

1      Stable isotope approach to farming and husbandry practices at the  
2      Phoenician site of Castro Marim between 7<sup>th</sup> – 5<sup>th</sup> century BCE

3      Roshan Paladugu<sup>\*,a,b,c</sup>, Alessandra Celant<sup>\*\*,c</sup>, Federico Di Rita<sup>\*\*,c</sup>, Ana Margarida Arruda<sup>\*\*,d</sup>, Elisa de  
4      Sousa<sup>\*\*,d</sup>, Anne-France Maurer<sup>\*\*,a,b</sup>, Donatella Magri<sup>\*\*,c</sup>, Cristina Barrocas Dias<sup>\*,a,b</sup>

5      <sup>a</sup>Departamento de Química, Escola de Ciências e Tecnologia, Universidade de Évora, Colégio Luís António Verney, Rua  
6      Romão Ramalho 59, Évora, Portugal (7000-671)

7      <sup>b</sup>Laboratório HERCULES, Universidade de Évora, Palácio do Vimioso, Largo Marquês de Marialva 8, 7000-554 Évora,  
8      Portugal

9      <sup>c</sup>Dipartimento di Biologia Ambientale, SAPIENZA Università di Roma, Piazzale A. Moro 5, 00185 Roma, Italy

10     <sup>d</sup>Centro de Arqueologia da Universidade de Lisboa, Faculdade de Letras da Universidade de Lisboa, Alameda da Universidade,  
11     1600-214, Lisboa, Portugal

12     **Abstract**

Castro Marim is an Iron Age site from the Algarve region, Portugal. The earliest evidence of settlement, from the Late Bronze Age, dates to the 9<sup>th</sup> century BCE, with the Phoenician-Punic period dating from the 7<sup>th</sup> to the 3<sup>th</sup> century BCE. This study focuses on the stable isotope analysis of plant and collagen of faunal remains to reconstruct the cultivation and husbandry practices. Barley was the most abundantly cultivated cereal crop. The stable isotope results of barley indicate that it depended primarily on natural precipitation with a certain intensity of manuring. The differences from stable isotope data of domesticated fauna indicate a diverse management strategy for different species based on their economic importance and to capitalize from the animal by-products such as wool and dairy products.

13     **Key words:** Archaeobotany, Zooarchaeology, Agriculture, Portugal, Iron Age

14     **1. Introduction**

15     The Iberian Peninsula underwent Oriental colonization originating from the Near East during the 9<sup>th</sup>  
16     century BCE. These colonizers, referred to as Phoenicians, were mostly culturally homogeneous and politically  
17     independent city-states with the Levant's power nucleus (present-day Lebanon) (Aubet, 1987; Dietler, 2009;  
18     Gomes and Arruda, 2018; Quinn, 2019). The city-states served as nodes of an expansive trade network across  
19     the Mediterranean, including the Atlantic coast of Europe (Arruda, 2000; Aubet, 2001; Markoe, 2005). It is  
20     widely accepted that the main driving force behind this westward expansion was the need to establish a stable  
21     supply of metalliferous resources (Arruda, 2009; Aubet, 2001; Aubet, 1987; Eshel et al., 2019; Markoe, 2005).  
22     Phoenicians, through the establishment of agreements and negotiations with the native Iberian communities,  
23     mined the Iberian Pyrite belt for silver, tin, lead, and copper in the early 8<sup>th</sup> century BCE (Eshel et al., 2019;  
24     Renzi et al., 2012; Wood et al., 2019). These mined metals were hauled back to the inner Mediterranean  
25     region through their well-established networks through posts along the rivers and the southern shore of the  
26     Iberian Peninsula (Eshel et al., 2019).

27     The intense and prolonged settlements along the Southern Iberian coast cannot simply be explained by  
28     the quest for mineral sources, primarily because a considerable part of them are situated in locations with  
29     neither metallogenic minerals nor pre-existing indigenous settlements. This settlement pattern is further

---

\*Corresponding Author

\*\*Equal contribution

Email addresses: rpaladugu@uevora.pt (Roshan Paladugu), alessandra.celant@uniroma1.it (Alessandra Celant), federico.dirita@uniroma1.it (Federico Di Rita), ana2@campus.ul.pt (Ana Margarida Arruda), e.sousa@campus.ul.pt (Elisa de Sousa), annefrance.maurer@gmail.com (Anne-France Maurer), donatella.magri@uniroma1.it (Donatella Magri), cmbd@uevora.pt (Cristina Barrocas Dias)

30 emphasized by the contrast between the densely clustered settlements of Iberia and the sparsely scattered  
31 settlements of North Africa. Other factors influencing settlement density include agricultural resources  
32 (Wagner and Alvar, 2003; Wagner and Alvar, 1989), exploitation of marine resources (e.g., salt (Manfredi,  
33 1992), Tyrrhenian Purple production (Uriel, 2000)), timber (Treumann, 2009; Treumann, 1998), and labor  
34 force (Arrastio, 2000, 1999). The Phoenician traders had to ensure stable sources of food for the population  
35 apart from the industrial activities. Southwestern Iberia has been noted for its rich mineral veins and  
36 abundant natural fertility, and the Phoenicians exploited this fertile landscape while actively transforming  
37 it, including cultivable land (Arruda, 2009, 2003; Neville, 1998; Roller, 2014). While the Phoenician metal  
38 exploitation perspective has been studied, the agricultural aspects have received little attention so far. This  
39 study aims to shed light on the farming strategies and animal husbandry practices in the Phoenician – Punic  
40 period of Portugal, specifically at Castro Marim, based on the stable isotope approach.

## 41 2. Context

### 42 2.1. Phoenician - Punic Agriculture

43 Most knowledge about Phoenician and Punic agriculture comes from the famous treaty by Mago, of  
44 which only a few fragments have survived and subsequently translated (Martin, 1971). Other accounts are by  
45 authors from the Greek and Roman domains, usually written centuries after the pinnacle of the Phoenician  
46 – Punic cultures. The current understanding has been mainly developed due to systematic excavations of  
47 different Phoenician – Punic settlements in Iberia and subsequent zooarchaeological and archaeobotanical  
48 studies on the recovered faunal and plant remains (Aubet, 2001; Wagner and Alvar, 2003; Wagner and  
49 Alvar, 1989). The Southwest Iberian region has been praised by Strabo (3, 2, 8) for possessing the rare  
50 combination of abundant mineral deposits and natural fertility (Roller, 2014). From the 9<sup>th</sup> century BCE,  
51 the Phoenician presence is noted in the Iberian Peninsula along the Mediterranean and Atlantic coastal zone.  
52 This strategic location gave them reasonable access to the sailing routes and provided them with a plethora  
53 of cultivable land (Aubet, 2001). Colonies in Iberia were located in a landscape similar to that in the Levant  
54 with proximity to the coast and marked with steep mountain ranges and riverine valleys. Being located in a  
55 river valley gave the colonizers the ease of adapting existing practices from the Mediterranean in the Iberian  
56 hinterland. This included modifying and adapting the landscape to suit their agricultural needs, comprising  
57 farming and animal husbandry (Gómez Bellard, 2019).

58 Agricultural techniques from the East, such as irrigation, were probably used to improve upon the native  
59 practices, at least in some areas. The iron production technology gave more robust implements such as  
60 plowshare, to the farmers. Better yielding cultivars (e.g., grapes and olives) and new species of animals  
61 (e.g., horse, donkey, and chicken) were introduced (Davis, 2007; Queiroz et al., 2006; Van Leeuwaarden and  
62 Janssen, 1985). Following the “sixth century crisis”, in the period referred to as the Punic period. This  
63 economic change brought a drastic change in space use concerning both settlement and domain. In the latter  
64 phase of the Iron Age, in addition to the cultivation of cash crops and wine, local usable arboreal products  
65 such as timber and fruits were identified and exploited to boost exports (Gómez Bellard, 2019; Neville,  
66 1998). The exploitation of arboreal products and perennial crops meant the existence of both short-term and  
67 long-term agricultural investments. Such diverse investments with different harvest times must have led to  
68 the development of a complex agricultural economy.

### 69 2.2. Site background

70 Castro Marim is located on the Guadiana estuary (Fig. 1) as a portal to the metallogenic mineral-rich  
71 Baixo – Alentejo region as well as to the fertile cultivable lands in the interior regions. The Iron Age settlement  
72 was located on an elevation with adequate natural defensive elements and overlooked vast swatches of land,  
73 which allowed domination of estuarine traffic and agricultural activities in its domain of influence. These  
74 conditions allowed trade and cultural networks between the indigenous communities and the Mediterranean  
75 communities to flourish. The earliest Iron Age occupation of the site is characterized by East-West orthogonal  
76 settlement architecture dating from the first half of 7<sup>th</sup> century BCE, in the Orientalising period (Arruda  
77 et al., 2013; Arruda, 1996). This earliest Iron Age occupation corresponds to Castro Marim’s phase II (1<sup>st</sup>

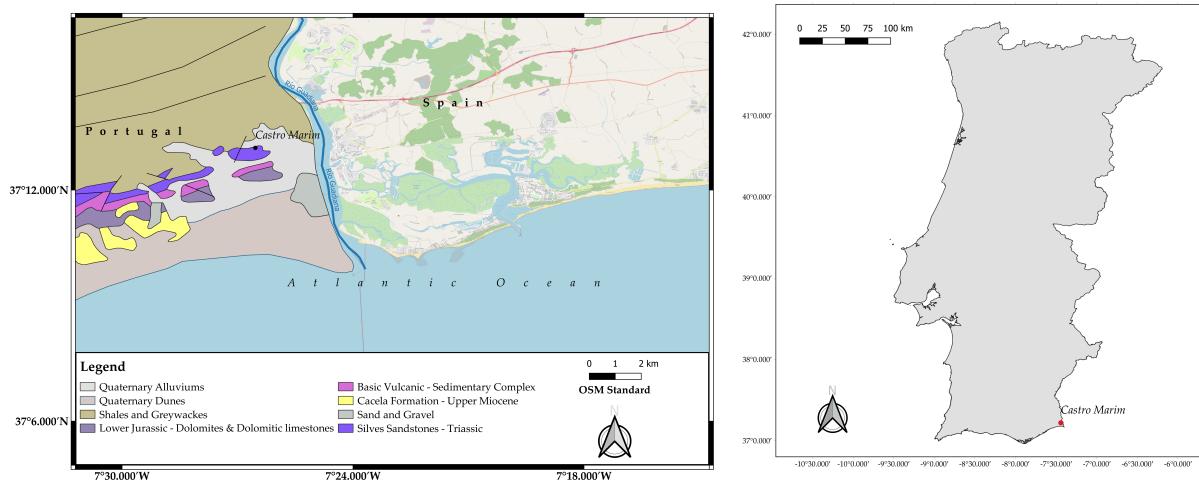


Figure 1: Geological map of the region around Castro Marim on the banks of Guadiana River, Algarve Region of Portugal (Source: Directorate General of Mines and Geological Services - Carta de Geológica de Portugal).

half of the 7<sup>th</sup> century BCE), III (2<sup>nd</sup> half of the 7<sup>th</sup> century BCE) and IV (6<sup>th</sup> century BCE). Phoenician imports and other evidence for human presence declined from the second half of the 6th century BCE till the first half of the 5<sup>th</sup> century BCE (Arruda, 1996). Significant changes in material culture and restructuring of the settlement architecture with a Northeast – Southwest orientation are observed from the second half of the 5<sup>th</sup> century BCE (Arruda et al., 2013, 2006; Arruda and Freitas, 2008). The earlier period's departure was marked by imports from Greek products – specifically ceramics such as *kilikes*, *skyphoi*, and *kantharoi* (Arruda et al., 2020; Arruda, 1997). This resurgence put Castro Marim back in the main commercial circuits along the Iberian Peninsula's Atlantic coast till the 3<sup>rd</sup> century BCE (Arruda et al., 2013, 2006; Arruda, 2000; Sousa, 2019). The Phoenician – Punic period is represented by archaeological phases III, IV, and V.

Being in a littoral zone made it was possible to adopt a wide range of agricultural strategies and husbandry practices at Castro Marim. The presence of cereals (*Hordeum* and *Triticum*), grapes (*Vitis vinifera/sylvestris*), pulses (*Vicia* and *Cicer*), and other cultivated species (*Olea* and *Coriandrum*), as well as the exploitation of wild woody plants (*Pinus* and *Arbutus* etc.) have been elucidated from the archaeological record (Queiroz et al., 2006). Animals recovered from the excavation (native to Portugal) include cattle (*Bos taurus*), goat (*Capra hircus*), sheep (*Ovis aries*), pig (*Sus scrofa/domesticus*), red deer (*Cervus elaphus*), and rabbit (*Oryctolagus cuniculus*) (Davis, 2007). The arrival of chicken (*Gallus domesticus*) has been documented, being introduced in the second half of 5<sup>th</sup> century BCE (Davis, 2007).

### 2.3. Environmental Settings

Landscape surrounding during the Iron Age was quite different from what it is in modern times. Paleoogeographic reconstruction based on geophysical and lithological data of the Guadiana estuary indicates muddy-bottom shallow estuarine setting at the mouth of the river during the Phoenician period, with the Iron Age settlement situated on a ridge projecting northward (Fig. 2) with a Pleistocene/mid-Holocene bedrock platform (Wachsmann et al., 2009). After the arrival of Phoenicians (874 BCE), there was a decline in pinewood, *Quercus* forest, and sclerophyllous thickets with an increase in scrub vegetation consisting of fire-adapted Cistaceae and Ericaceae (Fletcher et al., 2007). This is due to prevailing warm and dry climatic conditions corresponding to a more arid regime across southern Iberia (Jalut et al., 2000; Magny et al., 2002).

### 2.4. Archaeobotanical assessment

The original archaeobotanical assessment was carried out by Queiroz et al. (2006). Cereals make up the most significant fraction of the carpological remains. The bulk of cereals is barley (*Hordeum vulgare*)

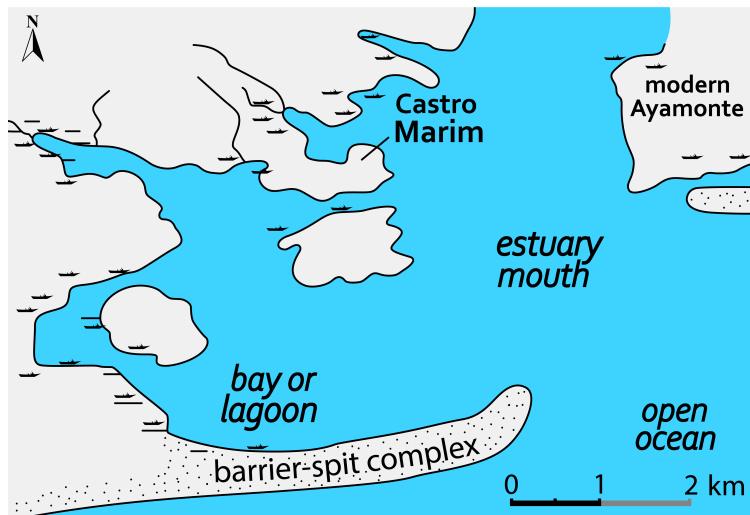


Figure 2: Reconstruction of the Guadiana estuary during the Phoenician period based on geophysical and lithological data (adapted from Wachsmann et al. (2009)).

