc Natl Acad Sci 98:14180–14185. https://doi.org/10.1073/pnas.241522898