107 with a tiny fraction of wheat (*Triticum durum/aestivum*). Pulses are mainly broad beans (*Vicia faba*)  
 108 and chickpeas (*Cicer arietinum*), of which the former has been present in Portugal since prehistoric times,  
 109 whereas the latter is introduced as a luxury food in the Roman period from Asia. The presence of grape  
 110 (*Vitis vinifera/sylvestris*) pips and charred wood is typical, starting from the Roman period in Portugal.  
 111 The presence of grape pips in Iron Age Castro Marim indicates cultivation by the local population. The  
 112 most exciting carpological remains are of coriander (*Coriandrum sativum*) which is not native to Portugal  
 113 and was supposed to be introduced during medieval times, making this the earliest coriander occurrence in  
 114 Portugal. Charred pine, oak, ash, and poplar wood were recovered abundantly. The exploitation of wild  
 115 woody plants for timber and fruits marks the Phoenician colonization of the Iberian peninsula. Due to  
 116 unforeseen circumstances, these identified remains could not be accessed for isotope analyses. Previously  
 117 unprocessed sediments were studied again to gain plant remains.

#### 118 2.5. Zooarchaeological assessment

119 Ovicaprids (sheep and goats) followed by pigs and cattle dominate the Castro Marim mammal taxa  
 120 (Davis, 2007). Both sheep and goats were equally represented with negligible fluctuations throughout the  
 121 Iron Age at Castro Marim. The wild species in the assemblage consisted mainly of red deer and rabbits.  
 122 Both the species (red deer and rabbits) are present consistently in all the phases of the settlement. It is  
 123 worth mentioning here that no morphometric distinction could be made between wild and domesticated pigs.  
 124 There is a spike in the presence of bird remains in the later phases of the Iron Age (Phase IV - V), primarily  
 125 due to the introduction of domesticated chicken. The presence of partridge, a common wild species of Iberia,  
 126 is also noted. Unlike the chicken, partridge has never been domesticated. Ovicaprids and cattle were kept  
 127 well into maturity indicating that they were prized more for their secondary purposes than their meat. Sheep  
 128 and goats were kept for their milk and wool, usually slaughtered after they reach at least two years of age.  
 129 Cattle were valued for their power to plow in the fields as well as to pull heavy loads. Also, they too, were a  
 130 source of milk. Pigs, on the other hand, were slaughtered as juveniles as they were primarily reared for meat.  
 131 Most of the red deer found were adults, suggesting a hunting preference of that period as a vital subsidiary  
 132 source of meat. Chicken seems to be slaughtered at a young age, whereas the partridges at an adult age.  
 133 The slaughter age indicates the domesticated status of chicken and wild status of partridge, respectively.

134 **3. Methodological approach**

135 *3.1. ZooMS Analysis of Ovicaprids*

136 Skeletal elements of goats and sheep are a common occurrence in archaeological contexts. A significant  
137 issue plaguing comparative husbandry studies between sheep and goats is the overlap of skeletal elements  
138 (Boessneck et al., 1964; Payne, 1969; Schramm, 1967). Zooarchaeology through mass spectrometry applies  
139 peptide mass fingerprinting to identify archaeological remains (Buckley et al., 2009). The main protein used  
140 for this is collagen, which is the most abundant protein in bone. Due to sequence differences in collagen of  
141 sheep and goat, ZooMS is able to differentiate between these two species, which is often not possible using  
142 standard morphological analysis (Buckley et al., 2010).

143 *3.2. Stable isotope analysis of plants and animals*

144 Stable isotope ( $\delta^{13}C$ , and  $\delta^{15}N$ ) analyses of faunal bone collagen are valuable means of reconstructing  
145 foddering practices and other animal husbandry aspects (Price et al., 2017). The variation in  $\delta^{13}C$  of  
146 terrestrial organisms is determined by the primary producers' photosynthetic pathway, distinguished as C<sub>3</sub>,  
147 C<sub>4</sub>, and CAM plants (DeNiro and Epstein, 1978; Farquhar et al., 1989; Kohn, 2010; Tieszen, 1991). Plant  
148 species are overwhelmingly C<sub>3</sub> in nature, including most cultivated plants such as barley, wheat, oats, and  
149 other wild edible plants (Fernández-Crespo et al., 2019). C<sub>4</sub> plants consist primarily of tropical grasses,  
150 millets, sugarcane, corn, and sorghum. C<sub>4</sub> plants thrive in warm and high-temperature environments and  
151 thus are restricted to coastal zones in regions with temperate climates (Leegood, 2013; Price et al., 2017).  
152 The analysis of faunal bones can help in determining whether these animals ate C<sub>3</sub> or C<sub>4</sub> plants, as there is  
153 an enrichment in  $\delta^{13}C$  between diet and consumers (5‰ for herbivores and 0-2‰ between trophic levels  
154 (Bocherens and Drucker, 2003)).  $\delta^{13}C$  measurements are also helpful to differentiate between terrestrial C<sub>3</sub>  
155 and aquatic food sources (Froehle et al., 2010; Kellner and Schoeninger, 2007).

156  $\delta^{15}N$  values indicate the trophic position (herbivore, omnivore, carnivore) of consumers in a food chain  
157 (Hedges and Reynard, 2007; Price et al., 2017; Schoeninger, 1985), with an enrichment between diet and  
158 consumer of around 3-5‰ (Hedges and Reynard, 2007; Schoeninger, 1985).  $\delta^{15}N$  values can also be used  
159 to distinguish between terrestrial and marine diets (Deniro and Epstein, 1981; Webb et al., 2017), and the  
160 consumption of manured, and unmanured crops (Bogaard et al., 2013; Deniro and Epstein, 1981; Fernández-  
161 Crespo et al., 2019; Fraser et al., 2013).  $\delta^{34}S$  of bone collagen from terrestrial species is often measured  
162 along with  $\delta^{13}C$  and  $\delta^{15}N$  to identify consumption of marine foods (Nehlich et al., 2010).

163 The mean  $\delta^{34}S$  value of terrestrial sources is assumed to be 0‰ (Nehlich, 2015). Inorganic sulphur enters  
164 the food web through plants from the weathered bedrock (in a complete terrestrial setting), precipitation  
165 (sea spray), and microbial activity due to flooding events (Nitsch et al., 2019). As the inorganic sulphur  
166 passes through the food web in the form of proteins, only a negligible fractionation occurs between diet and  
167 consumer (Hobson, 1999; Nehlich, 2015). Thus, the  $\delta^{34}S$  ratio of collagen closely reflects that of the native  
168 water source, bedrock, and soluble sulphur-bearing minerals.

169 There are two significant inputs that humans can manipulate to cultivate plants: water and nitrogen  
170 input, which can be investigated using stable isotopes. Variation in  $\delta^{13}C$  values of plants is primarily due to  
171 water availability as any dry spells affect the movement of carbon dioxide through the stomata (Ferrio et al.,  
172 2007; Ferrio et al., 2005; Fiorentino et al., 2015). The water status of crops can be artificially controlled by  
173 irrigation regimes, reflected in  $\delta^{13}C$  values (Ferrio et al., 2005; Wallace et al., 2013).  $\delta^{13}C$  values measured  
174 in archaeological plants must be converted to carbon discrimination values to be compared with those of the  
175 modern crops grown under controlled watering regimes (Farquhar et al., 1989; Wallace et al., 2013):

$$\Delta^{13}C = \frac{\delta^{13}C_{air} - \delta^{13}C_{plant}}{1 + \delta^{13}C_{plant}/1000}$$

176 Another major factor, which affects the  $\delta^{13}C$  measurements of plants, is the canopy effect, where forested  
177 areas are more depleted in the heavier  $^{13}C$  isotope compared to open areas (Bonafini et al., 2013). Thus, the  
178  $\delta^{13}C$  measurements of plants are the result of multiple factors and should be interpreted with caution.

179 One of the most ancient practices to increase soil fertility is by manuring with animal waste, as animal  
180 manure is much higher than endogenous soil in terms of nitrogen isotopic composition (Bogaard et al., 2013).  
181 Usually, the plants treated with manure exhibit higher  $\delta^{15}N$  values (as much as 10‰) when compared to  
182 unfertilized plants (Bogaard et al., 2007; Fraser et al., 2011). The  $\delta^{13}C$  and  $\delta^{15}N$  values themselves do not  
183 reveal the agricultural practices but reveal patterns when interpreted within a specific site.

## 184 4. Materials and Methods

### 185 4.1. Sample Selection

186 Fifty faunal bone samples (Table 1) from conclusively adult individuals as well as 9 charred plant  
187 macro-remains of *Hordeum vulgare* subsp. *vulgare*, *Hordeum vulgare* subsp. *nudum*, and *Pinus* sp. each  
188 have been selected for this study. The sampled faunal bones represent the Phoenician – Punic period of the  
189 settlement (phases III, IV, and V), whereas the charred plant macro – remains are only from phase V due to  
190 the absence of plant remains only from the older phases.

### 191 4.2. Archaeobotanical Analysis

192 200 grams of sediment from each stratigraphic layer of the excavation site was weighed and handpicked  
193 for plant macro remains (seeds/fruits and charcoal). The recovered remains were examined under a  
194 stereomicroscope and taxonomically identified (Table 2).

### 195 4.3. Bone Preservation: Fourier Transform Infrared Spectroscopy

196 500 – 700 mg of bone was cut using a DREMEL® rotary drill with a diamond disc and cleaned of dirt,  
197 discoloration, and other foreign content with a dental burr. Compact bone was sampled over spongy bone.  
198 Bone fragments were slightly polished with fine sandpaper to obtain a flat surface (Hollund et al., 2013).  
199 Infrared spectra were collected using a Bruker® Alpha™ Spectrometer with a single-reflection diamond crystal  
200 ATR module. Each spectrum was obtained by an accumulation of 128 scans with a spectral resolution  
201 of 4 cm<sup>-1</sup>, from 2000 cm<sup>-1</sup> to 375 cm<sup>-1</sup>. Infrared Splitting Factor (IRSF) and relative carbonate content  
202 (C/P) were calculated using absorbance heights at 565 cm<sup>-1</sup>, 590 cm<sup>-1</sup>, 605 cm<sup>-1</sup>, 1035 cm<sup>-1</sup>, and 1415 cm<sup>-1</sup>  
203 wavenumbers (Trueman et al., 2008; Weiner and Bar-Yosef, 1990; Wright and Schwarcz, 1996).

### 204 4.4. Pretreatment of plant macro-remains

205 In carbonized plant macro-remains, barley grain samples consist of at least ten whole grains, and pine  
206 samples consist of shell fragment. Morphologically intact samples were chosen after examination under  
207 a stereomicroscope (7-45x magnification) and removing any visibly adhering foreign contaminant. An  
208 acid-base-acid (ABA) treatment was applied as a pre-treatment (Bogaard et al., 2013; Fraser et al., 2013).  
209 First, the samples were treated with 10 mL of 0.5 M HCl at 70 °C for 60 minutes (or until effervescent stops)  
210 and then rinsed with ultrapure water until a neutral pH was achieved. 10 mL of 0.1 NaOH solution was  
211 added to the samples at 70 °C for 60 minutes and then rinsed with ultrapure water to achieve a neutral pH.  
212 Finally, the samples were treated with 0.5 M HCl at 70 °C for 30-60 minutes, followed by three rinses with  
213 ultrapure water and subsequent freeze-drying.

### 214 4.5. Collagen Extraction

215 The modified Longin (1971) method was used to extract collagen from faunal bones pieces previously  
216 analysed with FTIR were demineralised (Richards and Hedges, 1999). Approximately 600 mg of bone sample  
217 was demineralized using 0.5 M HCl at 4 °C for a fortnight with daily vortex and an acid change after 7  
218 days. Repeated rinses with ultrapure water to reach neutral pH were performed, and the demineralized  
219 bones were subjected to an overnight treatment in 0.125 M NaOH at room temperature to remove fulvic  
220 and humic acid contamination. The samples were then rinsed repeatedly with ultrapure water to achieve  
221 neutrality and gelatinized in 0.01 M HCl at 70 °C for 48 hours. The impurities were separated by filtering the  
222 collagen-containing liquid fraction using Ezee – Filter™ filters (Elkay® Laboratory Products). The solubilized  
223 collagen was frozen and subsequently lyophilized for 48 hours.

224 *4.6. ZooMS analysis*

225 A small subsample of the extracted collagen was placed into a microfuge tube and 100  $\mu\text{L}$  50mM  
226 ammonium bicarbonate (Ambic) was added to the samples. The samples were digested overnight using 1  $\mu\text{L}$   
227 of 0.5  $\mu\text{g}/\mu\text{L}$  porcine trypsin (Promega<sup>®</sup>, UK) at 37 °C and the digestion was stopped by the addition of  
228 trifluoroacetic acid (TFA) at a concentration of 0.5–1 of the total solution. The samples were desalted using  
229 C18 zip-tips (van Doorn et al., 2011) and eluted using 100  $\mu\text{L}$  of 50% acetonitrile (ACN)/0.1 TFA (v/v).  
230 The zip-tipped samples were spotted in triplicate onto a MTP384 Bruker ground steel MALDI target plate;  
231 1  $\mu\text{L}$  of sample was pipetted onto each sample spot and then mixed with 1  $\mu\text{L}$  of  $\alpha$ -cyano-4-hydroxycinnamic  
232 acid matrix solution (1 in 50 acetonitrile / 0.1 trifluoroacetic acid (v/v/v)).

233 The samples were analysed on a Bruker<sup>®</sup> Ultraflex III<sup>TM</sup> MALDI-ToF mass spectrometer. The resulting MS  
234 spectra were analysed using mMass (Strohalm et al., 2010) an Open Source mass spectrometry interpretation  
235 tool. The three spectra for each sample were averaged and the averaged spectrum was cropped between 800  
236 and 3000 m/z and peak picking was carried out using a signal to noise ratio of 6. The resulting spectra were  
237 compared to a publicly available ZooMS database.

238 *4.7. Stable carbon and nitrogen isotope analysis*

239 An amount of 0.5 - 0.7 mg of freeze-dried collagen powder/barley grain samples were weighed in tin  
240 capsules and combusted in an elemental analyzer (EA) with oxygen (Flash 2000 HT<sup>TM</sup>, Thermo Fisher  
241 Scientific<sup>®</sup>, Bremen, Germany) using pure helium as carrier gas. Isotopic ratios were obtained on a Delta  
242 V Advantage Continuous Flow<sup>TM</sup> – Isotope Ratio Mass Spectrometer (Thermo Fisher Scientific<sup>®</sup>, Bremen,  
243 Germany). The raw machine output was normalised by a three-point calibration using international standard  
244 reference materials (SRM), namely IAEA-CH-6 (sucrose,  $\delta^{13}\text{C} = -10.499\text{\textperthousand}$ ), IAEA-600 (caffeine,  $\delta^{13}\text{C} = -$   
245 27.771‰;  $\delta^{15}\text{N} = +1\text{\textperthousand}$ ), and IAEA-N-2 (ammonium sulphate,  $\delta^{15}\text{N} = +20.3\text{\textperthousand}$ ) and in-house standard  
246 L-Alanine ( $\delta^{13}\text{C} = -18.5\text{\textperthousand}$ ;  $\delta^{15}\text{N} = +1.1\text{\textperthousand}$ ). The standards were regularly (after eleven analyses) included  
247 in the analytical routine to correct for instrumental drifts. The isotope values are expressed in per mil  
248 (‰) relative to VPDB (Vienna Pee-Dee Belemnite) for carbon and AIR (Ambient Inhalable Reservoir) for  
249 nitrogen. In order to correct for charring effect in plant remains, 0.11‰ and 0.31‰ were subtracted from  
250 their  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values, respectively (Nitsch et al., 2015). The fluctuations in  $\delta^{13}\text{C}$  of the atmospheric  
251 CO<sub>2</sub> throughout the Holocene were considered while interpreting the stable carbon isotope ratios. The  $\delta^{13}\text{C}$   
252 of atmospheric CO<sub>2</sub> during the period in the study was approximated using the AIRCO<sub>2</sub>\_LOESS system,  
253 and then this value was used to compute the  $\delta^{13}\text{C}$  discrimination of plants independent of the source CO<sub>2</sub>  
254 (Farquhar et al., 1982; Ferrio et al., 2005).

255 *4.8. Stable sulphur isotope analysis*

256 The collagen samples were combusted with additional V<sub>2</sub>O<sub>5</sub> and an oxygen pulse (IsoPrime<sup>TM</sup> Mass  
257 spectrometer, Elementar Analysensysteme GmbH<sup>®</sup>, Langenselbold, Germany). Calibration of  $\delta^{34}\text{S}$  values  
258 was performed using international inorganic standards for stable sulphur isotope analysis: NBS127 (+20.3‰)  
259 and IAEA S1 (-0.3‰). B2155 protein (+6.96 ± 0.04‰) was used as an internal quality control standard.  
260 Stable sulphur isotope values are reported in parts per thousand relative to Vienna-Canyon Diablo Troilite  
261 (VCDT).

262 *4.9. Statistical Analysis*

263 The obtained data were subjected to statistical analysis using R programming language (R Core Team,  
264 2020; Wickham, 2016). Initially, means and standard deviations were calculated per species. Z-scores were  
265 calculated to detect the presence of outliers. Deviance from normal distribution was assessed using the  
266 Shapiro-Wilks test. F-tests were first used to check for significant equal variance, and subsequently, unpaired  
267 Student's t-tests were used for two-sample comparison since all the datasets were normally distributed.

268 **5. Results and Discussion**

269 **5.1. Bone Preservation**

Table 1: Collagen yield and FT-IR results (IRSF and C/P) of selected faunal bone samples.

Sample ID	Species	Phase	Collagen yield (%)	IRSF	C/P
CMOF779	<i>Pluvialis squatarola</i>	III	2.5	2.43	0.26
CMOF777	<i>Rissa tridactyla</i>	V	3.9	3.37	0.40
CMOF756	<i>Alectoris rufa</i>	IV	8.8	2.53	0.33
CMOF737	<i>Alectoris rufa</i>	V	6.3	2.79	0.23
CMOF710	<i>Gallus domesticus</i>	V	4.5	2.63	0.25
CMOF774	<i>Gallus domesticus</i>	V	10.5	2.87	0.35
CMOF750	<i>Gallus domesticus</i>	V	6.0	2.65	0.41
CMOF751	<i>Gallus domesticus</i>	V	31.1	3.28	0.31
CMOF772	<i>Gallus domesticus</i>	V	3.1	2.91	0.22
CMOF743	<i>Gallus domesticus</i>	V	4.5	2.74	0.22
CMOF746	<i>Gallus domesticus</i>	V	24.7	2.54	0.28
CMOF744	<i>Gallus domesticus</i>	V	6.5	2.37	0.41
CMOF731	<i>Gallus domesticus</i>	V	10.4	2.54	0.30
CMOF730	<i>Gallus domesticus</i>	V	15.8	2.48	0.30
CMOF709	<i>Gallus domesticus</i>	V	29.1	3.12	0.40
CMOF745	<i>Gallus domesticus</i>	V	4.5	2.83	0.30
CMOF158	<i>Sus scrofa</i>	III	5.1	2.78	0.40
CMOF439	<i>Sus scrofa</i>	IV	6.6	3.24	0.25
CMOF354	<i>Sus scrofa</i>	IV	41.4	2.75	0.28
CMOF253	<i>Sus scrofa</i>	IV	16.2	2.65	0.37
CMOF338	<i>Sus scrofa</i>	V	6.0	2.61	0.22
CMOF466	<i>Sus scrofa</i>	V	19.8	2.59	0.23
CMOF323	<i>Sus scrofa</i>	V	2.6	3.33	0.29
CMOF435	<i>Bos taurus</i>	III	10.9	2.98	0.21
CMOF370	<i>Bos taurus</i>	III	41.6	2.78	0.38
CMOF402	<i>Bos taurus</i>	III	12.3	2.45	0.36
CMOF201	<i>Bos taurus</i>	IV	29.1	2.96	0.37
CMOF480	<i>Bos taurus</i>	IV	10.8	2.56	0.40
CMOF147	<i>Bos taurus</i>	IV	19.8	2.62	0.40
CMOF468	<i>Bos taurus</i>	V	22.9	3.27	0.30
CMOF393	<i>Bos taurus</i>	V	36.2	2.39	0.42
CMOF94	<i>Bos taurus</i>	V	34.0	3.14	0.37
CMOF397	<i>Capra hircus</i>	III	13.3	2.87	0.43
CMOF181	<i>Capra hircus</i>	III	24.6	2.97	0.26
CMOF420	<i>Capra hircus</i>	IV	19.8	2.66	0.21
CMOF673	<i>Capra hircus</i>	IV	20.9	2.40	0.37
CMOF660	<i>Capra hircus</i>	IV	4.0	2.60	0.28
CMOF14	<i>Capra hircus</i>	V	7.9	2.59	0.34
CMOF394	<i>Capra hircus</i>	V	21.4	2.47	0.24
CMOF424	<i>Ovis aries</i>	III	45.7	2.48	0.21
CMOF374	<i>Ovis aries</i>	III	15.6	2.41	0.41
CMOF419	<i>Ovis aries</i>	IV	9.6	3.14	0.41
CMOF463	<i>Ovis aries</i>	IV	5.3	2.93	0.20
CMOF656	<i>Ovis aries</i>	IV	49.1	2.50	0.38
CMOF260	<i>Ovis aries</i>	IV	6.8	2.61	0.34
CMOF691	<i>Ovis aries</i>	V	6.8	2.79	0.42
CMOF477	<i>Ovis aries</i>	V	10.8	2.59	0.22
CMOF303	<i>Ovis aries</i>	V	17.8	2.39	0.28
CMOF230	<i>Oryctolagus cuniculus</i>	III	8.4	3.01	0.37
CMOF254	<i>Oryctolagus cuniculus</i>	IV	7.2	3.01	0.32
CMOF99	<i>Oryctolagus cuniculus</i>	V	6.5	3.12	0.20
CMOF457	<i>Oryctolagus cuniculus</i>	V	4.9	2.81	0.23
CMOF353	<i>Oryctolagus cuniculus</i>	V	23.1	3.31	0.20
CMOF334	<i>Oryctolagus cuniculus</i>	V	11.0	3.26	0.31
CMOF324	<i>Oryctolagus cuniculus</i>	V	7.7	2.79	0.42
CMOF388	<i>Cervus elaphus</i>	III	6.7	2.59	0.29
CMOF373	<i>Cervus elaphus</i>	III	6.3	2.60	0.39

Table 1: Collagen yield and FT-IR results (IRSF and C/P) of selected faunal bone samples. (*continued*)

Sample ID	Species	Phase	Collagen yield (%)	IRSF	C/P
CMOF677	<i>Cervus elaphus</i>	IV	6.2	2.51	0.34
CMOF467	<i>Cervus elaphus</i>	V	15.5	2.64	0.36
CMOF508	<i>Cervus elaphus</i>	V	3.0	2.50	0.23
CMOF643	<i>Cervus elaphus</i>	V	8.4	2.69	0.28
CMOF504	<i>Cervus elaphus</i>	V	10.9	2.69	0.36

### 270 5.1.1. Fourier Transform - Infrared Spectroscopy

271 The IRSF index values (Table 1) are in a range of 2.37 - 3.37 (accepted range is 2.96 - 4.04), and the  
 272 C/P index values are in the range of 0.2-0.428 (accepted range is 0.054 - 0.47), which fall well within the  
 273 accepted range for crystallinity and carbonate content of well-preserved archaeological bones (Hollund et al.,  
 274 2013; Lebon et al., 2016).

### 275 5.1.2. Collagen Quality

276 Collagen yields range between 2.5% to 49.1% (Table 1). Collagen extraction was considered successful for  
 277 all the bone samples, based on published criteria, with carbon content between 15.3% and 47.0% (Ambrose,  
 278 1990), nitrogen content between 5.5% and 17.3% (Ambrose, 1990), C/N values between 2.9 and 3.6 (DeNiro,  
 279 1985), C/S values between 300% and 900% (Nehlich and Richards, 2009), and collagen yields greater than  
 280 1% (Klinken, 1999). The extracted bone collagen samples exhibit C/N values ranged between 3.1 and 3.5  
 281 and C/S values between 225.9 and 688.4. Carbon and nitrogen amounts range from 20.3% to 50.0% and  
 282 7.3% and 18.1% respectively. All the faunal samples exhibited collagen quality parameters indicative of good  
 283 preservation.

### 284 5.2. ZooMS Results

285 Sheep and goat samples were successfully distinguished on the basis of ZooMS. The identified sample  
 286 entries are in bold format (Table 4).

### 287 5.3. Botanical Remains

Table 2: Recovered plant remains from archaeological sediments.

Species	Quantity	Phase
<i>Hordeum vulgare</i>	1300	V
<i>Triticum aestivum/durum</i>	4	V
<i>Apium graveolens</i>	1	V
<i>Pinus pinea</i>	2	V
<i>Brassica nigra</i>	3	V
<i>Pisum sativum</i>	1	V
<i>Galeopsis tetrahit</i>	1	V
<i>Vicia faba</i>	2	V

288 No botanical remains could be recovered from the soil samples of phases I – IV. The bulk of the recovered  
 289 remains are from phase V representing the most mature chronological period of the occupation. Barley  
 290 (*Hordeum vulgare*) is the dominant taxon in the botanical record (Table 2). *Hordeum vulgare* var. *nudum*  
 291 and *Hordeum vulgare* subsp. *vulgare* (Fig. 3 (f) and (g), respectively) are the two cultivars that constitute  
 292 the barley fraction with equal abundance. Wheat (*Triticum aestivum/durum*) is the second most abundant  
 293 taxon after barley. Large-scale cereal cultivation has been observed in sites located in river valleys near  
 294 the South Iberian sea coast (including, Castillo de Doña Blanca in Guadalquivir Valley and El Villar in  
 295 Guadalhorce Valley) (Semmler, 1992, 1990), two sites which are located in similar geographical settings to  
 296 Castro Marim). Cereal cultivation seems to be a significant activity, implying that cereals were the principal  
 297 source of carbohydrates for both humans and animals. The greater presence of barley compared to wheat

Table 3:  $\delta^{13}C$  and  $\delta^{15}N$  values of the charred plant macro-remains.

Sample ID	Species	% C	% N	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	$\delta^{13}C_{cr}^*$ (‰)	$\delta^{15}N_{cr}^*$ (‰)	$\Delta^{13}C$ (‰)
CMHV1	<i>Hordeum vulgare</i> subsp. <i>vulgare</i>	37.7	2.1	-22.1	9.6	-22.2	9.3	16.1
CMHV2	<i>Hordeum vulgare</i> subsp. <i>vulgare</i>	49.7	2.8	-22.6	9.4	-22.7	9.1	16.6
CMHV3	<i>Hordeum vulgare</i> subsp. <i>vulgare</i>	50.0	2.2	-24.7	9.1	-24.8	8.8	18.8
CMHN1	<i>Hordeum vulgare</i> var. <i>nudum</i>	49.1	3.6	-23.0	8.9	-23.1	8.6	17.0
CMHN2	<i>Hordeum vulgare</i> var. <i>nudum</i>	49.5	3.9	-23.2	8.4	-23.3	8.1	17.2
CMHN3	<i>Hordeum vulgare</i> var. <i>nudum</i>	47.6	2.6	-23.1	9.8	-23.2	9.5	17.1
CMPP1	<i>Pinus pinea</i>	58.8	0.7	-25.5	11.4	-25.6	11.1	19.6
CMPP2	<i>Pinus pinea</i>	48.3	0.8	-24.7	11.3	-24.8	11.0	18.8
CMPP3	<i>Pinus pinea</i>	56.7	0.6	-25.4	13.8	-25.5	13.5	19.5

\*  $\delta^{13}C$  and  $\delta^{15}N$  values corrected for charring effect.

can be a strategy of ‘minimum returns on investment’ against dry climatic conditions exploiting the fact that barley has a higher tolerance to drier conditions than wheat (Riehl, 2009). Two taxa of pulses have been noted, namely, peas (*Pisum sativum*) and broad bean (*Vicia faba*) (Fig. 3 (d) and (i) respectively). Pulses serve as a rich source of proteins and act as an alternative to animal-sourced protein for humans. The combined cultivation of pulses with cereals helps to maintain adequate soil nitrogen levels, leading to sustainable and diverse production. The presence of black mustard (*Brassica nigra*) (Fig. 3 (a)) has been recorded. Black mustard is a common species along the rocky Mediterranean coasts and has long found its place as a culinary taste enhancer (Dixon, 2006). Like many members of *Brassica*, black mustard was also used as a source of oil (Peña-Chocarro et al., 2019). A fragment of a charred fruit has been attributed to *Apium* taxon, suspected to be a seed of celery (*Apium graveolens*) (Fig. 3 (b)). This attribution is done due to the presence of five slender longitudinal ridges on the surface of the fruit (Wilson, 2016).

This species is native to the coastal Mediterranean region, considered to be its center of origin. The recorded use of celery as a vegetable in Europe is only from the 1600s, originating in Italy, gradually spreading westwards in the subsequent centuries (Tobyn et al., 2011). Hortulus, a Strabo poem from 9th century BCE., describes the use of celery as a medicinal plant, implying that the plant was cultivated as a medicinal herb rather than a food plant (Sturtevant, 1886) in the Phoenician - Punic period. Shells of pine nuts (*Pinus* sp.) (Fig. 3 (h)) are suspected to be from the species *Pinus pinea*, commonly known as Mediterranean stone pine. Pine nut consumption has been documented in Portugal since the Palaeolithic period (Gale and Carruthers, 2000). The stone pine nuts are high in protein and fat with low carbohydrates (Haws, 2004). The nuts are a valuable source of nutrition and could have been stored during low cultivated food production periods.

#### 5.4. Water and nutrient nitrogen availability for vegetation

Table 3 shows the results of stable isotope ratios of the two barley cultivars and stone pine. In the case of barley, the isotope ratios fall within the established predicted ranges obtained from experimentally charred modern cereals (Fraser et al., 2013). Since the isotope ratios of the stone pine are similar to that of barley, they are considered consistent. The  $\delta^{13}C$  values of all the plants are within the range expected for C<sub>3</sub> plants with mean values of  $-23.2 \pm 1.4\text{‰}$ ,  $-23.2 \pm 0.1\text{‰}$ , and  $-25.3 \pm 0.4\text{‰}$  for *Hordeum vulgare* var. *nudum*, *Hordeum vulgare* subsp. *vulgare*, and *Pinus pinea* respectively. Though the plants are located in salt marshes (Fig. 1), the source of carbon is from the atmosphere (Cloern et al., 2002), and thus the values are similar to terrestrial plants. The  $\delta^{13}C$  means of both barley cultivars show no statistically significant difference (t-statistic: -0.04, degrees of freedom: 4, p-value: 0.97). The  $\Delta^{13}C$  values (Figure 4 (a)) show barley cultivated in poor to moderate watering conditions, which would indicate that the plants have been dependent on natural precipitation with little or no artificial irrigation in an arid climatic regime (Fernández-Crespo et al., 2019; Fletcher et al., 2007).

The plants analysed all exhibit high  $\delta^{15}N$  mean values of  $9.1 \pm 0.3\text{‰}$ ,  $8.7 \pm 0.7\text{‰}$  and  $11.9 \pm 1.4\text{‰}$  for *Hordeum vulgare* var. *nudum*, *Hordeum vulgare* subsp. *vulgare*, and *Pinus pinea* respectively. There is no significant difference (t-statistic: 0.77, degrees of freedom: 4, p-value: 0.49) between the two barley cultivars, but *Pinus pinea* yields higher  $\delta^{15}N$  values. The  $\delta^{15}N$  mean values of the plants in salt marshes are higher

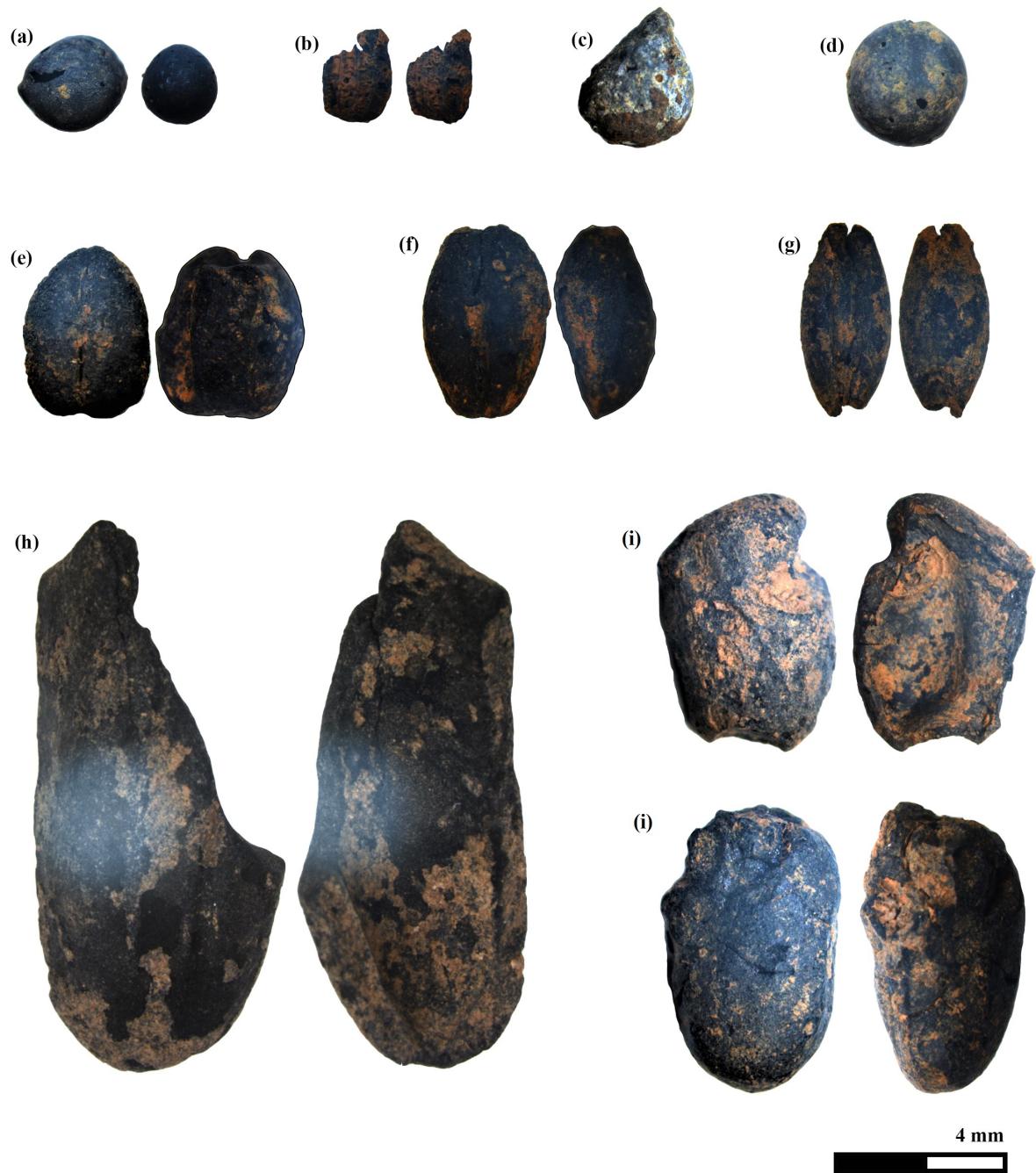


Figure 3: Charred plant remains of settlement phase V from Castro Marim; (a) *Brassica nigra*; (b) *Apium graveolens*; (c) *Galeopsis tetrahit*; (d) *Pisum sativum*; (e) *Triticum aestivum/durum*; (f) *Hordeum vulgare* var. *nudum*; (g) *Hordeum vulgare* subsp. *vulgare*; (h) *Pinus pinea*; (i) *Vicia faba*

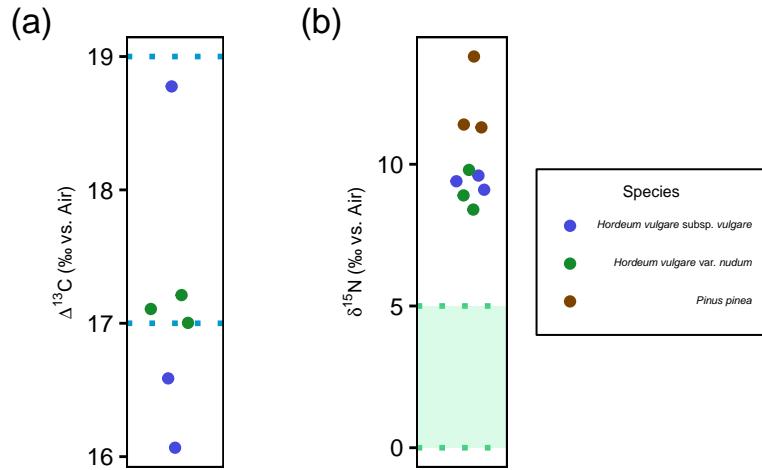


Figure 4: (a). Beeswarm plot showing  $\Delta^{13}\text{C}$  values of barley cultivars where the area between the blue dashed lines represents ‘moderately-watered’ condition with the ‘well-watered’ condition being above the top blue line and ‘poorly-watered’ condition being below the lower blue line, based on the study of modern crops in varying watering conditions (Wallace et al., 2013). (b). Beeswarm plot showing the manuring status of barley cultivars with green shaded region representing 1 SD range of estimated wild herbivore forage value (calculated from subtraction 4 ‰ from red deer  $\delta^{15}\text{N}$  mean  $\pm$  1 SD range).

when compared to completely inland sites (Cloern et al., 2002). The  $\delta^{15}\text{N}$  isotope ratios are elevated, as the coastal/saline soils are enriched in nutrient nitrogen because of nitrate sea-spray, nitrification, denitrification, and ammonium absorption (Ambrose, 1991; Heaton, 1987; Virginia and Delwiche, 1982). The stone pine samples exhibit higher mean values than the barley cultivars despite the possibility that the latter could be subjected to manuring regimes (Figure 4 (b)). This indicates that the barley was cultivated in locations farther away from the coastline than the stone pine and explains the poor to moderate watering conditions despite Castro Marim being close to Guadiana estuary. Because the settlement was located on a narrow strip of land surrounded by water (Figure 2), the lack of space to grow crops must have been the primary reason for growing the barley away from the coast. Thus, any effects of manure on  $\delta^{15}\text{N}$  isotope ratios of barley are masked by the increase caused by the proximity to the coast/salt marsh.

Table 4: Carbon, nitrogen, and sulphur isotope composition of the fauna.

Sample ID	Species	% C	% N	% S	C:N	C:S	N:S	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}(\text{‰})$	$\delta^{34}\text{S}(\text{‰})$
CMOF779	<i>Pluvialis squatarola</i>	40.8	14.8	0.3	3.2	375.9	81.6	-14.9	10.3	9.5
CMOF777	<i>Rissa tridactyla</i>	40.9	15.1	0.3	3.2	376.9	109.7	-15.5	13.9	15.8
CMOF756	<i>Alectoris rufa</i>	41.0	15.1	0.3	3.2	438.1	53.3	-20.6	5.8	13.9
CMOF737	<i>Alectoris rufa</i>	40.6	14.9	0.3	3.2	416.8	49.0	-20.0	5.6	13.9
CMOF710	<i>Gallus domesticus</i>	40.5	14.7	0.3	3.2	415.9	81.5	-18.9	9.3	16.2
CMOF774	<i>Gallus domesticus</i>	40.7	14.9	0.2	3.2	452.9	74.4	-20.2	7.8	15.1
CMOF750	<i>Gallus domesticus</i>	40.6	15.1	0.2	3.1	451.9	94.8	-18.2	9.9	13.5
CMOF751	<i>Gallus domesticus</i>	40.6	14.8	0.2	3.2	515.8	106.5	-18.1	9.8	14.9
CMOF772	<i>Gallus domesticus</i>	40.7	14.9	0.2	3.2	452.8	91.1	-18.5	9.6	14.9
CMOF743	<i>Gallus domesticus</i>	41.1	15.0	0.2	3.2	498.4	100.2	-18.1	9.6	12.5
CMOF746	<i>Gallus domesticus</i>	42.4	15.8	0.2	3.1	514.6	100.4	-17.3	9.6	12.2
CMOF744	<i>Gallus domesticus</i>	43.4	16.0	0.3	3.2	429.3	80.1	-17.5	9.5	14.7
CMOF731	<i>Gallus domesticus</i>	42.8	15.6	0.3	3.2	393.6	86.0	-19.3	10.9	16.2
CMOF730	<i>Gallus domesticus</i>	50.0	18.1	0.2	3.2	606.3	115.5	-19.6	11.1	14.1
CMOF709	<i>Gallus domesticus</i>	42.8	15.7	0.2	3.2	544.0	119.8	-18.7	11.0	14.6
CMOF745	<i>Gallus domesticus</i>	41.0	15.3	0.2	3.1	476.1	95.2	-18.2	9.6	15.2
CMOF158	<i>Sus scrofa</i>	41.0	15.2	0.2	3.2	521.0	119.5	-19.3	11.0	14.6
CMOF439	<i>Sus scrofa</i>	21.7	8.0	—	3.2	—	—	-19.8	8.8	—
CMOF354	<i>Sus scrofa</i>	40.9	15.3	0.2	3.1	496.0	133.8	-18.0	12.9	11.4
CMOF253	<i>Sus scrofa</i>	40.3	15.0	0.2	3.1	489.3	76.3	-19.6	7.3	11.9
CMOF338	<i>Sus scrofa</i>	40.8	15.0	—	3.2	—	—	-20.3	8.5	—

Table 4: Carbon, nitrogen, and sulphur isotope composition of the fauna. (*continued*)

Sample ID	Species	% C	% N	% S	C:N	C:S	N:S	$\delta^{13}C(\text{\textperthousand})$	$\delta^{15}N(\text{\textperthousand})$	$\delta^{34}S(\text{\textperthousand})$
CMOF466	<i>Sus scrofa</i>	40.8	15.0	0.2	3.2	544.1	100.4	-20.1	8.8	14.4
CMOF323	<i>Sus scrofa</i>	40.4	14.9	—	3.2	—	—	-20.3	7.3	—
CMOF435	<i>Bos taurus</i>	41.1	14.9	0.2	3.2	477.5	88.9	-20.2	8.9	10.3
CMOF370	<i>Bos taurus</i>	39.8	14.6	0.2	3.2	443.1	66.7	-21.2	7.0	15.2
CMOF402	<i>Bos taurus</i>	41.8	15.8	—	3.1	—	—	-19.0	7.6	—
CMOF201	<i>Bos taurus</i>	41.9	15.6	0.2	3.1	558.6	69.4	-21.4	6.1	8.3
CMOF480	<i>Bos taurus</i>	39.1	14.4	0.2	3.2	580.6	52.5	-21.7	4.1	15.3
CMOF147	<i>Bos taurus</i>	43.0	16.2	—	3.1	—	—	-20.0	7.2	—
CMOF468	<i>Bos taurus</i>	40.9	15.5	0.2	3.1	642.4	122.8	-21.6	9.1	11.6
CMOF393	<i>Bos taurus</i>	42.1	15.3	—	3.2	—	—	-20.3	3.9	—
CMOF94	<i>Bos taurus</i>	36.7	13.9	0.2	3.1	490.4	58.0	-20.9	5.1	7.8
CMOF397	<i>Capra hircus</i>	38.7	14.2	0.2	3.2	688.4	64.5	-19.8	4.2	10.9
CMOF181	<i>Capra hircus</i>	41.3	15.3	0.2	3.2	580.4	59.5	-19.8	4.9	12.6
CMOF420	<i>Capra hircus</i>	40.7	15.1	0.2	3.2	494.3	59.4	-19.3	5.7	13.6
CMOF673	<i>Capra hircus</i>	20.3	7.3	0.2	3.3	225.9	51.9	-19.2	5.4	14.8
CMOF660	<i>Capra hircus</i>	42.3	15.6	0.2	3.2	564.3	48.5	-19.8	4.2	12.8
CMOF14	<i>Capra hircus</i>	36.6	13.1	—	3.3	—	—	-20.3	3.9	—
CMOF394	<i>Capra hircus</i>	27.2	10.0	0.2	3.2	426.9	85.7	-19.6	6.4	9.2
CMOF424	<i>Ovis aries</i>	40.6	14.8	0.2	3.2	493.1	73.3	-20.7	7.0	7.7
CMOF374	<i>Ovis aries</i>	41.1	15.3	0.3	3.1	406.0	68.4	-17.3	8.1	13.4
CMOF419	<i>Ovis aries</i>	36.8	13.5	0.2	3.2	516.5	67.1	-20.8	5.6	7.0
CMOF463	<i>Ovis aries</i>	40.7	15.3	0.2	3.1	543.5	86.6	-20.8	7.6	15.9
CMOF656	<i>Ovis aries</i>	40.9	15.2	0.2	3.1	574.2	46.8	-19.8	3.9	17.3
CMOF260	<i>Ovis aries</i>	42.5	15.9	—	3.1	—	—	-19.8	5.9	—
CMOF691	<i>Ovis aries</i>	40.9	15.4	0.2	3.1	545.9	106.4	-20.7	9.3	12.4
CMOF477	<i>Ovis aries</i>	43.9	15.6	0.2	3.3	558.3	61.0	-19.5	5.6	8.8
CMOF303	<i>Ovis aries</i>	42.1	15.7	0.2	3.1	562.5	80.0	-20.2	7.0	9.6
CMOF230	<i>Oryctolagus cuniculus</i>	40.9	14.9	0.3	3.2	436.8	43.3	-21.6	4.7	16.7
CMOF254	<i>Oryctolagus cuniculus</i>	40.4	14.6	0.3	3.2	385.5	96.8	-21.5	11.8	11.4
CMOF99	<i>Oryctolagus cuniculus</i>	42.9	14.4	0.2	3.5	602.2	99.9	-20.5	8.3	14.3
CMOF457	<i>Oryctolagus cuniculus</i>	40.5	15.0	0.2	3.2	450.9	41.3	-23.2	4.3	14.2
CMOF353	<i>Oryctolagus cuniculus</i>	42.7	15.8	0.2	3.2	495.4	110.2	-21.0	11.1	12.6
CMOF334	<i>Oryctolagus cuniculus</i>	43.3	15.9	—	3.2	—	—	-20.6	11.2	—
CMOF324	<i>Oryctolagus cuniculus</i>	43.9	15.4	—	3.3	—	—	-22.9	4.0	—
CMOF388	<i>Cervus elaphus</i>	28.3	10.3	0.2	3.2	504.4	62.6	-20.0	4.1	15.6
CMOF373	<i>Cervus elaphus</i>	41.3	15.2	0.2	3.2	524.5	39.8	-20.0	3.6	16.3
CMOF677	<i>Cervus elaphus</i>	41.4	14.9	0.3	3.2	394.8	31.4	-20.3	3.8	15.8
CMOF467	<i>Cervus elaphus</i>	34.4	12.8	0.2	3.1	539.9	59.3	-20.0	4.4	14.3
CMOF508	<i>Cervus elaphus</i>	38.0	14.3	—	3.1	—	—	-20.0	3.5	—
CMOF643	<i>Cervus elaphus</i>	42.8	15.9	—	3.1	—	—	-19.7	2.9	—
CMOF504	<i>Cervus elaphus</i>	38.6	13.9	—	3.2	—	—	-19.8	3.4	—

Note:

The ovicaprid samples which were identified as goats and sheep are in bold.

### 5.5. Faunal bone collagen $\delta^{13}C$ and $\delta^{15}N$ values

#### 5.5.1. Wild fauna (mammals)

All fifty faunal samples, demonstrate (Table 4) stable isotope values within the range expected for a C<sub>3</sub> temperate ecosystem. The mean  $\delta^{13}C$  and  $\delta^{15}N$  values of red deer are  $-20 \pm 0.2\text{\textperthousand}$  and  $3.7 \pm 0.5\text{\textperthousand}$  respectively. The other undomesticated mammal is the rabbit which has mean  $\delta^{13}C$  values of  $-21.6 \pm 1.1\text{\textperthousand}$  and mean  $\delta^{15}N$  values of  $7.9 \pm 3.5\text{\textperthousand}$ . The mean  $\delta^{13}C$  values of red deer are significantly higher than those of rabbits (t-statistic: -4.01, degrees of freedom: 12, p-value: 0). This can be attributed to the rabbits' foraging ground level flora with high recycling of CO<sub>2</sub> and shade from the higher levels of the canopy in contrast with the red deer foraging at greater heights. Feeding in forested areas causes the  $\delta^{13}C$  values to deplete due to the canopy effect (Bonafini et al., 2013). The  $\delta^{15}N$  values of rabbits are anomalous with a standard deviation spanning almost a trophic level (standard deviation of  $\delta^{15}N$ : 3.5%). It can be observed from Fig. 5 that the rabbits consist of two distinct groups, indicative that the group with higher  $\delta^{13}C$  and

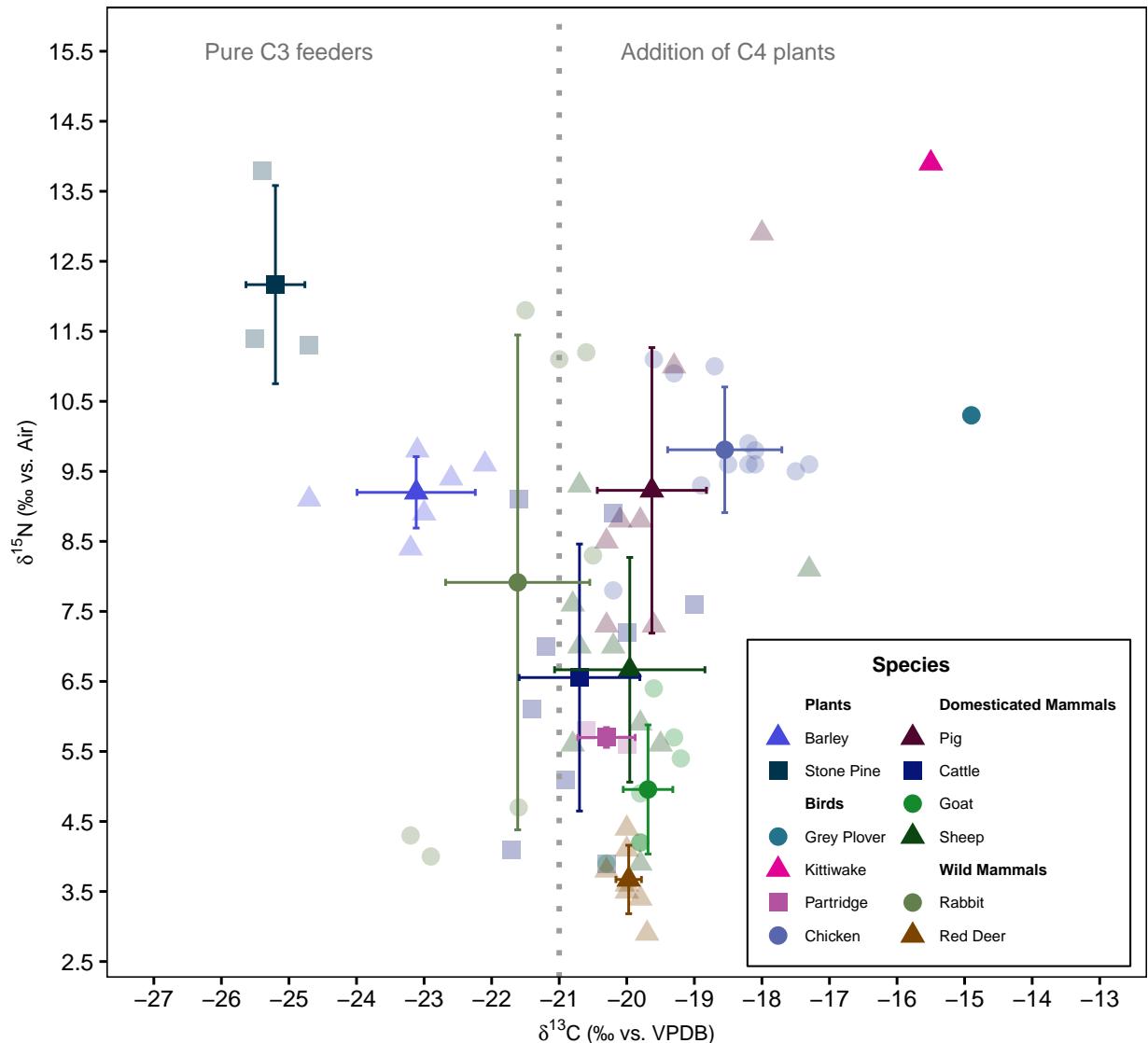


Figure 5: Plot showing mean  $\delta^{13}C$  and  $\delta^{15}N$  values (mean  $\pm$  1 SD range) of faunal bone collagen. The colour palette is produced with the Colorgorical web app (Gramazio et al., 2017).

357  $\delta^{15}N$  values was foraging in coastal/salt-marsh zones, whereas the other group had more inland located food  
358 sources (Figure 5).

359 *5.5.2. Domesticated fauna (mammals)*

360 Sheep show mean  $\delta^{13}C$  values of  $-20 \pm 1.1\text{\textperthousand}$  and mean  $\delta^{15}N$  values of  $6.7 \pm 1.6\text{\textperthousand}$ , while goats exhibit  
361 mean  $\delta^{13}C$  values of  $-19.7 \pm 0.4\text{\textperthousand}$  and mean  $\delta^{15}N$  values of  $5 \pm 0.9\text{\textperthousand}$ . Goat mean  $\delta^{13}C$  values are not  
362 significantly different from those of sheep (t-statistic: 0.61, degrees of freedom: 14, p-value: 0.55). The  
363 ovicaprids' statistically similar mean  $\delta^{13}C$  values indicate similar foraging in open forests (due to slightly  
364 positive  $\delta^{13}C$  values). Sheep exhibit significantly higher  $\delta^{15}N$  values than goats (t-statistic: 2.5, degrees  
365 of freedom: 14, p-value: 0.03), demonstrating that sheep were foddered on food sourced from manured  
366 vegetation with the assumption of uniform coastal impact on all vegetation (Figure 5). Sheep are superior to  
367 goats both in terms of secondary products and ease of management (Davis, 2007; Rutter, 2002). Owing to  
368 the more attached economic interests with sheep, it is natural to give food sourced from cultivated crops.  
369 Since the coastal/salt marsh effect masks the increase of  $\delta^{15}N$  values caused by manuring in cultivated crops,  
370 the statistically significant difference of  $\delta^{15}N$  between goats and sheep can be attributed to the consumption  
371 of manured crops. Cattle show mean  $\delta^{13}C$  values of  $-20.7 \pm 0.9\text{\textperthousand}$  and mean  $\delta^{15}N$  values of  $6.6 \pm 1.9\text{\textperthousand}$ . The  
372 cattle have statistically non-significant (t-statistic: -1.57, degrees of freedom: 16, p-value: 0.14)  $\delta^{13}C$  isotope  
373 ratios compared to sheep. Cattle also seem to have grazed in open areas similar to the sheep. The  $\delta^{15}N$   
374 isotope ratios of cattle are also significantly not different from sheep (t-statistic: 0.13, degrees of freedom:  
375 16, p-value: 0.9). Though significantly not different than sheep, the mean  $\delta^{15}N$  values of cattle are lower  
376 (Figure 5). Most of the cattle bones are from adults, which indicates that they were used as a source of  
377 power and only slaughtered for meat towards the end of their lives (Davis, 2007). Since they were used for  
378 labour intense tasks, their diet could have a considerable amount of cultivated crop components. Pigs show  
379 mean  $\delta^{13}C$  values of  $-19.6 \pm 0.8\text{\textperthousand}$  and mean  $\delta^{15}N$  values of  $9.2 \pm 2\text{\textperthousand}$ . The high  $\delta^{15}N$  values of pigs reflect  
380 an omnivorous diet consisting of agricultural components and human food scraps similar to the Neolithic  
381 and Chalcolithic periods from Portugal (Waterman et al., 2016; Žalaitė et al., 2018).

382 *5.5.3. Wild and domesticated birds*

383 Partridges show mean  $\delta^{13}C$  values of  $-20.3 \pm 0.4\text{\textperthousand}$  and mean  $\delta^{15}N$  values of  $5.7 \pm 0.1\text{\textperthousand}$  while chicken  
384 exhibit mean  $\delta^{13}C$  values of  $-18.6 \pm 0.8\text{\textperthousand}$  and mean  $\delta^{15}N$  values of  $9.8 \pm 0.9\text{\textperthousand}$ . The  $\delta^{13}C$  values (t-statistic:  
385 2.8, degrees of freedom: 12, p-value: 0.02) and  $\delta^{15}N$  values (t-statistic: 6.26, degrees of freedom: 12, p-value:  
386  $4 \times 10^{-5}$ ) are significantly different. The chicken owing to its domesticated status, has higher  $\delta^{13}C$  and  
387  $\delta^{15}N$  values. In Iron Age, chickens were usually reared in domestic spaces while being fed on food scraps  
388 and possibly millet (a C<sub>4</sub> plant) (Fernández-Crespo et al., 2019). Chicken also eat insects alongside the  
389 human-provided food which can lead to an increase of  $\delta^{15}N$  values. Usual partridge diet consists of arthropods,  
390 grass seeds, flowers, and weeds while they prefer foraging at the edges of agricultural fields (Green, 1984)  
391 which can explain the higher  $\delta^{15}N$  values in comparison with red deer. All the partridges recovered are  
392 adults, whereas the chickens constitute juvenile-adult mix, further indicative that the former were hunted  
393 for consumption. Grey plover has a mean  $\delta^{13}C$  value of  $-14.9\text{\textperthousand}$  and a mean  $\delta^{15}N$  value of  $10.3\text{\textperthousand}$ . Grey  
394 plovers are known to feed in muddy intertidal zones on insects (such as Coleoptera), polychaetes, molluscs,  
395 and crustaceans (Perez-Hurtado et al., 1997). The isotope values are consistent with a diet including both  
396 terrestrial and marine prey. Kittiwake has a mean  $\delta^{13}C$  value of  $-15.5\text{\textperthousand}$  and a mean  $\delta^{15}N$  value of  $13.9\text{\textperthousand}$ .  
397 Kittiwake's diet consists of fish, marine invertebrates, and plankton (Bull et al., 2004). The  $\delta^{13}C$  and  $\delta^{15}N$   
398 values are as expected of a species with a marine diet.

399 Overall, the domesticated mammals are not above one trophic level ( $< 4\text{\textperthousand} \delta^{15}N$ ) over the plants (both  
400 cultivated barley and stone pine) (Figure 5). Thus, they seem to be foraging in areas away from the  
401 coastal/salt-marsh zones. Inland Iron Age domesticated mammals have mean  $\delta^{13}C$  values ranging between  
402 21 - 23‰ (for C<sub>3</sub> temperate ecosystem) and  $\delta^{15}N$  mean values ranging between 3-5‰ for herbivores and  
403 > 6‰ for omnivores (Fernández-Crespo et al., 2019; Hamilton et al., 2019; Schulting et al., 2019; Styring  
404 et al., 2017). In comparison, the fauna at Castro Marim have similar  $\delta^{13}C$  values and slightly higher  $\delta^{15}N$   
405 mean values. Apart from manuring, another reason for these slightly higher  $\delta^{15}N$  values could be periodic  
406 movement to a territory away from the coast. Since Iron Age Castro Marim settlement was short of foraging

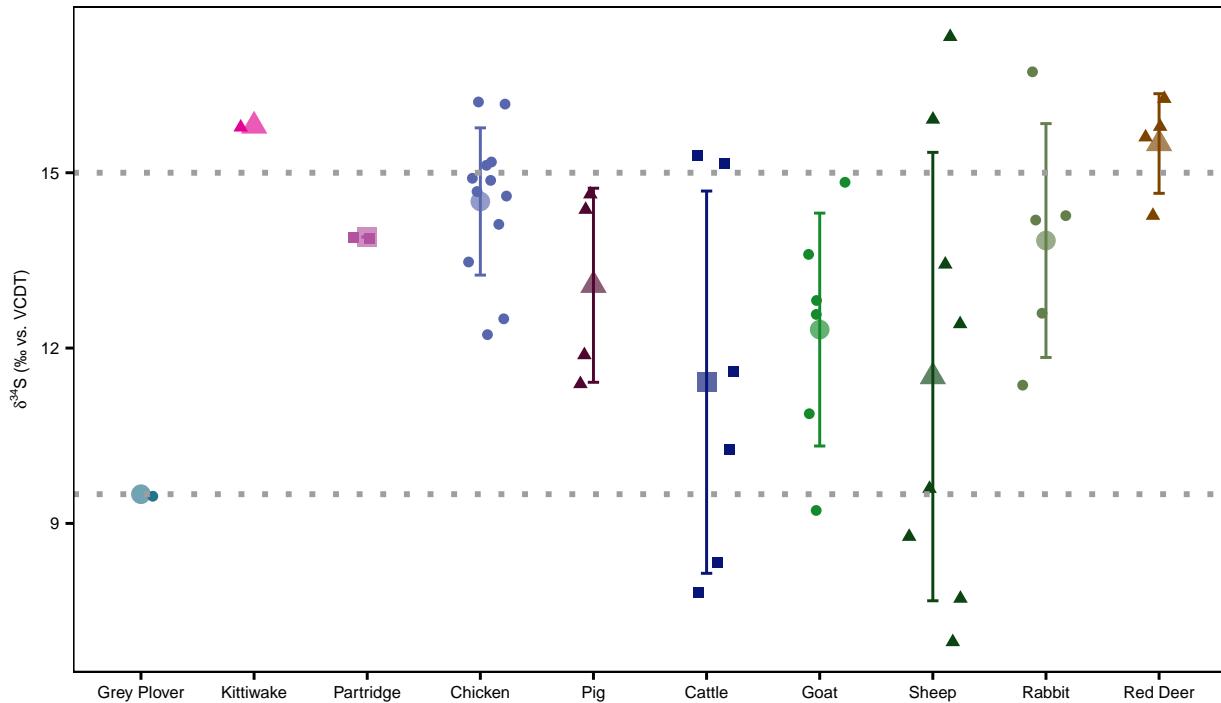


Figure 6: Plot showing mean  $\delta^{34}\text{S}$  values (mean  $\pm$  1 SD range) of faunal bone collagen. The values are horizontally jittered to increase the visibility of the data points. The region between the gray lines represents Western European Triassic sediment  $\delta^{34}\text{S}$  value range.

space (Figure 2), the animals could be in a periodic movement between the settlement and a space more inland. This movement can be investigated further by sequential sampling of faunal enamel for future  $\delta^{13}\text{C}_{\text{carbonate}}$  and  $\delta^{18}\text{O}$  studies (Vaiglova et al., 2020). Any substantial increase in  $\delta^{15}\text{N}$  gained due to salt marsh foraging (Britton et al., 2008) or physiological stress from saline water (Ambrose, 1991) would be evened by the subsequent migration towards inland of the domesticated fauna leading to slightly higher  $\delta^{15}\text{N}$  values.

#### 5.6. Faunal bone collagen $\delta^{34}\text{S}$ values

$\delta^{34}\text{S}$  values of fauna range from 9.5 ‰ to 15.8 ‰. The offset of  $\delta^{34}\text{S}$  between diet to collagen is considered to be negligible (Nehlich, 2015). Since the diet-collagen offset is negligible, collagen  $\delta^{34}\text{S}$  values often reflect the local geological settings and sea-spray due to proximity to the coast (<30 km). The geological substrate of areas surrounding Castro Marim consists of patches of Triassic sediments surrounded by Quaternary bedrock zones (Terrinha, 1998). A compilation of  $\delta^{34}\text{S}$  of Triassic sediments from Western Europe (Claypool et al., 1980) presents a range of 9.5‰ to 15‰. Thus, any values between this range can be considered as a signal for local. Both grey plover and kittiwake are known to migrate seasonally, which makes the interpretation of their  $\delta^{34}\text{S}$  values complicated (Coulson, 2011; Thompson and Byrkjedal, 2010). Kittiwake has higher  $\delta^{34}\text{S}$  value than the Triassic range that can attributed to its highly marine diet, indicated by its  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values. The average  $\delta^{34}\text{S}$  values of all other fauna fall within the range of Western European Triassic sediments, thus indicating that most of them are of local origin (Figure 6). Though some animals (two chicken, four cattle, five sheep, one goat, one rabbit, and two red deer) yield  $\delta^{34}\text{S}$  values outside the Triassic range. This could be due to these individuals originating from a different geological bedrock.  $\delta^{34}\text{S}$  mean values of rabbits are  $13.8 \pm 2\text{\%}$ , and the  $\delta^{34}\text{S}$  mean values of red deer are  $15.5 \pm 0.9\text{\%}$ . Both the wild mammals have low standard deviations indicating that individuals are of close spatial origins or with similar bedrocks (Figure 6). From the domesticated species, goats have mean  $\delta^{34}\text{S}$  values of  $12.3 \pm 2\text{\%}$ , pigs have mean  $\delta^{34}\text{S}$  values of  $13.1 \pm 1.7\text{\%}$ , and chickens have mean  $\delta^{34}\text{S}$  values of  $14.5 \pm 1.3\text{\%}$ . These three

431 species have relatively low standard deviations similar to wild mammals (Figure 6). Pigs and chicken could  
432 have been penned in spaces attached to human residences, giving rise to the low standard deviations. The  
433  $\delta^{34}S$  values of goats can be explained by foraging in areas with similar bedrocks. In the case of sheep, the  
434 mean  $\delta^{34}S$  values are  $11.5 \pm 3.8\text{‰}$  while the mean  $\delta^{34}S$  values of cattle are  $11.4 \pm 3.3\text{‰}$ . Sheep and cattle  
435 have the highest standard deviation amongst the fauna, which could be caused due to periodic movement  
436 between areas with different bedrocks (Figure 1 and Figure 6). Since the average  $\delta^{34}S$  values of sheep and  
437 cattle are still within the range of what is considered local, the movement could be somewhere inland within  
438 the territory of the settlement.

## 439 6. Conclusions

440 The  $\delta^{13}C$  values of the two barley cultivars indicate complete dependence on natural precipitation with  
441 little to no artificial irrigation. In the case of stone pine,  $\delta^{13}C$  values are non-conclusive concerning watering  
442 status due to the lack of established studies for *Pinus* species. The  $\delta^{15}N$  ratios of the plants are elevated due  
443 to the proximity of coast/salt marsh. The manuring of barley was masked by the high nitrogen nutrient soils  
444 of the salt marshes but manuring of crops fed to ovicaprids can be inferred from the significant difference  
445 between the mean  $\delta^{15}N$  values of sheep and goats. The  $\delta^{15}N$  values of stone pine are greater than those  
446 of the barley, indicating that the cultivation took place in locations far away from coast/salt marsh which  
447 is evident from the absence of space near the settlement in Iron Age. In the case of wild fauna, the  $\delta^{13}C$   
448 values of rabbits indicate foraging at ground level in closed settings, while those of red deer indicate grazing  
449 at higher levels in more open areas. The  $\delta^{15}N$  values of rabbits indicate two different groups, with one  
450 group foraging in salt marshes and the other from a more terrestrial setting. Ovicaprid  $\delta^{13}C$  values indicate  
451 foraging in open pastures. Comparing the  $\delta^{15}N$  ratios of sheep and goats show that the former was fed  
452 agricultural produce/by-products, which the latter lacked. The cattle also foraged in open areas and had  
453 cultivated components in its diet compared to the sheep. Pigs exhibit  $\delta^{13}C$  and  $\delta^{15}N$  values consistent with  
454 an omnivorous diet. In the case of the seabirds, both grey plover and kittiwake exhibit  $\delta^{13}C$  and  $\delta^{15}N$  values  
455 consistent with their diet. Chicken has  $\delta^{13}C$  and  $\delta^{15}N$  values reflective of its domesticated status with  
456 a mixture of C<sub>3</sub> and C<sub>4</sub> plants, insects, and food scraps. The  $\delta^{15}N$  values of the fauna are not a trophic  
457 level above the plants, which can be because of either periodic movement or salt stress. The  $\delta^{34}S$  values of  
458 overall fauna indicate a local origin. Goats, pigs, and chickens have a low range of values due to penning in  
459 domestic spaces. The  $\delta^{34}S$  values of cattle and sheep have a more extensive range of values which could be  
460 due to periodic migration or of being non-local origin.

461 This study is the first of its kind on Phoenician-Punic fauna from the Iberian Peninsula. The study has  
462 given a preliminary insight into the cultivation and husbandry practices in Castro Marim during the Iron  
463 Age. The stable isotope data has also raised the possibility of transhumance at Castro Marim, which can  
464 only be answered in future studies.

## 465 7. Acknowledgements

466 This project has received funding from the European Union's Horizon 2020 research and innovation  
467 programme under the Marie Skłodowska-Curie grant agreement No. 766311. The ZooMS analysis was  
468 carried out by Samantha Presslee at BioArCh, University of York who gratefully acknowledges the use of  
469 the Ultraflex III MALDI-ToF/ToF instrument in the York Centre of Excellence in Mass Spectrometry. The  
470 centre was created thanks to a major capital investment through Science City York, supported by Yorkshire  
471 Forward with funds from the Northern Way Initiative, and subsequent support from EPSRC (EP/K039660/1;  
472 EP/M028127/1). The authors would like to thank Rui Parreira for providing access to the samples (Direção  
473 Regional de Cultura do Algarve, Faro).

## 474 References

- 475 Ambrose, S.H., 1991. Effects of diet, climate and physiology on nitrogen isotope abundances in terrestrial  
476 foodwebs. Journal of Archaeological Science 18, 293–317. [https://doi.org/10.1016/0305-4403\(91\)90067-Y](https://doi.org/10.1016/0305-4403(91)90067-Y)

- 477 Ambrose, S.H., 1990. Preparation and characterization of bone and tooth collagen for isotopic analysis.  
 478 Journal of Archaeological Science 17, 431–451. [https://doi.org/10.1016/0305-4403\(90\)90007-R](https://doi.org/10.1016/0305-4403(90)90007-R)
- 479 Arrastio, F.J.M., 2000. Tartessos, estelas, modelos pesimistas, in: Intercambio y Comercio Preclásico En El  
 480 Mediterráneo: Actas Del I Coloquio Del CEFYP, Madrid, 9-12 de Noviembre, 1998. Centro de Estudios  
 481 Fenicios y Púnicos, pp. 153–174.
- 482 Arrastio, F.J.M., 1999. Conflictos y perspectivas en el periodo precolonial tartésico. Gerión. Revista de  
 483 Historia Antigua 17, 149.
- 484 Arruda, A.M., 2009. Phoenician colonization on the Atlantic Coast of the Iberian Peninsula. Chicago: The  
 485 University of Chicago Press, 2009.
- 486 Arruda, A.M., 2003. Contributo da colonização fenícia para a domesticação da terra portuguesa. Ecohistoria  
 487 del paisaje agrario-la agricultura fenicio-púnica en el mediterráneo.
- 488 Arruda, A.M., 2000. Los fenicios en Portugal. Fenicios y mundo indígena en el centro y sur de Portugal  
 489 (siglos VIII-VI aC). Universidad Pompeu Fabra de Barcelona/Carrera Edició, SL.
- 490 Arruda, A.M., 1997. Os núcleos urbanos litorais da Idade do Ferro no Algarve. Noventa Séculos entre a  
 491 Serra e o Mar 243–255.
- 492 Arruda, A.M., 1996. O Castelo de Castro Marim, in: In De Ulisses a Viriato. O Primeiro Milénio a.C..  
 493 Ministério da Cultura, Instituto Português de Museus, Museu Nacional de Arqueologia, Lisboa, pp.  
 494 95–100.
- 495 Arruda, A.M., Ferreira, D., Sousa, E. de, 2020. A cerâmica grega do Castelo de Castro Marim. UNIARQ.  
 496 Centro de Arqueologia da Universidade de Lisboa.
- 497 Arruda, A.M., Freitas, V.T. de, 2008. O castelo de castro marim durante os séculos VI e v a.n.e. Sidereum  
 498 Ana I: El río Guadiana en época Post-Orientalizante. 429–446.
- 499 Arruda, A.M., Soares, A.M., Freitas, V.T. de, Oliveira, C.F., Martins, J.M.M., Portela, P.J., 2013. A  
 500 cronologia relativa e absoluta da ocupação sidérica do Castelo de Castro Marim. Saguntum 45, 101–114.
- 501 Arruda, A.M., Viegas, C., Bargão, P., Pereira, R., 2006. A importação de preparados de peixe em Castro  
 502 Marim: Da Idade do Ferro á Época Romana. Setúbal Arqueológica 13, 153–176.
- 503 Aubet, M.E., 2001. The Phoenicians and the West: Politics, colonies and trade. Cambridge Univ. Press.
- 504 Aubet, M.E., 1987. Tiro y las colonias fenicias de Occidente. Ed. Bellaterra.
- 505 Bocherens, H., Drucker, D., 2003. Trophic level isotopic enrichment of carbon and nitrogen in bone collagen:  
 506 Case studies from recent and ancient terrestrial ecosystems. International Journal of Osteoarchaeology  
 507 13, 46–53. <https://doi.org/10.1002/oa.662>
- 508 Boessneck, J., Müller, H.-H., Teichert, M., 1964. Osteologische Unterscheidungsmerkmale zwischen Schaf  
 509 (*Ovis aries* Linné) und Ziege (*Capra hircus* Linné). Verlag nicht ermittelbar.
- 510 Bogaard, A., Fraser, R., Heaton, T.H.E., Wallace, M., Vaiglova, P., Charles, M., Jones, G., Evershed, R.P.,  
 511 Styring, A.K., Andersen, N.H., Arbogast, R.-M., Bartosiewicz, L., Gardeisen, A., Kanstrup, M., Maier, U.,  
 512 Marinova, E., Ninov, L., Schäfer, M., Stephan, E., 2013. Crop manuring and intensive land management  
 513 by Europe's first farmers. PNAS 110, 12589–12594. <https://doi.org/10.1073/pnas.1305918110>
- 514 Bogaard, A., Heaton, T.H.E., Poulton, P., Merbach, I., 2007. The impact of manuring on nitrogen isotope  
 515 ratios in cereals: Archaeological implications for reconstruction of diet and crop management practices.  
 516 Journal of Archaeological Science 34, 335–343. <https://doi.org/10.1016/j.jas.2006.04.009>
- 517 Bonafini, M., Pellegrini, M., Ditchfield, P., Pollard, A.M., 2013. Investigation of the 'canopy effect' in  
 518 the isotope ecology of temperate woodlands. Journal of Archaeological Science 40, 3926–3935. <https://doi.org/10.1016/j.jas.2013.03.028>
- 519 Britton, K., Mildner, G., Bell, M., 2008. Stable isotope evidence for salt-marsh grazing in the Bronze Age  
 520 Severn Estuary, UK: Implications for palaeodietary analysis at coastal sites. Journal of Archaeological  
 521 Science 35, 2111–2118. <https://doi.org/10.1016/j.jas.2008.01.012>
- 522 Buckley, M., Collins, M., Thomas-Oates, J., Wilson, J.C., 2009. Species identification by analysis of  
 523 bone collagen using matrix-assisted laser desorption/ionisation time-of-flight mass spectrometry. Rapid  
 524 Communications in Mass Spectrometry 23, 3843–3854. <https://doi.org/10.1002/rcm.4316>
- 525 Buckley, M., Whitcher Kansa, S., Howard, S., Campbell, S., Thomas-Oates, J., Collins, M., 2010. Dis-  
 526 tinguishing between archaeological sheep and goat bones using a single collagen peptide. Journal of  
 527 Archaeological Science 37, 13–20. <https://doi.org/10.1016/j.jas.2009.08.020>

- 529 Bull, J., Wanless, S., Elston, D.A., Daunt, F., Lewis, S., Harris, M.P., J, B., Wanless, S., Elston, D.A.,  
530 Daunt, F., Lewis, S., Harris, M.P., 2004. Local-scale variability in the diet of Black-legged Kittiwakes  
531 Rissa tridactyla. *Ardea* 43–52.
- 532 Claypool, G.E., Holser, W.T., Kaplan, I.R., Sakai, H., Zak, I., 1980. The age curves of sulfur and  
533 oxygen isotopes in marine sulfate and their mutual interpretation. *Chemical Geology* 28, 199–260.  
534 [https://doi.org/10.1016/0009-2541\(80\)90047-9](https://doi.org/10.1016/0009-2541(80)90047-9)
- 535 Cloern, J.E., Canuel, E.A., Harris, D., 2002. Stable carbon and nitrogen isotope composition of aquatic and  
536 terrestrial plants of the San Francisco Bay estuarine system. *Limnology and Oceanography* 47, 713–729.  
537 <https://doi.org/10.4319/lo.2002.47.3.0713>
- 538 Coulson, J., 2011. The kittiwake. A&C Black.
- 539 Davis, S., 2007. The mammals and birds from the Iron Age and Roman periods of Castro Marim, Algarve,  
540 Portugal. *Trabalhos do CIPA* 107.
- 541 Deniro, M.J., Epstein, S., 1981. Influence of diet on the distribution of nitrogen isotopes in animals.  
542 *Geochimica et Cosmochimica Acta* 45, 341–351. [https://doi.org/10.1016/0016-7037\(81\)90244-1](https://doi.org/10.1016/0016-7037(81)90244-1)
- 543 DeNiro, M.J., 1985. Postmortem preservation and alteration of in vivo bone collagen isotope ratios in relation  
544 to palaeodietary reconstruction. *Nature* 317, 806–809. <https://doi.org/10.1038/317806a0>
- 545 DeNiro, M.J., Epstein, S., 1978. Influence of diet on the distribution of carbon isotopes in animals. *Geochimica  
546 et Cosmochimica Acta* 42, 495–506. [https://doi.org/10.1016/0016-7037\(78\)90199-0](https://doi.org/10.1016/0016-7037(78)90199-0)
- 547 Dietler, M., 2009. Colonial encounters in Iberia and the Western Mediterranean: An exploratory framework.
- 548 Dixon, G.R., 2006. Origins and diversity of Brassica and its relatives., in: Dixon, G.R. (Ed.), *Vegetable  
549 Brassicas and Related Crucifers*. CABI, Wallingford, pp. 1–33. [https://doi.org/10.1079/9780851993959.0001](https://doi.org/10.1079/9780851993959.<br/>550 0001)
- 551 Eshel, T., Erel, Y., Yahalom-Mack, N., Tirosh, O., Gilboa, A., 2019. Lead isotopes in silver reveal  
552 earliest Phoenician quest for metals in the west Mediterranean. *Proc Natl Acad Sci USA* 116, 6007.  
553 <https://doi.org/10.1073/pnas.1817951116>
- 554 Farquhar, G.D., Ehleringer, J.R., Hubick, K.T., 1989. Carbon Isotope Discrimination and Photosynthesis.  
555 Annu. Rev. Plant. Physiol. Plant. Mol. Biol. 40, 503–537. [https://doi.org/10.1146/annurev.pp.40.060189.002443](https://doi.org/10.1146/annurev.pp.40.<br/>556 060189.002443)
- 557 Farquhar, G., O'Leary, M., Berry, J., 1982. On the Relationship Between Carbon Isotope Discrimination  
558 and the Intercellular Carbon Dioxide Concentration in Leaves. *Functional Plant Biol.* 9, 121. <https://doi.org/10.1071/PP9820121>
- 559 Fernández-Crespo, T., Ordoño, J., Bogaard, A., Llanos, A., Schulting, R., 2019. A snapshot of subsistence in  
560 Iron Age Iberia: The case of La Hoya village. *Journal of Archaeological Science: Reports* 28, 102037.  
561 <https://doi.org/10.1016/j.jasrep.2019.102037>
- 562 Ferrio, J.P., Araus, J.L., Buxó, R., Voltas, J., Bort, J., 2005. Water management practices and climate in  
563 ancient agriculture: Inferences from the stable isotope composition of archaeobotanical remains. *Veget  
564 Hist Archaeobot* 14, 510–517. <https://doi.org/10.1007/s00334-005-0062-2>
- 565 Ferrio, J.P., Voltas, J., Alonso, N., Araus, J.L., 2007. Reconstruction of Climate and Crop Conditions in  
566 the Past Based on the Carbon Isotope Signature of Archaeobotanical Remains, in: *Terrestrial Ecology*.  
567 Elsevier, pp. 319–332. [https://doi.org/10.1016/S1936-7961\(07\)01020-2](https://doi.org/10.1016/S1936-7961(07)01020-2)
- 568 Fiorentino, G., Ferrio, J.P., Bogaard, A., Araus, J.L., Riehl, S., 2015. Stable isotopes in archaeobotanical  
569 research. *Veget Hist Archaeobot* 24, 215–227. <https://doi.org/10.1007/s00334-014-0492-9>
- 570 Fletcher, W.J., Boski, T., Moura, D., 2007. Palynological evidence for environmental and climatic change  
571 in the lower Guadiana valley, Portugal, during the last 13 000 years. *The Holocene* 17, 481–494.  
572 <https://doi.org/10.1177/0959683607077027>
- 573 Fraser, R.A., Bogaard, A., Charles, M., Styring, A.K., Wallace, M., Jones, G., Ditchfield, P., Heaton, T.H.E.,  
574 2013. Assessing natural variation and the effects of charring, burial and pre-treatment on the stable  
575 carbon and nitrogen isotope values of archaeobotanical cereals and pulses. *Journal of Archaeological  
576 Science* 40, 4754–4766. <https://doi.org/10.1016/j.jas.2013.01.032>
- 577 Fraser, R.A., Bogaard, A., Heaton, T., Charles, M., Jones, G., Christensen, B.T., Halstead, P., Merbach, I.,  
578 Poultney, P.R., Sparkes, D., Styring, A.K., 2011. Manuring and stable nitrogen isotope ratios in cereals  
579

- 580 and pulses: Towards a new archaeobotanical approach to the inference of land use and dietary practices.  
 581 Journal of Archaeological Science 38, 2790–2804. <https://doi.org/10.1016/j.jas.2011.06.024>
- 582 Froehle, A.W., Kellner, C.M., Schoeninger, M.J., 2010. FOCUS: Effect of diet and protein source on carbon  
 583 stable isotope ratios in collagen: Follow up to Warinner and Tuross (2009). Journal of Archaeological  
 584 Science 37, 2662–2670. <https://doi.org/10.1016/j.jas.2010.06.003>
- 585 Gale, R., Carruthers, W., 2000. Charcoal and charred seed remains from Middle Palaeolithic levels at  
 586 Gorham's and Vanguard Caves. Neanderthals on the Edge. Oxford: Oxbow Books 207–210.
- 587 Gomes, F.B., Arruda, A.M., 2018. On the edge of history? The Early Iron Age of southern Portugal, between  
 588 texts and archaeology. World Archaeology 50, 764–780. <https://doi.org/10.1080/00438243.2019.1604258>
- 589 Gómez Bellard, C., 2019. Agriculture, in: The Oxford Handbook of The Phoenician and Punic Mediterranean.  
 590 Oxford University Press, pp. 732–745.
- 591 Gramazio, C.C., Laidlaw, D.H., Schloss, K.B., 2017. Colgorical: Creating discriminable and preferable  
 592 color palettes for information visualization. IEEE Trans. Visual. Comput. Graphics 23, 521–530.  
 593 <https://doi.org/10.1109/TVCG.2016.2598918>
- 594 Green, R.E., 1984. The Feeding Ecology and Survival of Partridge Chicks (*Alectoris rufa* and *Perdix perdix*) on  
 595 Arable Farmland in East Anglia. Journal of Applied Ecology 21, 817–830. <https://doi.org/10.2307/2405049>
- 596 Hamilton, W.D., Sayle, K.L., Boyd, M.O.E., Haselgrove, C.C., Cook, G.T., 2019. “Celtic cowboys” reborn:  
 597 Application of multi-isotopic analysis ( $\delta^{13}\text{C}$ ,  $\delta^{15}\text{N}$ , and  $\delta^{34}\text{S}$ ) to examine mobility and movement of  
 598 animals within an Iron Age British society. Journal of Archaeological Science 101, 189–198. <https://doi.org/10.1016/j.jas.2018.04.006>
- 599 Haws, J., 2004. An Iberian perspective on Upper Paleolithic plant consumption. Promontoria 2, 49–106.
- 600 Heaton, T.H.E., 1987. The  $^{15}\text{N}/^{14}\text{N}$  ratios of plants in South Africa and Namibia: Relationship to climate  
 601 and coastal/saline environments. Oecologia 74, 236–246. <https://doi.org/10.1007/BF00379365>
- 602 Hedges, R.E.M., Reynard, L.M., 2007. Nitrogen isotopes and the trophic level of humans in archaeology.  
 603 Journal of Archaeological Science 34, 1240–1251. <https://doi.org/10.1016/j.jas.2006.10.015>
- 604 Hobson, K.A., 1999. Tracing origins and migration of wildlife using stable isotopes: A review. Oecologia 120,  
 605 314–326. <https://doi.org/10.1007/s004420050865>
- 606 Hollund, H.I., Ariese, F., Fernandes, R., Jans, M.M.E., Kars, H., 2013. Testing an Alternative High-  
 607 Throughput Tool for Investigating Bone Diagenesis: Ftir in Attenuated Total Reflection (atr) Mode\*.  
 608 Archaeometry 55, 507–532. <https://doi.org/10.1111/j.1475-4754.2012.00695.x>
- 609 Jalut, G., Amat, A.E., Bonnet, L., Gauquelin, T., Fontugne, M., 2000. Holocene climatic changes in the  
 610 Western Mediterranean, from south-east France to south-east Spain. Palaeogeography, Palaeoclimatology,  
 611 Palaeoecology 160, 255–290.
- 612 Kellner, C.M., Schoeninger, M.J., 2007. A simple carbon isotope model for reconstructing prehistoric human  
 613 diet. American Journal of Physical Anthropology 133, 1112–1127. <https://doi.org/10.1002/ajpa.20618>
- 614 Klinken, G.J. van, 1999. Bone Collagen Quality Indicators for Palaeodietary and Radiocarbon Measurements.  
 615 Journal of Archaeological Science 26, 687–695. <https://doi.org/10.1006/jasc.1998.0385>
- 616 Kohn, M.J., 2010. Carbon isotope compositions of terrestrial C3 plants as indicators of (paleo)ecology and  
 617 (paleo)climate. Proc Natl Acad Sci U S A 107, 19691–19695. <https://doi.org/10.1073/pnas.1004933107>
- 618 Lebon, M., Reiche, I., Gallet, X., Bellot-Gurlet, L., Zazzo, A., 2016. Rapid Quantification of Bone Collagen  
 619 Content by ATR-FTIR Spectroscopy. Radiocarbon 58, 131–145. <https://doi.org/10.1017/RDC.2015.11>
- 620 Leegood, R.C., 2013. Photosynthesis, in: Lennarz, W.J., Lane, M.D. (Eds.), Encyclopedia of Biological  
 621 Chemistry (Second Edition). Academic Press, Waltham, pp. 492–496. <https://doi.org/10.1016/B978-0-12-378630-2.00049-9>
- 622 Longin, R., 1971. New Method of Collagen Extraction for Radiocarbon Dating. Nature 230, 241–242.  
 623 <https://doi.org/10.1038/230241a0>
- 624 Magny, M., Miramont, C., Sivan, O., 2002. Assessment of the impact of climate and anthropogenic factors on  
 625 Holocene Mediterranean vegetation in Europe on the basis of palaeohydrological records. Palaeogeography,  
 626 Palaeoclimatology, Palaeoecology 186, 47–59.
- 627 Manfredi, L.I., 1992. Le saline et il sale nel mundo punico. Rivista di Studi Fenici 20, 3–14.
- 628 Markoe, G.E., 2005. Phoenicians. London: The British Museum.
- 629 Martin, R., 1971. Recherches sur les agronomes latins et leurs conceptions économiques et sociales.

- 632 Nehlich, O., 2015. The application of sulphur isotope analyses in archaeological research: A review. *Earth-  
633 Science Reviews* 142, 1–17. <https://doi.org/10.1016/j.earscirev.2014.12.002>
- 634 Nehlich, O., Borić, D., Stefanović, S., Richards, M.P., 2010. Sulphur isotope evidence for freshwater fish  
635 consumption: A case study from the Danube Gorges, SE Europe. *Journal of Archaeological Science* 37,  
636 1131–1139.
- 637 Nehlich, O., Richards, M.P., 2009. Establishing collagen quality criteria for sulphur isotope analysis of  
638 archaeological bone collagen. *Archaeological and Anthropological Sciences* 1, 59–75. <https://doi.org/10.1007/s12520-009-0003-6>
- 640 Neville, A., 1998. The Phoenicians in Iberia: Settlements, Cemeteries, Trade and Agriculture.
- 641 Nitsch, E.K., Charles, M., Bogaard, A., 2015. Calculating a statistically robust  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  offset  
642 for charred cereal and pulse seeds. *STAR: Science & Technology of Archaeological Research* 1, 1–8.  
643 <https://doi.org/10.1179/2054892315Y.0000000001>
- 644 Nitsch, E.K., Lamb, A.L., Heaton, T.H.E., Vaiglova, P., Fraser, R., Hartman, G., Moreno-Jiménez, E.,  
645 López-Piñeiro, A., Peña-Abades, D., Fairbairn, A., Eriksen, J., Bogaard, A., 2019. The Preservation  
646 and Interpretation of  $\delta^{34}\text{S}$  Values in Charred Archaeobotanical Remains. *Archaeometry* 61, 161–178.  
647 <https://doi.org/10.1111/arcm.12388>
- 648 Payne, S., 1969. A metrical distinction between sheep and goat metacarpals. The domestication and  
649 exploitation of plants and animals 295–305.
- 650 Peña-Chocarro, L., Pérez- Jordá, G., Alonso, N., Antolín, F., Teira-Brión, A., Tereso, J.P., Montes Moya,  
651 E.M., López Reyes, D., 2019. Roman and medieval crops in the Iberian Peninsula: A first overview of  
652 seeds and fruits from archaeological sites. *Quaternary International, Food Production and Land Use* 499,  
653 49–66. <https://doi.org/10.1016/j.quaint.2017.09.037>
- 654 Perez-Hurtado, A., Goss-Custard, J.D., Garcia, F., 1997. The diet of wintering waders in Cádiz bay, southwest  
655 Spain. *Bird Study* 44, 45–52. <https://doi.org/10.1080/00063659709461037>
- 656 Price, G.C., Krigbaum, J., Shelton, K., 2017. Stable isotopes and discriminating tastes: Faunal management  
657 practices at the Late Bronze Age settlement of Mycenae, Greece. *Journal of Archaeological Science: Reports* 14, 116–126. <https://doi.org/10.1016/j.jasrep.2017.05.034>
- 658 Queiroz, P., Mateus, J., Leeuwaarden, W., Pereira, T., Dise, D., 2006. Castro Marim e o seu território  
659 imediato durante a Antiguidade. Paleo-ethno-Botânica. Relatório Final. <https://doi.org/10.13140/RG.2.2.25361.63848>
- 660 Quinn, J., 2019. In search of the Phoenicians. Princeton University Press.
- 661 R Core Team, 2020. R: A Language and Environment for Statistical Computing. R Foundation for Statistical  
662 Computing, Vienna, Austria.
- 663 Renzi, M., Rovira Llorens, S., Montero Ruiz, I., 2012. Riflessioni sulla metallurgia fenicia dell'argento nella  
664 Penisola Iberica.
- 665 Richards, M.P., Hedges, R.E.M., 1999. Stable Isotope Evidence for Similarities in the Types of Marine Foods  
666 Used by Late Mesolithic Humans at Sites Along the Atlantic Coast of Europe. *Journal of Archaeological  
667 Science* 26, 717–722. <https://doi.org/10.1006/jasc.1998.0387>
- 668 Riehl, S., 2009. Archaeobotanical evidence for the interrelationship of agricultural decision-making and  
669 climate change in the ancient Near East. *Quaternary International* 197, 93–114. <https://doi.org/10.1016/j.quaint.2007.08.005>
- 670 Roller, D.W., 2014. The geography of Strabo: An English translation, with introduction and notes. Cambridge  
671 University Press.
- 672 Rutter, S.M., 2002. Behaviour of Sheep and Goats, in: The Ethology of Domestic Animals: An Introductory  
673 Text. pp. 148–155.
- 674 Schoeninger, M.J., 1985. Trophic level effects on  $15\text{N}/14\text{N}$  and  $13\text{C}/12\text{C}$  ratios in bone collagen and strontium  
675 levels in bone mineral. *Journal of Human Evolution* 14, 515–525. [https://doi.org/10.1016/S0047-2484\(85\)80030-0](https://doi.org/10.1016/S0047-2484(85)80030-0)
- 676 Schramm, Z., 1967. Morphological differences of some goat and sheep bones. Wyższa Szkoła Rolnicza.
- 677 Schulting, R.J., le Roux, P., Gan, Y.M., Pouncett, J., Hamilton, J., Snoeck, C., Ditchfield, P., Henderson, R.,  
678 Lange, P., Lee-Thorp, J., Gosden, C., Lock, G., 2019. The ups & downs of Iron Age animal management

- 683 on the Oxfordshire Ridgeway, south-central England: A multi-isotope approach. *Journal of Archaeological*  
684 *Science* 101, 199–212. <https://doi.org/10.1016/j.jas.2018.09.006>
- 685 Semmler, M.E.A., 1992. Proyecto Cerro del Villar (Guadalhorce, Málaga): Estudio de materiales 1990, in:  
686 *Anuario Arqueológico de Andalucía* 1990. pp. 304–306.
- 687 Semmler, M.E.A., 1990. Cerro del Villar 1987. Informe de la primera campaña de excavaciones en el  
688 asentamiento fenicio de la desembocadura del río Guadalhorce (Málaga), in: *Anuario Arqueológico de*  
689 *Andalucía* 1987. pp. 310–316.
- 690 Sousa, E. de, 2019. The use of "Kouass Ware" during the Republican Period in the Algarve (Portugal). *Rei*  
691 *Cretariae Romanae Fautorum Acta* 41 41, 523–528.
- 692 Strohalm, M., Kavan, D., Novák, P., Volný, M., Havlíček, V., 2010. mMass 3: A Cross-Platform Software  
693 Environment for Precise Analysis of Mass Spectrometric Data. *Anal. Chem.* 82, 4648–4651. <https://doi.org/10.1021/ac100818g>
- 695 Sturtevant, E.L., 1886. History of Celery. *The American Naturalist* 20, 599–606. <https://doi.org/10.1086/274288>
- 697 Styring, A., Rsch, M., Stephan, E., Stika, H.-P., Fischer, E., Sillmann, M., Bogaard, A., 2017. Centralisation  
698 and long-term change in farming regimes: Comparing agricultural practices in Neolithic and Iron Age  
699 south-west Germany. *Proc. Prehist. Soc.* 83, 357–381. <https://doi.org/10.1017/ppr.2017.3>
- 700 Terrinha, P.A.G., 1998. Structural geology and tectonic evolution of the Algarve Basin, South Portugal.  
701 Imperial College London (University of London).
- 702 Thompson, D., Byrkjedal, I., 2010. Tundra plovers: The Eurasian, Pacific and American golden plovers and  
703 grey plover. A&C Black.
- 704 Tieszen, L.L., 1991. Natural variations in the carbon isotope values of plants: Implications for archaeology,  
705 ecology, and paleoecology. *Journal of Archaeological Science* 18, 227–248. [https://doi.org/10.1016/0305-4403\(91\)90063-U](https://doi.org/10.1016/0305-4403(91)90063-U)
- 707 Tobyn, G., Denham, A., Whitelegg, M., 2011. CHAPTER 9 - Apium graveolens, wild celery, in: Tobyn,  
708 G., Denham, A., Whitelegg, M. (Eds.), *Medical Herbs*. Churchill Livingstone, Edinburgh, pp. 79–89.  
709 <https://doi.org/10.1016/B978-0-443-10344-5.00014-8>
- 710 Treumann, B., 2009. Lumbermen and Shipwrights: Phoenicians on the Mediterranean Coast of Southern  
711 Spain.
- 712 Treumann, B.W., 1998. The role of wood in the rise and decline of the Phoenician settlements on the Iberian  
713 Peninsula.
- 714 Trueman, C.N., Privat, K., Field, J., 2008. Why do crystallinity values fail to predict the extent of  
715 diagenetic alteration of bone mineral? *Palaeogeography, Palaeoclimatology, Palaeoecology* 266, 160–167.  
716 <https://doi.org/10.1016/j.palaeo.2008.03.038>
- 717 Uriel, P.F., 2000. El comercio de la púrpura, in: *Intercambio y Comercio Preclásico En El Mediterráneo:*  
718 *Actas Del I Coloquio Del CEFYP*, Madrid, 9-12 de Noviembre, 1998. Centro de Estudios Fenicios y  
719 Púnicos, pp. 271–280.
- 720 Vaiglova, P., Gardeisen, A., Buckley, M., Cavanagh, W., Renard, J., Lee-Thorp, J., Bogaard, A., 2020. Further insight into Neolithic agricultural management at Kouphovouno, southern Greece: Expanding  
721 the isotopic approach. *Archaeol Anthropol Sci* 12, 43. <https://doi.org/10.1007/s12520-019-00960-y>
- 723 van Doorn, N.L., Hollund, H., Collins, M.J., 2011. A novel and non-destructive approach for ZooMS analysis:  
724 Ammonium bicarbonate buffer extraction. *Archaeol Anthropol Sci* 3, 281–289. <https://doi.org/10.1007/s12520-011-0067-y>
- 726 Van Leeuwaarden, W., Janssen, C.R., 1985. A preliminary palynological study of peat deposits near an  
727 oppidum in the Lower Tagus Valley, Portugal, in: *Actas*. pp. 225–236.
- 728 Virginia, R.A., Delwiche, C.C., 1982. Natural  $^{15}\text{N}$  abundance of presumed  $\text{N}_2$ -fixing and non- $\text{N}_2$ -fixing  
729 plants from selected ecosystems. *Oecologia* 54, 317–325.
- 730 Wachsmann, S., Dunn, R.K., Hale, J.R., Hohlfelder, R.L., Conyers, L.B., Ernenwein, E.G., Sheets, P.,  
731 Blot, M.L.P., Castro, F., Davis, D., 2009. The Palaeo-Environmental Contexts of Three Possible  
732 Phoenician Anchorages in Portugal. *International Journal of Nautical Archaeology* 38, 221–253. <https://doi.org/10.1111/j.1095-9270.2009.00224.x>

- 734 Wagner, C.G., Alvar, J., 2003. La colonización agrícola en la Península Ibérica. Estado de la cuestión y  
735 nuevas perspectivas. Ecohistoria del paisaje agrario. La agricultura fenicio-púnica en el Mediterráneo 95,  
736 187–204.
- 737 Wagner, C.G., Alvar, J., 1989. Fenicios en Occidente: La colonización agrícola. *Rivista di Studi Fenici* 17,  
738 61–102.
- 739 Wallace, M., Jones, G., Charles, M., Fraser, R., Halstead, P., Heaton, T.H.E., Bogaard, A., 2013. Stable  
740 carbon isotope analysis as a direct means of inferring crop water status and water management practices.  
741 *World Archaeology* 45, 388–409. <https://doi.org/10.1080/00438243.2013.821671>
- 742 Waterman, A.J., Tykot, R.H., Silva, A.M., 2016. Stable Isotope Analysis of Diet-based Social Differentiation  
743 at Late Prehistoric Collective Burials in South-Western Portugal. *Archaeometry* 58, 131–151. <https://doi.org/10.1111/arcm.12159>
- 744 Webb, E.C., Lewis, J., Shain, A., Kastrisianaki-Guyton, E., Honch, N.V., Stewart, A., Miller, B., Tarlton, J.,  
745 Evershed, R.P., 2017. The influence of varying proportions of terrestrial and marine dietary protein on  
746 the stable carbon-isotope compositions of pig tissues from a controlled feeding experiment. *STAR: Science  
747 & Technology of Archaeological Research* 3, 28–44. <https://doi.org/10.1080/20548923.2016.1275477>
- 748 Weiner, S., Bar-Yosef, O., 1990. States of preservation of bones from prehistoric sites in the Near East: A  
749 survey. *Journal of Archaeological Science* 17, 187–196. [https://doi.org/10.1016/0305-4403\(90\)90058-D](https://doi.org/10.1016/0305-4403(90)90058-D)
- 750 Wickham, H., 2016. *Ggplot2: Elegant Graphics for Data Analysis*. Springer-Verlag New York.
- 751 Wilson, L., 2016. Spices and Flavoring Crops: Fruits and Seeds, in: Caballero, B., Finglas, P.M., Toldrá, F.  
752 (Eds.), *Encyclopedia of Food and Health*. Academic Press, Oxford, pp. 73–83. <https://doi.org/10.1016/B978-0-12-384947-2.00647-4>
- 753 Wood, J.R., Montero-Ruiz, I., Martinón-Torres, M., 2019. From Iberia to the Southern Levant: The  
754 Movement of Silver Across the Mediterranean in the Early Iron Age. *Journal of World Prehistory* 32,  
755 1–31. <https://doi.org/10.1007/s10963-018-09128-3>
- 756 Wright, L.E., Schwarcz, H.P., 1996. Infrared and Isotopic Evidence for Diagenesis of Bone Apatite at  
757 Dos Pilas, Guatemala: Palaeodietary Implications. *Journal of Archaeological Science* 23, 933–944.  
758 <https://doi.org/10.1006/jasc.1996.0087>
- 759 Žalaitė, I., Maurer, A.F., Grimes, V., Silva, A.M., Ribeiro, S., Santos, J.F., Barrocas Dias, C., Valera, A.C.,  
760 2018. Diet and mobility of fauna from Late Neolithic–Chalcolithic site of Perdigões, Portugal. *Journal of  
761 Archaeological Science: Reports* 19, 674–685. <https://doi.org/10.1016/j.jasrep.2018.03.033>
- 762
- 763